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Study on the Impact of Dye – Sublimation Printing on the Effectiveness of Underwear

Raziskava vpliva sublimacijskega tiska na učinkovitost spodnjega perila

Original Scientific Paper/*Izvirni znanstveni članek*
Received/*Prispelo* 02-2014 • Accepted/*Sprejeto* 04-2014

Abstract

This study deals with the effect of dye-sublimation printing on the performance of underwear. Two groups of polyester knitted fabrics were analysed. The change of tree selected groups of properties was investigated before and after the application of dye-sublimation printing, namely durability (breaking force and elongation, abrasion resistance and pilling resistance), physiological properties (water vapour permeability, air permeability) and colour-fastness (resistance to rubbing, to domestic and commercial laundering, to perspiration). Further, the structure changes of fabrics (thickness and density) during heat pressing both without application of dyes (without transfer printing on material) and with application of dyes were also studied to analyse the affect extent of printing conditions (particularly pressure and temperature) on total wear comfort printed fabrics. The results show that the tested materials meet requirements in terms of colour-fastness to rubbing, to domestic and commercial laundering and to perspiration to a very high standard (grade 5). In terms of abrasion resistance and pilling resistance the material also showed high resistance. The air permeability for both fabrics decreased by about 40% in comparison with the value obtained before printing and the mechanical properties slightly increased (about 8%). This was due to an increase in the stitch density and a decrease in the thickness, therefore reducing the porosity of the material for printing conditions, mainly due to the influence of the pressure and temperature within the heat press machine.
Keywords: dye-sublimation printing, underwear, physiological comfort, colour-fastness, mechanical properties, structure changes

Izvleček

Raziskava je osredinjena na učinek sublimacijskega tiska na učinkovitost spodnjega perila. Analizirali smo dve skupini poliestrnih pletiv. Spremembe v treh skupinah lastnosti so bile raziskane pred uporabo sublimacijskega tiska in po njej, in sicer trpežnost (pretržna sila in raztezek, odpornost proti abraziji in pilingu), fiziološke lastnosti (prepustnost vodne pare, zračna prepustnost) ter barvna obstojnost (odpornost proti drgnjenju, domačemu in industrijskemu pranju, proti znojenju). Raziskali smo tudi spremembe v strukturi pletiv (debelina in gostota) med vročim tiskom brez uporabe barvil (brez prenosa tiska na substrat) ter z uporabo barvil, da bi analizirali učinek vpliva pogojev, pod katerimi poteka tiskanje (še posebno pritisk in temperatura), na udobje med nošenjem potiskanih tkanin. Rezultati raziskave so pokazali, da testirani materiali izpolnjujejo zahteve v smislu barvne obstojnosti proti drgnjenju, domačemu in industrijskemu pranju in proti znojenju v zelo veliki meri (ocena 5). V primeru odpornosti na abrazijo in piling je material ravno tako pokazal dobro obstojnost. Zračna prepustnost se je za obe vrsti pletiv znižala za približno 40 % v primerjavi z vrednostjo, ki smo jo dobili pred tiskanjem. Mehanske lastnosti so se zvišale za približno 8 %, kar je bila posledica večje gostote šivov in zmanjšanja debeline. To je posledično vodilo v zmanjšanje poroznosti materiala za pogoje, pod katerimi poteka tiskanje, predvsem zaradi vpliva pritiska in temperature, ki sta prisotna pri stroju za vroči tisk.
Ključne besede: sublimacijski tisk, spodnje perilo, fiziološko udobje, barvna obstojnost, mehanske lastnosti, spremembe v strukturi

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Tekstilec, 2014, letn. 57*(2), str. 133–138*
DOI: 10.14502/Tekstilec2014.57.133–138

1 Introduction

Heat transfer presses have been used for the dye-sublimation printing of polyester and other fabrics for over 30 years. The process is environmentally clean and the vibrant colours and clear images give the process many advantages [1]. Heat Transfer printing is the primary step in apparel manufacturing operations utilizing the increasingly popular agile manufacturing. It is the perfect medium for the demands of today's marketplace – short run and sample production [2]. Digital-print textile technology and heat transfer processing have the advantages of facilitating the reproduction of several colours, reducing post processing, and lowering equipment investment and maintenance [3]. Because it is simple, cheap, easy to reproduce colour, and does not need post treatment, this process has its advantages when looking for a quick and easy way to print on fabrics [4].

In his papers, [5, 6], Wu found that heat transfer temperature and dwell time are the two key factors affecting colour reproduction on polyester fabric. Heat presses can heat a transfer up to 218 degrees C and can press between 40 and 80 psi (0.276 and 0.552 MPa) [7]. This value only represents the amount of air pressure brought to the machine and is displayed on the air gauge. The actual applied pressure (2 to 6 psi) is calculated from the cylinder size and the plate area [8]. A heat press is the machine used to transfer a design from transfer paper to the object. Transfers done with a heat press are permanently adhered to the object [7]. The high pressure and temperature have a considerable effect on the properties of the printed fabrics.

Many scientific papers have dealt with the topic of heat transfer printing or dye-sublimation printing and have tested the quality of printing and researched the dye used. However, it is also necessary to look at the changes in the properties of the fabric (linked to the structure) which have been dye-sublimation printed. It is assumed that the changes in the fabric due to dye-sublimation printing are induced by the following parameters: temperature, dwell time and pressure. These changes are reflected especially regarding comfort (air permeability, water vapor permeability) and durability (strength, elongation, thickness).

The following studies have investigated print quality and the properties of the applied dye in the process of heat transfer printing or dye-sublimation printing. Abd El-Thalouth [9] examined the feasibility of transferring colour from a screen-printed polyester fabric to another polyester fabric using the heat transfer printing technique. Guo [10] researched parameters such as printing density, printing colour gamut, the colour efficiency of heat transfer printing papers and fabrics and Hallas [11] examined the heat transferability of dyes on polyester fibres. Kiatkamjornwong [12] compares textile print quality between inkjet and screen-printing onto cotton fabrics and, furthermore, examines the properties of the printed fabrics, such as stiffness, air permeability and crock-fastness. Mikuž [13] reviews the current and future trends of textile digital ink-jet printing and compares the production costs of different ink-jet and screen printing technologies.

Underwear is the first layer of functional clothing and therefore must be comfortable enough so as not to infringe upon the functionality of the whole clothing system [14, 15]. For this reason, this paper also deals with the physiological properties of printed fabrics.

2 Methods

The aim of this study is to observe the impact of dye-sublimation printing on a selected group of properties of fabrics that are commonly used in corset production.

The investigated knitted fabrics were printed by multipurpose inject and sublimation plotter JV4-130 produced by MINAKI. There no special pretreatments were applied to tested materials before their printing. The dispersive dye and classical heat transfer paper (weight 100g/m^2) were used.

Two groups of knitted fabrics (Table 1) were analysed in terms of their physiological properties, colourfastness and durability. Changes in these properties were investigated before and after dye-sublimation printing. The changes in the structure (thickness and density) were studied and, subsequently, the changes in the physiological properties of the fabrics during heat pressing without application of dyes (without transfer printing on material) were also studied. The same conditions of temperature, pressure, dwell time and type of dye were applied as for the original transfer printing. The printing parameters were also set the same for all tests. This experiment was designed to measure the effect of the dye on the material properties tested and the effect of transfer dye conditions

Table 1: Characteristics of selected fabrics

Knit	Raw material	Pattern	Density course/ wale [per cm]	Weight [g/m²]	Thickness [mm]
A	92% Polyester / 8% Elastane	single-knit fabric	32/24	130	0.32
B	90% Polyester / 10% Elastane	single-knit fabric	33/22	145	0.32

during heat pressing. The printed area corresponded to about 85% of the original (unprinted) fabric surface. The materials tested comply with the requirements for dye-sublimation printing.

All experiments were carried out in a standard atmosphere for testing in line with Standard ISO 139:2002.

The optimal parameter setting of dye-sublimation printing (dye, pressure, temperature, time) has been examined in several studies [5–10]. Based on these studies, on our own experiment and on our previous study [16], the optimal printing conditions were set (using discontinuous heat press): heat transfer temperature – 180 °C, dwell time – 60 s and pressure – 12 kPa. A plate heat press machine was used for the dye-sublimation printing.

The changes in the following properties of the knitted fabrics were investigated:

- *durability properties* (mechanical properties – breaking force and elongation at break, abrasion resistance and pilling resistance) according to Standard EN ISO 13934 – 1:2013 Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method, EN ISO 12945-2:2000, Textiles – Determination of fabric propensity to surface fuzzing and to pilling – Part 2: Modified Martindale method, EN ISO 12947-2:1998 Textiles – Determination of the abrasion resistance of fabrics by the Martindale method – Part 2: Determination of specimen breakdown;
- *physiological properties* (water vapour permeability, air permeability) according to Standard ISO 11092:1993 Textiles. Determination of physiological properties. Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded – hotplate test), EN ISO 9237:1995 Textiles – Determination of the permeability of fabrics to air;
- *colour-fastness* (resistance to domestic and commercial laundering, to perspiration, to rubbing) according to Standard EN ISO 105 – C06:1994 Textiles – Tests for colour-fastness – Part C06: Colour-fastness to domestic and commercial laundering, Part E04:2008 Colour-fastness to perspiration, Part X12:1995 Colour-fastness to rubbing.

The conditions for taking measurements in all the tests comply with the aforementioned standards with the exceptions of the air permeability measurement. In this case, the pressure gradient was set at 10 Pa due to the properties of the tested materials and due to test equipment used (SDL M0215).

Average values in the testing of the properties are based on five independent measurements. The coefficients of variation for all tests do not exceed 5% and are there for not statistically significant.

3 Results and discussion

3.1 Colour-fastness

The results show that the tested materials meet requirements in terms of colour-fastness to rubbing, to domestic and commercial laundering, and to perspiration to a very high standard (grade 5) (Figure 1).

In terms of abrasion resistance and pilling resistance, the material also showed high resistance. Tests were conducted using the Martindale machine. In the abrasion resistance test, no crossing points of the fabric frayed through after 50.000 rpm: only the colour of the fabric changed from grade 5 to grade 3 (Figure 2). The piling resistance tests were also very good: grade 5.

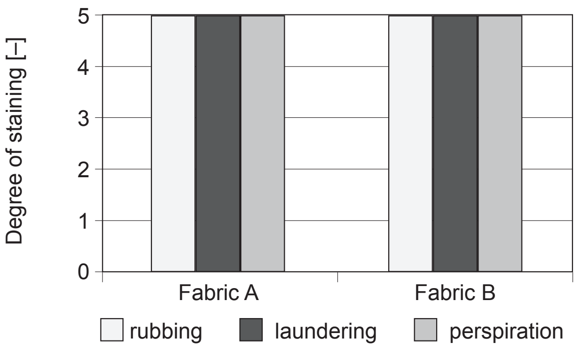

Figure 1: Evaluation of colour-fastness to rubbing, laundering, perspiration of tested materials

Figure 2: Change of colour of knitted fabric B after test of abrasion resistance

3.2 Physiological properties

Interesting differences were investigated regarding both the changes in the air permeability of the tested fabrics and their mechanical properties (breaking force and elongation at break) after printing. The air permeability for both fabrics decreased by about 40% in comparison with the value obtained before printing (Figure 4) and the mechanical properties slightly increased (about 8%). This was due to an increase in the stitch density of about 15% (Figure 8) and a decrease in the thickness of about 18%, therefore reducing the porosity of the material (Figure 7) for printing conditions, mainly due to the influence of the pressure and temperature within the heat press machine. Further water vapour resistance (R_{et}) was investigated by SGHP 8.2. Water vapour resistance is water vapour pressure difference between the two sides of specimen divided by the resultant evaporative heat flux per unit area in the direction of the gradient. Values of R_{et} decreased slightly after printing (Figure 3) for tested materials. This could be due to the change in the thickness of the fabrics after printing. A study by Havenith [14] supports this theory. However the R_{et} values of the tested material fall inside of the limits of 0-6 R_{et} that means the knitted fabrics have very good water vapour permeability.

3.3 Durability properties

Mechanical properties were investigated both in the course and in the wale directions before and after

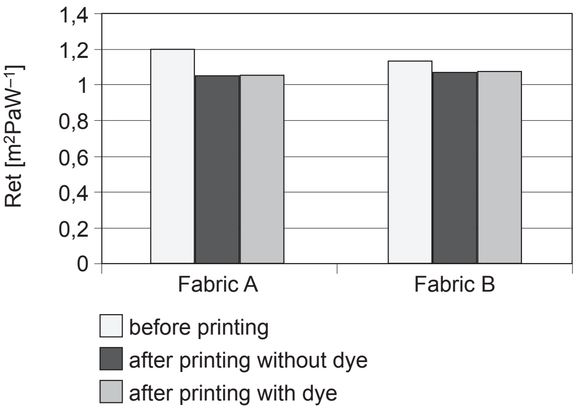

Figure 3: Evaluation of water vapour permeability of the tested materials before and after printing

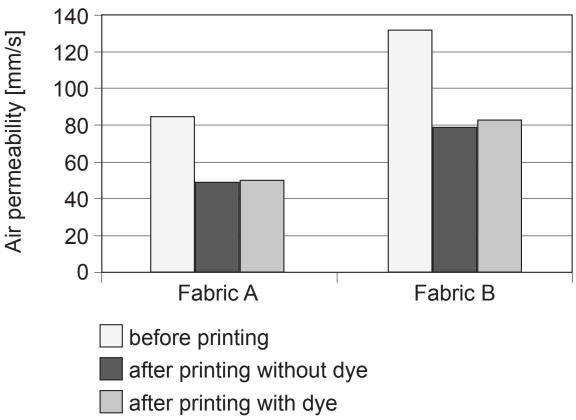

Figure 4: Evaluation of air permeability of the tested materials before and after printing

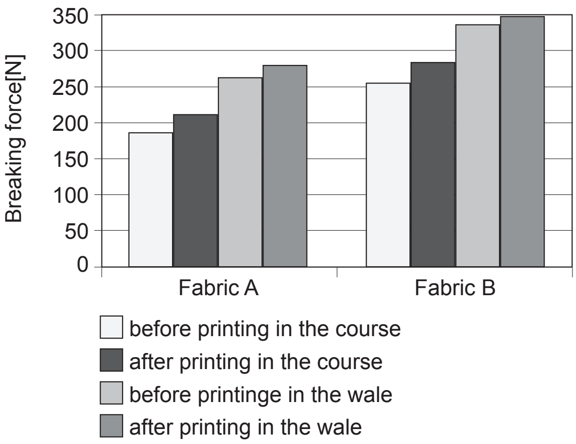

Figure 5: Evaluation of breaking force of the tested materials before and after printing

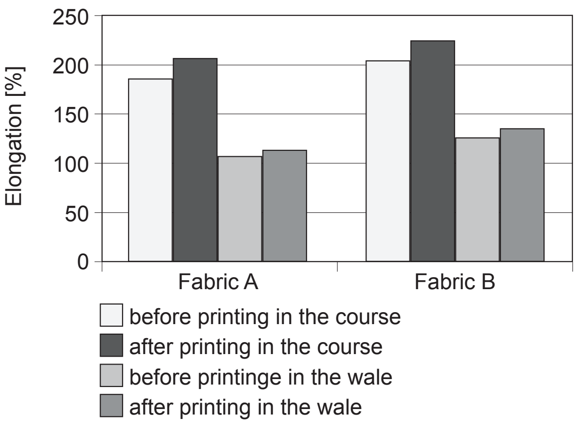

Figure 6: Evaluation of elongation of the tested material before and after printing

printing. Changes in these properties occurred after printing, namely a slight increase in the breaking force value [N] and the value of elongation at break [%] ranging from 5 to 12% (from former value) (Figures 5, 6). This was caused by the aforementioned increase in the density of the fabrics after printing.

3.4 Structural properties

The effect of temperature and pressure during transfer of dye to the fabrics (inside the heat press machine) led to an increased compression of the tested materials (Figure 7) and structure densification (Figure 8). The most considerable change of the fabric structure was noticed after printing without dye. It means that the dye itself contributes to the change of fabric structure (and subsequently to others observed properties) very low degree. Figures 9 and 10 show the changes in the structure of the material (before and after printing without dye) using an image analysis system called 'NIS Element'.

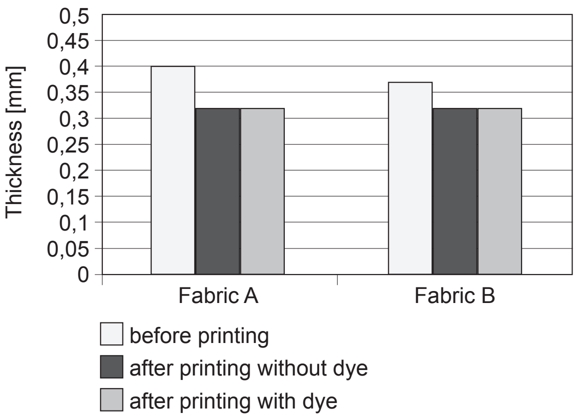

Figure 7: Evaluation of the thickness of the tested materials before and after printing

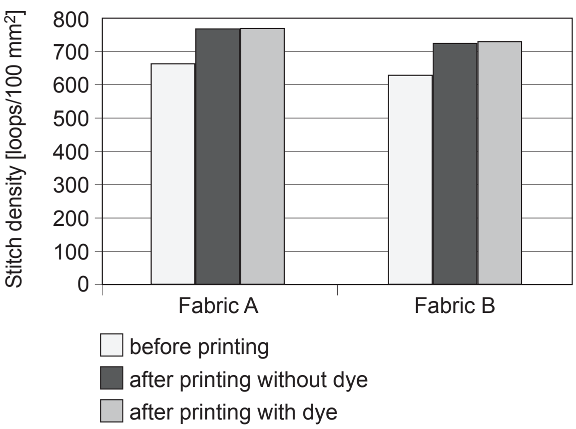

Figure 8: Evaluation of the stitch density of the tested material before and after printing

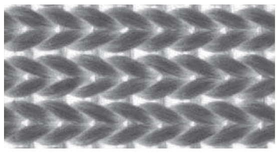

Figure 9: Detail of fabric B before printing by image analysis Nis – elements

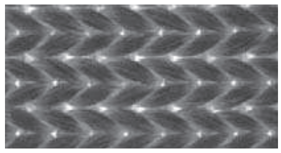

Figure 10: Detail of fabric B after printing by image analysis Nis – elements

4 Conclusion

This study showed the suitability of the tested polyester knitted fabrics for dye-sublimation printing for ladies undergarment production, namely for corsets. The change of durability, physiological properties, colour-fastness and structure changes of fabrics (thickness and density) was investigated before and after the application of dye-sublimation printing, according to corresponding technical standard for textile metrology.

The printing conditions (for used discontinuous heat press) were set to following values: heat transfer temperature – 180 °C, dwell time – 60 s and pressure – 12 kPa.

The tested fabrics show both excellent colour- and crock-fastness properties (grade 5) and high durability.

Changes mainly occurred in the physiological properties. Particularly the air permeability change was noticed, in the concrete decrease by about 40% in comparison with the value obtained before printing. It was caused by the decrease in porosity; specifically stitch density increase (of about 15%) and compression thickness of the tested materials (about 18%). These facts were affected especially by the dye transfer conditions (pressure, temperature, dwell time) on the knitted fabrics within the heat press machine. This is clear not only from above mentioned fabric structure change but also from image of the material structure (before and after printing without dye) made by image analysis NIS-Elements. However, the water vapour permeability, one of the most important properties of the undergarment, was not significantly affected.

In conclusion, the overall physiological comfort of the tested undergarments showed very similar levels both before and after dye-sublimation printing, therefore this printing method is suitable for final application to undergarment production.

This paper demonstrates the possibility of clothing decoration by using the sublimation printing for increasing their aesthetic value without reducing their comfortable properties.

References

1. Advanced Innovative Technologies. Heat transfer printing – sublimation [dostopno na daljavo], [citirano 04. 07. 2013]. Dostopno na svetovnem spletu: <http://www.aitequipment.com/cgi-bin/db_searchz.cgi?database=dbpg_contactus.exm&template=dbpg_contactus_tmplt.htm&0=1>.
2. JESSE J. HEAP & SON, Inc. Introduction to heat transfer printing [dostopno na daljavo], [citirano 05. 07. 2013]. Dostopno na svetovnem spletu: <http://www.jesseheap.com/heat-transfer-printing-introduction.html>.
3. WU, Yu-Ju, DILWORTH, J. K., GRANT, G. Light fastness of heat transfer on polyester blend fabrics. V *NIP25: 25th International Conference on Digital Printing Technologies and Digital Fabrication*. Louisville, United States, 2009, 118–121.
4. HUNTING, Brad, DERBY, Stephen, PUFFER, Raymond, LOOMIE, Leo. Thermal Ink Jet Printing of Textiles. V *Recent Progress in Ink Jet Technologies II*. Edited by Eric Hanson. Springfield, Virginia : Society for Imaging Science and Technology, 1999, 568 –573.
5. WU, Yu-Ju, GRANT, G. Key factors affecting color reproduction on polyester fabrics using heat transfer printing. V *63rd Annual Technical Conference of the Technical Association of the Graphic Arts*. Pittsburgh, Pennsylvania, 2011, 118–134.
6. WU, Yu-Ju, BAI, R. Color reproduction capability on 100% cotton fabrics using dye-sublimation heat transfer printing. V *Proceedings of the NIP 27th International Conference on Digital Printing Technologies and 7th International Conference on Digital Fabrication*. Minneapolis, United States, 2011, 41–44.
7. SWANSON, Joanna. Heat transfer printing method [dostopno na daljavo], [citirano 22. 07. 2013]. Dostopno na svetovnem spletu: <http://www.ehow.co.uk/about_6599022_heat-transfer-printing-method.html>.
8. PEARSON, M. The Key Elements of Sublimation Heat Transfer Printing. *Advanced Innovative Technologies* [dostopno na daljavo], [citirano 22. 07. 2013]. Dostopno na svetovnem spletu: <http://www.aitequipment.com/cgi-bin/db_searchz.cgi?database=dbpg_resources.exm&template=dbpg_resources_tmplt.htm&0=2>.
9. ABD EL-THALOUTH, I., EL-KASHOUTI, M. A., HEBEISH, A. Novel methods for heat transfer printing of polyester. *Acta Polymerica,* 1982, **33**(6), 385–387, doi: 10.1002/actp.1982.010330613.
10. GUO, L. H., Zhang, M. Y., Guo, X. H., Zhu, Q. Research on the color models of the heat transfer printing paper. V *International Conference on Chemical Engineering and Advanced Materials*. Changsha, 2011, 1332–1335, doi: 10.4028/www.scientific.net/AMR.236-238.1332.
11. HALLAS, Geoffrey, CHOI, Jae – Hong. Synthesis and properties of novel aziridinyl azo dyes from 2-aminothiophenes-Part 2: Application of some disperse dyes to polyester fibres. *Dyes and Pigments*, 1999, **40**(2–3), 119–129, doi: 10.1016/S0143-7208(98)00032-1.
12. KIATKAMJORNWONG, Suda, PUTTHIMAI, P., NOGUACHI, H. Comparison of textile print quality between inkjet and screen printings. *Surface Coatings International Part B: Coatings Transactions*, 2005, **88**(1), 25–34, doi: 10.1007/BF02699704.
13. MIKUŽ, Mašenka, ŠOSTAR-TURK, Sonja, FORTE-TAVČER, Petra. Printing and design in the processes of textile inkjet printing, *Tekstilec*, 2008, **51**(1–3), 7–29.
14. HAVELKA, Antonin, KUS, Zdenek. The transport phenomena of semi-permeable membrane for sport cloth. *International Journal of Clothing Science and Technology,* 2011, **23**(2/3), 119–130, doi: 10.1108/09556221111107315.
15. HAVENITH, George. Heat balance when wearing protective clothing. *The annals of occupation hygiene,* 1999, **43**(5), 289–296, doi: 10.1093/annhyg/43.5.289.
16. GLOMBIKOVA, Viera, KOMARKOVA, Petra. To investigate the effect of dye-sublimation printing on the performance of underwear. V *8th International Conference TEXCI 2013*. TU Liberec, Czech Republic, 2013.