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[1.]Mladen STANČIĆ, [2.]Dragana GRUJIĆ, [3.]Branka RUŽIČIĆ,
[4.]Miloš SORAK, [5.]Miroslav DRAGIĆ, [6.]Đorđe VUJČIĆ

IMPACT OF PRINT PARAMETERS ON AIR PERMEABILITY OF PRINTED KNITWEAR

[1, 3-6.] University of Banja Luka, Faculty of Technology, Graphic Engineering, Banja Luka, BOSNIA & HERZEGOVINA
[2.] University of Banja Luka, Faculty of Technology, Textile Engineering, Banja Luka, BOSNIA & HERZEGOVINA

Abstract: The heat and humidity of human body retain as layers of air before passing into the environment. This creates the characteristic microclimate between the skin and clothing which is defined as a feeling of comfort. In addition to comfort, clothing should meet the aesthetic requirements of the individual. Process of printing is often used for the increasing of the aesthetic value of clothing. The printed ink covers part of the surface material, and partly fills the pores between fibers in the yarn, creating an additional barrier to the process of transfer of heat and moisture from the body to the environment. The paper presents the research of the impact of digital printing parameters on sorption properties of printed textile materials. For research were used 100% knitted cotton fiber (100% CO), and 100% polyester fiber (100% PES), and as the essential parameters of the printing process were selected tone value and number of ink layers. The impact of print parameters on the sorption properties of the material has been tested using the air permeability as a parameter of sorption properties. Research results indicate that the printing process with its parameters have a significant impact on air permeability of printed cotton knitwear.
Keywords: air permeability, digital printing, textile materials, knitwear

INTRODUCTION

Nowadays from products in all aspects of life it is expected to fulfill personal requirements of individuals besides their basic function. One of the most common personal requirement refers to visual attractiveness of object. Therefore, today from selected clothes is expected to satisfy aesthetic and fashionable requirements, so it would in that way better portray personal character and lifestyle of individual (Mecheels, 1992). By printing clothes, in relatively simple way, its aesthetic value is being increased. In that way, printing process enables increase of perceived value of clothes, in a way that customer or user of product perceives higher utility of product compared to his price (Vladić et al, 2014). From technical aspect, process of printing clothes can be defined as process of transferring ink, which is carrier of information, on textile substrate (Kašiković et al, 2014). From the artistic point of view, process of printing clothes presents art and skill of transferring desired design on surface of textile material (Tippet, 2002).

Currently the world's annual print of textile material is between 11 i 13% , that is more than 27 billion m^2 of textile substrates, with annual growth rate of 2% (Momin, 2008; Provost, 2009; Onar Çatal, Özgüney & Akçakoca Kumbasar, 2012). The value of textile material printing industry in 2010 was 165 billion US$. Textile material printing industry is under great pressure of constant changes. This market is seasonal and highly dependent on fashion trends (Gupta, 2001). Demands of customers are changing very fast, therefore the collections are changing frequently in two months (Özgüney, Özerdem & Özkaya, 2007). Trends on market, like: decrease in circulation, demands for higher print quality, rapid job change and short deadlines, unique and personalized print, have led to increased interest for digital printing in textile material printing (Kanik et al, 2004; Mikuž, Šostar-Turk & Pogačar, 2005; Stančić et al, 2013). Digital printing efficiency, as flexible way of ink transfer on substrate in the form of a desirable design, is primarily reflected in respect of costs and time needed for production of smaller circulations

(Novaković et al, 2010). Besides that, digital printing technique enables faster response to market demands and mass individualization.

Beside aesthetic demands, clothes shall also meet the ergonomic and physiological requirements (Mecheels, 1992). Does clothing meet aesthetic and ergonomic demands customer easily evaluates before or during first wearing. With physiological function it is different, and clothing with good physiological characteristics should make man does not feel heat or cold in different climatic conditions (Mecheels i Umbach, 1976). Comfort is basic and universal need of human being and presents one of the most important aspects of clothing. During clothes wearing, heat and humidity produced by body has been stopped as layers of air before passing in the environment, resulting in characteristic microclimate between skin and clothing, defined as the feeling of comfort (Yoo, Hu & Kim, 2000; Grujić, Geršak & Ristić, 2010). Thermal effects largely contribute to the comfort of the individual, whereby a complex physiological and psychological factors together with clothes play an important role in defining the complex phenomenon of comfort (Andreen, Gibson & Wetmore, 1953).

Human body with the process of metabolism constantly transforms food chemical energy into work and heat. Produced heat is transferred through skin and further through clothing system to the environment. Heat exchange processes in dressed and undressed human are qualitatively equal, while quantitatively depend on the thermodynamic properties of clothing, which presents separating surface between body and environment (Mecheels, 1991; Grujić, 2010). The process of heat exchange between body and environment itself is done by processes of: conduction, convection, radiation, evaporation and respiration (Stoecker & Jones, 1982). Greatest part of heat exchange is done by the process of convection. With this process heat is transferred by the movement of gas or liquid. Quantity of heat lost by the convection is determined with difference between temperature of clothing surface and air, and also with convective heat transfer coefficient, which is, in turn, determined with speed of air movement through clothing system (Persons, 2003). The physiological properties of clothing, and thus wearing comfort, could be expressed, apropos quantified, through heat and sorption properties of material (Huang, 2006; Das et al, 2007). Among the most important sorption properties are: air permeability, water holding capacity and relative humidity.

Previous research showed that air permeability of textile material is conditioned by structural properties of material (Mezarciöz, Mezarciöz & Oğulata, 2014; Oğulata & Mavruz, 2010). However, during printing process layer of ink is transferred on clothing. Part of printed ink covers clothing surface, while other part of ink fills pores between fibers in yarn. Thereby, printed ink presents new layer of material, actually additional barrier for the movement of air through the clothing. In order to get new scientific knowledge, this study examined influence of printing process, as one of the methods for increasing visual attractiveness of clothes, on physiological comfort of printed textile materials. Thereby was examined influence of digital ink-jet printing parameters, tonal coverage and number of ink layers, on air permeability of cotton and polyester knitwear.

METHODS AND MATERIALS

Research of printing process influence on air permeability of printed knitwear was performed on purpose-made knitwear. Basic characteristics of examined knitwear are shown in Table 1.

Table 1. Characteristics of materials used in research

Sample	Material type	Type of weaves	Material composition (%)	Fabric weight (g/m^2)	Thread count (cm^{-1})
P-A	Knitwear	Single	Cotton 100 %	111,89	Vertical: Dv = 17 Horizontal: Dh = 17
P-B	Knitwear	Single	Polyester 100 %	114,12	Vertical: Dv = 12 Horizontal: Dh = 20
Method			ISO 1833-1	ISO 3801	ISO 7211-2

For research purposes special test image has been developed. Test image was created using Adobe Illustrator CS5 software application, and was consisted of twelwe patches dimension 20 x 20 cm, and coverage of 10%, 50% and 100% tonal values (TV) of four process colors: cyan, magenta, yellow and black (Figure 1).

Printing of samples was done using ink-jet printing system Polyprint TexJet. Samples were printed with one, three and five ink applications, without intermediate drying in case of printing with more ink applications. Printing of samples has been done with resolution of 720 x 720 dpi, using water-based pigment colors DuPont Artistri Pigment- 5000 Series (cyan, magenta, yellow and black). After printing process, prints were exposed to drying process and fixation of printed inks. Samples were dryed with heat effect at a temperature of 130 °C for 120 seconds, using device for drying imprints tp 4040s from manufacturer „Opremakv“. Before laboratory measurements samples were air-conditioned for 24 hours at standard atmosphere (temperature of 20 °C and relative air humidity 60%). In order to achieve higher accuracy of the measurement results, more samples were measured with repetition on the individual samples. As measurement results were taken arithemtic means of ten times measured numerical values.

Term air permeability of textile materials means the permeability to air passage through the material. While air is passing through clothing, cooling of the body is being enhanced, because part of produced energy is being drained away. The passage of the air through clothing happens when the partial pressure at surface of clothing is higher than pressure in immediate environment of the surface of the skin.

Air permeability measuring is done according to standard ISO 9237:1995 (ISO, 1995). Researches were carried out at different places of material, and on 10 cm distance from the ends of the material. Measurings were done using device Karl Schröder KG Air Permeability Tester, which is shown in figure 1.

Figure 1. Air permeability measuring device

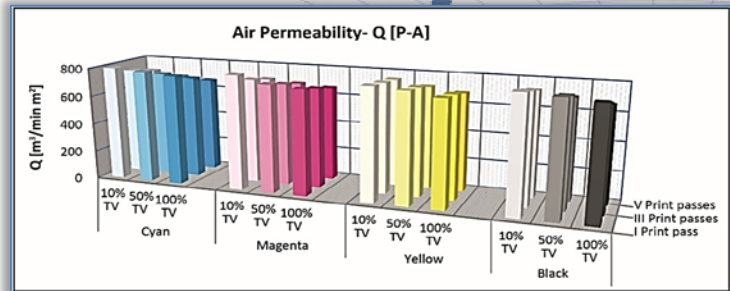
Obtained values of air permeability were recalculated into amount of passed air in m^3 during one minute, using expression (1) (ISO, 1995):

$$Q = \frac{q}{6 \cdot F} \tag{1}$$

where: Q - amount of passed air for certain height of water pillar [m^3/min m^2], q - amount of air that is passing through surface of tested sample [dm^3/h], F - tested surface [cm^2].

RESULTS AND DISCUSSION

Results of air permeability of printed cotton knitwear research are shown in figure 2. Obtained values are showing that printed knitwear have lower values compared to values of unprinted cotton knitwear. Exceptions are only samples printed with one layer of ink with 10% tone values of cyan, magenta, yellow and black for which registered values are equal with values of unprinted cotton knitwear. With further observation of values from figure 2. it can be noticed that air permeability of printed cotton knitwear decreases with increase of tonal coverage. At the same time, increased number of layers in printing, also, leads to decrease of air permeability values. Listed trends in air permeability values are present regardless of whether the samples were printed with cyan, magenta, yellow or black ink.



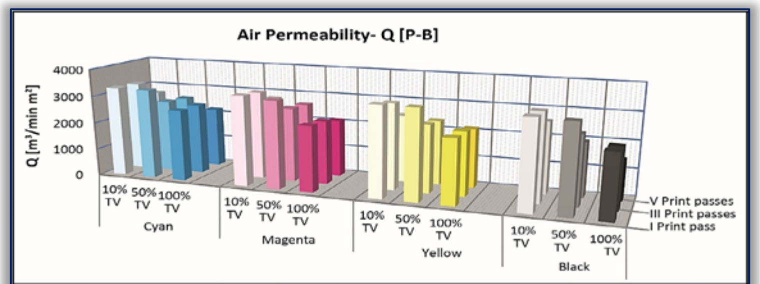
Air Permeability- Q [m³/min m²]											
Sample	Unprinted Material	Colour	I Print pass			III Print passes			V Print passes		
			10% TV	50% TV	100% TV	10% TV	50% TV	100% TV	10% TV	50% TV	100% TV
P-A	800	C	800	783	766	750	733	716	716	683	666
		M	800	750	733	733	716	700	700	683	666
		Y	783	766	733	766	750	716	750	716	683
		K	800	783	766	766	750	716	733	700	666

Figure 2. Air Permeability value of printed cotton knitwear

With analysis of air permeability values for printed cotton knitwear it can be noticed that, with combination of tonal coverage and number of ink layers in printing, similar values of air permeability can be obtained. Thus, in case of samples printed with cyan ink, values of air permeability are same for samples printed with 100% TV (tonal values) with three layers of ink and 10% TV with five ink layers. In case of samples printed with magenta ink equal values occured in case of printing with 100% TV with one ink layer and 10% TV with three ink layers, and also in case of printing with 100% TV with three ink layers and 10% TV with five ink layers. When printed with yellow ink equal values of air permeability appeared in case of printing with 50% TV with one ink layer and 10% TV with three ink layers, then in case of printing with 50% TV with three ink layers and 10% TV with five ink layers, and also in case of printing with 100% TV with three ink layers and 50% TV with five ink layers. In case of black ink equal values of air permeability appeared during printing with 100% TV with one ink layer and 10% TV with three ink layers.

Obtained values of air permeability for printed polyester knitwear (Figure 3) are showing that with the printing process in case of these knitwear, obtained values are also lower compared to values for unprinted knitwear. Exceptions are samples printed with one layer of ink with 10% tone values of cyan, magenta, yellow and black for which registered values are equal with values of unprinted polyester knitwear. Values from figure 3 are showing that air permeability of printed polyester knitwear, also, decreases with increase of tonal coverage. At the same time, increased number of layers in printing, again, leads to decrease of air permeability values. Listed trends in air permeability values are present regardless of whether the samples were printed with cyan, magenta, yellow or black ink.

Values in figure 3. show that also in case of polyester knitwear similar values of air peremability can be obtained with combination of tonal coverage and number of ink layers. Thus, in case of printing these knitwear values of air permeability are closely equal when printed with 50% TV with one ink layer and 10% TV with three ink layers, and in case of printing with 100% TV with three ink layers and 50% TV with five ink layers. In case of samples printed with magenta ink closely equal values occured in case of printing with 50% TV with one ink layer and 10% TV with three ink layers, and also in case of printing with 50% TV with three ink layers and 10% TV with five ink layers. When printed with yellow ink equal values of air permeability appeared in case of printing with 100% TV with one ink layer and 50% TV with five ink layers, and in case of printing with 50% TV with three ink layers and 10% TV with five ink layers, and also in case of printing with 100% TV with three ink layers and 50% TV with five ink layers. In case of black ink closely equal values appeared during printing with 50% TV with one ink layer and 10% TV with three ink layers.



Air Permeability- Q [m³/min m²]

Sample	Unprinted Material	Colour	I Print pass 10% TV	I Print pass 50% TV	I Print pass 100% TV	III Print passes 10% TV	III Print passes 50% TV	III Print passes 100% TV	V Print passes 10% TV	V Print passes 50% TV	V Print passes 100% TV
P-B	3300	C	3300	3283	2600	3266	2650	2583	2733	2566	2200
		M	3300	3200	2400	3216	2700	2316	2783	2633	2100
		Y	3300	3283	2350	3133	2466	2316	2466	2350	2150
		K	3216	3166	2300	3183	2500	2183	2600	1966	1433

Figure 3. Air Permeability value of printed polyester knitwear

Table 2. Statistical analysis of Air Permeability values of printed cotton knitwears

$Q(C) = 828{,}874 - 0{,}433 \cdot TV - 23{,}667 \cdot NP$										
Multiple reg. coef.	Std. Error of estimate	$b_0 = 828{,}874$			$b_1 = -0{,}433$			$b_2 = -23{,}667$		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,989	5,399	4,579	181,026	$1{,}9171 \cdot 10^{-12}$	0,049	-8,860	0,000115	1,102	-21,48	$6{,}6517 \cdot 10^{-7}$
$Q(M) = 804{,}724 - 0{,}490 \cdot TV - 19{,}500 \cdot NP$										
Multiple reg. coef.	Std. Error of estimate	$b_0 = 804{,}724$			$b_1 = -0{,}490$			$b_2 = -19{,}500$		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,946	10,710	9,083	88,595	$1{,}3931 \cdot 10^{-10}$	0,097	-5,049	0,002	2,186	-8,920	0,000111
$Q(Y) = 806{,}676 - 0{,}620 \cdot TV - 11{,}083 \cdot NP$										
Multiple reg. coef.	Std. Error of Estimate	$b_0 = 806{,}676$			$b_1 = -0{,}620$			$b_2 = -11{,}083$		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,974	5,841	4,945	162,840	$3{,}6181 \cdot 10^{-12}$	0,053	-11,73	0,000023	1,192	-9,296	0,000088
$Q(K) = 834{,}566 - 0{,}560 \cdot TV - 20{,}833 \cdot NP$										
Multiple reg. coef.	Std. Error of Estimate	$b_0 = 834{,}566$			$b_1 = -0{,}560$			$b_2 = -20{,}833$		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,978	7,314	6,203	134,549	$1{,}1367 \cdot 10^{-11}$	0,066	-8,451	0,000150	1,493	-13,95	0,000008

Note: the mark TV represents tone value, NP number of passes, C Cyan colour, M Magenta colour, Y Yellow colour, KBlack colour

In order to determine dependence of air permeability of printed cotton and polyester knitwear, when printing with different tonal coverage (TV) and different number of ink layers (NP) and using different inks, mathematical dependence models were created using multiple regression analysis. In creating model, as independent variable value, printing process parameter values were used, i.e. values of ink layers number in printing and tonal coverage values. At the same time, as the dependent variable values were used experimentally obtained values of measuring air permeability of tested knitwear. With research results analysis were obtained statistically reliable dependences of air permeability on the tonal values and number of ink layers, which are presented in tables 2 and 3.

Table 3. Statistical analysis of Air Permeability values of printed polyester knitwears

Q (C) = 3598,109 - 7,110 · TV - 140,333 · NP										
Multiple reg. coef.	Std. Error of Estimate	b_o = 3598,109			b_1 = -7,110			b_2 = -140,333		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,886	152,640	129,453	27,795	1,4345 · 10^{-7}	1,382	-5,145	0,002	31,158	-4,504	0,004
Q (M) = 3580,055 - 9,289 · TV - 115,333 · NP										
Multiple reg. coef.	Std. Error of Estimate	b_o = 3580,055			b_1 = -9,289			b_2 = -115,333		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,932	128,980	109,387	32,728	5,4126 · 10^{-8}	1,168	-7,954	0,00021	26,328	-4,381	0,005
Q (Y) = 3551,040 - 7,749 · TV - 163,917 · NP										
Multiple reg. coef.	Std. Error of Estimate	b_o = 3551,040			b_1 = -7,749			b_2 = -163,917		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,827	219,145	185,855	19,106	0,000001	1,984	-3,91	0,008	44,733	-3,664	0,011
Q (K) = 3785,007 - 11,419 · TV - 223,583 · NP										
Multiple reg. coef.	Std. Error of the Estimate	b_o = 3785,007			b_1 = -11,419			b_2 = -223,583		
R^2	s	Std. Error	t	p	Std. Error	t	p	Std. Error	t	p
0,931	185,261	157,118	24,090	3,36· 10^{-7}	1,677	-6,81	0,000492	37,583	-5,912	0,001

CONCLUSIONS

In the presented research, influence of digital ink-jet printing process parameters on sorption properties of printed clothes, apropos on parameters of physiological comfort of printed clothes was tested. In that purpose, dependence of air permeability of printed cotton and polyester knitwear on variable factors of printing process was tested, i.e. from different tonal coverage and different number of ink layers.

Measured values of air permeability for tested knitwear behave in a manner that with increasing the number of ink layers in printing, and also increasing the tonal coverage, leads to air permeability value decrease. Also, based on experimentally obtained results mathematical dependence models of air permeability on printing parameters were created. These models could be used in real production conditions, during printing clothes made from these materials, and in order to adjust printing process parameters to get clothes for different purpose, with optimal both aesthetic and sorption properties, and all of that in order to get clothes with optimal comfort properties.

With printing process part of printing ink is transferred on material surface, and other part penetrates the interior of material and fills pores between yarn as well as pores between fibers. In this way in textile material is created additional barrier, which disturbs the free passage of air through textile material. Decreasing the value of air permeability by increasing tonal coverage and number of ink layers in printing is explained by the fact that increasing of these parameters leads to application of larger amount of ink on and in printed material. This leads to covering the larger quantity of fibers, and thus to reducing possibilities for free passage of air through textile material.

Measured values of air permeability also shows that closely equal values of air permeability can be obtained with combination of number of ink layers in printing and tonal coverage. This fact is, in turn, important from an economic point of view, because it shows that similar values of sorption parameters can be obtained with smaller number of ink layers in printing by increasing tonal coverage. In this way it is possible to achieve an increase in productivity, because time needed for printing process is being reduced, without affecting the values of sorption properties of printed cotton knitwear, and also the comfort of the clothes made from these materials.

Summarizing the results of the research it can be concluded that printing parameters have great influence on air permeability, as one of the important parameters of clothes comfort. In order to obtain further knowledge, in future research it is planned to test the impact of materials of different composition. Also, done research should be carried out, besides knitwear, on fabrics. Besides that, all researches can be expanded on other sorption parameters, and also on the parameters of the thermal properties of clothing.

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