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Thermal Load Effect on Print Quality of Ink Jet Printined Textile Materials

ABSTRACT

Printed textile materials are often exposed to certain external impacts. One of the most common impact, these materials are subjected to, is thermal load. This effect causes certain changes in textile fibers as well as changes of ink colour reproduction printed on these materials. In this paper is presented an investigation of the series of thermal loads effects on print quality parameters of digitally produced impressions on textile substrates. The research includes basic print quality attributes: colour reproduction, macro non-uniformity and quality of line reproduction. Investigation results indicate that by increasing number of thermal loads, bigger changes in colour reproduction occur. Also, the influence of the series of thermal loads on mottle and line reproduction variations is confirmed, as well as the influence of printing substrate characteristics on print quality.

KEY WORDS
digital printing, textile, thermal load, print quality, colour reproduction, mottle, line quality

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Introduction

Today, an aspect of graphic industry that is becoming more and more interesting is printing of textile materials. Printing of textile materials can be the most appropriately described as an art and a science of desired design transfer onto textile material surface (Tippett, 2002). Some estimates indicate that more than 27 billion m2 of textile material substrates are printed every year (Onar Çatal et al, 2012). Also, it is considered that printing of textile materials has annual growth of 2% (Momin, 2008). Most textile materials are printed using rotary screen printing technique. Besides rotary screen printing, textile materials are possible to print using digital printing techniques as well as thermal transfer printing (Novaković et al, 2010). Screen printing has certain advantages in terms of expences of higher circulation printing and also in respect of its productivity (Lee et al, 2008; Krebs et al, 2009). But, this printing technique has also certain disadvantages. Textile printing community is changing rapidly. Trends such as: circulation reduction, higher printing quality requirements, fast job change and short delivery time of customer orders, unique and personalized printing become more important. Because of these reasons, and because of new technology development, a presence of digital printing is more and more growing on the market (Majnarić et al, 2010). Digital printing provides time and cost reductions when production of smaller circulations is considered. Using this printing technique, faster printing of new jobs, printing with a large number of inks, and flexibility in substrate format selection is enabled (Stančić et al, 2013). Impressions produced using this printing technique possess better visual attributes, good contrast and consistent quality (Kašiković et al, 2012).

Generally, textile printing quality depends on structure, texture as well as production technology of substrates (Vilar et al, 2013). Textile materials are often exposed to external impacts such as: thermal load, washing process, friction, UV radiation etc. One of the most influential factors is a thermal load process. Heat affects both printed ink and textile fibers of the substrate. As a result of this, reproduced colour gamut changes as well as structural changes of textile substrate happens (Novaković et al, 2010). Textile materials transfer heat in three ways: by conducting, convecting and via electromagnetic radiation (Mao & Russell, 2007), and that can lead to structural changes of the fibers (Michalak et al, 2009). Thermal load effects on material changes can be investigated using several standards. ISO 105-X11 is one of them, whereby thermal load is measured at temperatures of 110 °C, 150 °C and 200 °C (Kašiković et al, 2011). Printing process control mostly consists of colour reproduction monitoring. The color reproduction can be characterized using the CIE L, a, b colour coordinates and spectral reflectance curves. CIE L, a, b coordinates enable colour differences estimation between samples, or between samples and standards. Colour differences determination is based upon calculations of the differences of colour space coordinates (ΔL, Δa, Δb) (Kočevar, 2006).

Spectral reflectance curves provide visual representations of the colour's spectral data. Spectral data give an accurate colour description of an object, and show how reflected light is transformed due to the reflection from the observed object, and also provide percentage of incident light that is reflected at each wavelength or range of wavelengths (Beretta, 2008). The relative reflectance term denotes the ratio of reflected light energy from a surface and emitted, incident light energy on that surface, which is only a part of the reflected light spectrum that reached the observer. Analysis of slope and shape of the spectral reflectance curve also provides information on the amount of light absorption (Beretta, 2008).

Series of experiments proved that colour reproduction itself, is not sufficient parameter to define overall printing quality (Fedorovskaya et al, 1993; De Ridder, 1996; Fedorovskaya, 1997; Pedersen, 2009). Quality attributes such as: contrast, sharpness, macro non-uniformity are not connected to the colour reproduction, but certainly affects print quality. As the essential quality attributes are considered: contrast, print sharpness, image noise, line raggedness, resolution, text quality, micro and macro non-uniformity, gloss uniformity etc. (Pedersen, 2009). Many researchers were investigating and admitted the importance of quality attributes, however, there were no common conclusion in terms of which attributes are the most important. In study which conducted Lindberg, it was concluded that the greatest influence on print quality have: mottle, colour gamut, print sharpness and colour differences (Lindberg, 2004). This conclusion is in accordance with conclusions Engeldrum came to, which is that observers will not perceive more than five quality attributes at the same time (Engeldrum, 2004).

In this research, beside colour reproduction as an important print quality attribute, attention is also paid to mottle and line quality. Mottle or macro non-uniformity presents undesirable inequalities in perceived print optical density. One of the causes of this effect is uneven ink absorption into the printing substrate, which leads to smearing or „cloudy" areas of the impression (Dhopade, 2009). Line quality estimation can be performed via measuring of line raggedness. This parameter indicates shape deviation of printed lines from the ideal geometric shape, and represents unwanted line feature which leads to lower print quality. This can be characterized by measurements of the line perimeter. Excessive line raggedness, results in lower print sharpness, and can also cause text to become unclear or thicker.

The aim of this research is to investigate the effect of thermal load on digitally printed textile materials quality. Thereby, tests were conducted on the substrates of different material composition. Print quality assesment included analysis of basic impression quality: spectrophotometric analysis of colour reproduction, motle and line quality. Analysis of the above mentioned attributes were performed after printing and subsequent exposing to thermal loads.

Methods and materials

Three types of textile materials were tested in the research, two knitted textile materials and one weaved textile material. Material composition of the tested materials was determined according to ISO 1833 standard, grammage according to ISO 3801:1997 and density according to ISO 7211-2:1984 standard. Basic characteristic of tested materials are presented in Table 1.

For the needs of this research, a special test target was developed with the aid of Adobe Illustrator CS 5. Generated test target format is 297 x 420 mm and contains different elements for print quality analysis. In presented research, solid patches of 2.54 x 2.54 mm and 1 pt thick and 1.5 cm long lines, printed with black process ink, were analysed.

Ink jet printer Polyprint TexJet performed printing of test target. Printing process was done in two passes using water-based inks (Artistri Pigment Ink- P5400 Black), with the resolution of 720 x 720 dpi. Components (% by weight) in Artistri Pigment Ink are presented in Table 2.

Table 1
Characteristics of materials used in research

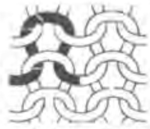
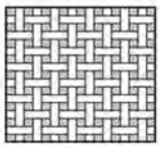
Textile material type	Interlance type	Sample	Grammage [g/m^2]	Density [cm^{-1}]	Material composition
 knitted textile	 right to left knitting	Material 1	190	vertical: Gv = 18 horizontal: Gh =14	100 % cotton
 knitted textile	 right to left knitting	Material 2	160	vertical: Gv = 18 horizontal: Gh = 15	80 % cotton/ 20 % lycra
 weaved textile	 plain weave	Material 3	200	warp: Go = 23 weft: Gp =22	100 % polyester

Table 2
ARTISTRI™ P5400 BLACK PIGMENT INK composition

Material	CAS Number	%
Water	7732-18-5	55-95
Aliphatic Alcohol	**	1-10
*Ethylene Glycol	107-21-1	1-10
Polyglycol Ether	**	1-10
Polymers	**	1-10
Carbon Black Pigment	1333-86-4	1-5

*Disclosure as a toxic chemical is required under Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.

**The specific identity for each component not identified by a CAS Registry Number is withheld as a trade secret.

Fixation of the printed ink was done under the temperature of 140 ºC for 90 seconds. Printed and fixed samples were subjected to five thermal loads under the temperature of 150 ºC for 15 seconds per load (pressure was 850 DaN). Thermal load was performed using Opremakv industrial iron tp 4040s.

After printing and ink fixing, test target was digitalized using flat scanner Canon CanoScan 5600F. Scanning resolution was 600 dpi without application of auto-correction functions. Important image elements were saved as separate TIFF files, and ordered by equally rasterized test target elements (ideal image generated by the computer, with the resolution of 600 ppi).

Spectrophotometric analysis of the colour reproduction was done via CIE Lab coordinates measurements of the black ink solid tone, through the estimation of color reproduction differences (ΔE) between reproduced colour of printed sample, and colour after each of five thermal loads, as well as via measurements of spectral reflectance curves. CIE Lab coordinates are determined using diffuse spectrophotometer HP200 (illuminant D65, standard observer 10º, measuring geometry d/8, measuring aperture 16 mm), while the spectral reflectance curves were measured by Techkon SpectroDens spectrophotometer (illuminant D50, standard observer 2º, measuring geometry 0º /45º, measuring aperture 3 mm).

Line quality was determined by perimeter measurements of 1 pt thick lines and by comparison of obtained printed samples' results to the results of samples which were subjected to thermal loads. Mottle estimation was done by determination of non-uniformity index, both on only printed samples and samples, which were afterwards subjected to thermal loads. Line perimeter measurements were performed using ImageJ software, and non-uniformity index was measured using its plug-in, developed by Muck et al. (2009). During testing all quality parameters, there were a total of 10 measurements, and as a representative value, average of those 10 measurements were calculated.

Results and discussion

Colour reproduction analysis

CIE Lab colour coordinates were measured spectrophotometrically, after printing process, and after exposing the samples to thermal load. Obtained values are presented in Table 3. As the reference values, during colour difference calculation (ΔE), were taken only printed samples values, and colour difference values were calculated in relation to them, after series of thermal loads for each material.

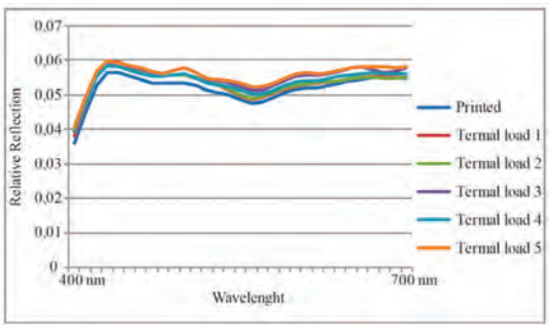
Table 3
CIE Lab colour coordinates and colour differences after printing and series of thermal loads applied

Sample	L	a	b	Δ E
Material 1 P	27,806	0,968	-0,936	/
Material 1 T1	27,73	1,13	-1,00	0,19
Material 1 T2	28,098	1,106	-1,23	0,44
Material 1 T3	27,64	1,19	-1,3	0,46
Material 1 T4	27,36	1,03	-1,03	0,46
Material 1 T5	27,19	1,11	-1,21	0,69
Material 2 P	29,892	0,922	-0,782	/
Material 2 T1	29,492	0,562	-1,086	0,62
Material 2 T2	28,78	0,88	-1,01	1,14
Material 2 T3	28,42	0,83	-1,05	1,5
Material 2 T4	28,3	0,81	-1	1,61
Material 2 T5	28,23	0,64	-1,14	1,72
Material 3 P	32,53	0,616	-1,352	/
Material 3 T1	32,596	0,616	-1,466	0,13
Material 3 T2	33,19	0,71	-1,57	0,70
Material 3 T3	33,51	0,60	-1,29	0,98
Material 3 T4	33,63	0,72	-1,43	1,11
Material 3 T5	33,67	0,62	-1,46	1,15

Remark: Letter P indicates solely printed material; T1 denotes sample after first thermal load, T2 denotes sample after second thermal load, T3 denotes sample after third thermal load, T4 denotes sample after fourth thermal load, T5 denotes sample after fifth thermal load.

Analysing results in Table 2, as a common conclusion for all materials, it can be drawn out that by increasing the number of applied thermal loads, a rise of colour differences in relation to solely printed samples occurs. After analysing the results of the Material 1, it can be noted that differences of reproduced colour are not significant and that generally, human eye cannot perceive them. Observing obtained results for Material 2, it can be noted that after first thermal load there was a difference in reproduced colour that cannot be distinguished by the human eye. Re-exposing Material 2 to thermal load, results in bigger colour differences that can be spotted by the "trained" eye. Considering Material 3 results, it is clear that series of three thermal loads lead to slight changes in colour reproduction, i.e. producing colour differences that human eye cannot generally detect. Further expositions of this material to thermal loads, generates colour differences that can be perceived by the "trained" eye.

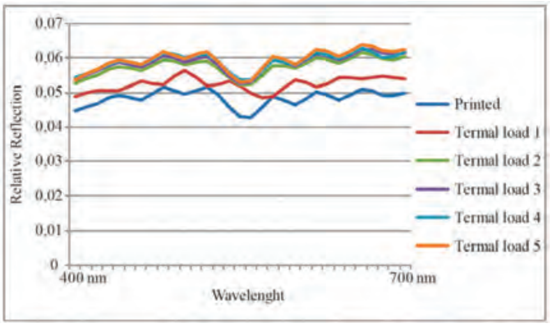
Simultaneously using CIE Lab colour coordinates and colour differences determination, spectral curves analysis were also conducted after printing and applying thermal load. In this way, the fashion of how thermal load affects surface reflectivity was monitored. Comparison of the spectral reflectance curves before and after thermal load is presented in Figures 1, 2, and 3. The figures clearly show that thermal load leads to higher relative reflectance values of the tested samples, whereas spectral curve shapes and the maximum spectral sensitivity remain the same for each material used. It must be pointed out, that neither relative reflectance values increases nor the values of colour differences are significant.



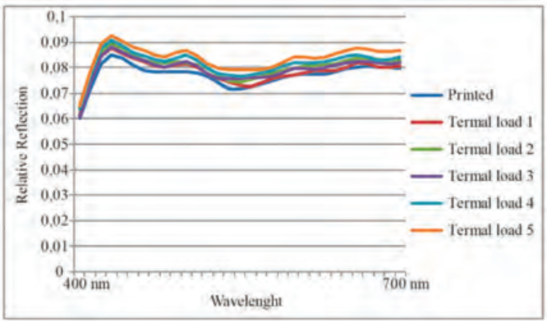
» **Figure 1:** *Spectral reflectance curves after printing and series of thermal loads - Material 1*

Spectrophotometric analysis of the results, give an assumption that thermal load causes partial evaporation and penetration of ink, from the surface of textile material into the structure of the material, between fibers. This means that certain ink quantity, that was previously situated on top of the fibers, must have been reduced, which caused differences in colour reproduction, as well as higher light amount reflection off the material surface.

Thermal load caused partial ink evaporation and penetration of the ink from the surface of textile materials in to the structure of materials (Novaković et al, 2010). That could be the reason for noticed colour difference as well as change in spectral reflectance of printed materials.



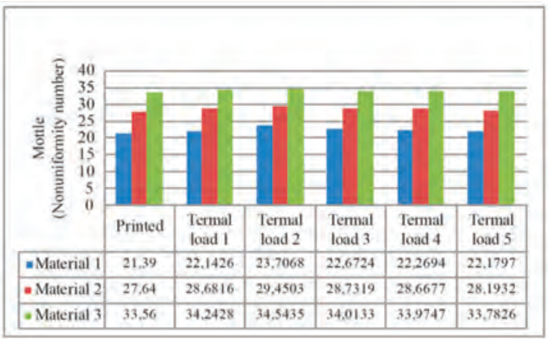
» **Figure 2:** *Spectral reflectance curves after printing and series of thermal loads - Material 2*



» **Figure 3:** *Spectral reflectance curves after printing and series of thermal loads - Material 3*

Mottle analysis

Mottle analysis was done by macro non-uniformity index determination. Degree of macro non-uniformity is defined by non-uniformity index. Figure 4 presents measured non-uniformity values, obtained on test materials after printing and series of thermal loads.

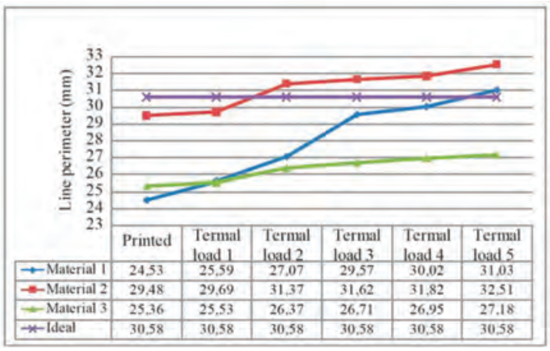


» **Figure 4:** *Macro non-uniformity values after printing and series of thermal loads*

From the analysis of macro non-uniformity index values, it can be noted that after first two thermal loads, the macro non-uniformity index value rise comparing to samples that were only printed. Further thermal loads application produce lower macro non-uniformity values. Presented trends were noticed amongst all tested materials. This phenomenon can be explained by the thing that initial thermal loads cause uneven ink absorption from the surface to the structure of the printing material, which cause ink gathering on certain areas of the impression. Further thermal loads make the ink penetration into the structure of the material more even, which gives more uniform ink deposition on the material surface. It is also confirmed that material characteristics affect macro non-uniformity values, under all thermal loads. Therefore, it can be seen that the highest non-uniformity values were recorded within the prints made on Material 3, while the lowest non-uniformity values were recorded on the prints of Material 1.

Line reproduction analysis

Line reproduction analysis was done by perimeter measurements of 1pt thick lines. Obtained results are presented in Figure 5. Measured values indicate that printing on all materials produces lines with lower perimeter in comparison to ideal value (line perimeter on the computer-generated image). Thermal loads cause the increase of the line perimeter values. By this perimeter increase, lines lose its sharpness and an ideal line shape, also line raggedness rise, which is an undesirable effect. In addition, this perimeter increase can be considered as a direct consequence of ink transition from the surface to the material structure. Measurement results indicate that material characteristics also affected the values of this print quality parameter. Reproduced lines on Material 2 have the perimeter values nearest to ideal values. On the other hand, thermal loads were the cause of the biggest changes in line perimeter values, comparing to line perimeter after printing. This was expected, given that the Material 1 is made of cotton fibers and has good absorbency properties.



» **Figure 5:** *Perimeter values of 1pt thick lines after printing and series of thermal loads*

Conclusion

Spectrophotometric analysis showed that increasing number of thermal loads, leads to bigger differences of reproduced colour, comparing to colour of the samples which did not undergo series of thermal loads. However, it needs to be pointed out that changes of the samples' quality, still, were not very pronounced, so the maximum value for colour difference was ΔE = 1,72, which is considered to be very small difference that can be noticed by only „trained" eye. From the analysis of spectral reflectance data, it was concluded that with increasing number of thermal loads, spectral reflectance values of the samples rise. The cause of this phenomenon is partial ink penetration from the surface to the structure of fibers during thermal load. In that way, the ink volume that had been on a material surface reduced, and surface of printed area becomes smoother which increases its reflectivity.

Mottle analysis confirmed that this printing quality parameter also changes under series of thermal loads. Samples exposition to initial thermal loads, leads to uneven penetration of the ink portion, from the textile material surface to the material structure, and rising of prints macro non-uniformities. By incrasing the number of thermal loads, deformable changes are generated which is the consequence of pressure applied during thermal loads, and leads to lower macro non-uniformity values, but they still stay above the values recorded on only printed samples. As well, it is confirmed that material characteristics have certain affect on macro non-uniformity values under all thermal loads.

Number of thermal loads also affects the line reproduction. It is noticed that thermal loads lead to the increase of line perimeter values. These line expansions cause the loss of line sharpness and an ideal geometric shape and increase of line raggedness.

Considering research results, it can be concluded that application of thermal load process on textile materials as well as its frequency have effects on print quality change on tested materials. Beside this parameter, material characteristics also affect print quality of tested samples. In order to gain new facts and deepen knowledge about this field of research, it is planned to investigate how various temperatures and pressure levels for thermal load tests affect print quality on the textile materials. Also, the way of how other external influences affect print quality should be investigated, first of all washing and rubbing processes.

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References

1. Beretta, G. (2008) Understanding Color. Alexandria, Hewlett-Packard Co. [Online] Available from:http://www.inventoland.net/imaging/uc/understandColor.pdf [Accessed 6th June 2013].
2. De Ridder, H. (1996) Naturalness and Image Quality: Saturation and lightness variation in colour images. Journal of Imaging Science and Technology, 40 (6), 487-493.
3. Dhopade, A. (2009) Image quality assessemnet according to ISO 13660 and ISO 19751. Test Targets 9.0, RIT School of Print Media. [Online] Available from: http://cias.rit.edu/~-gravure/tt/pdf/pc/TT9_image_quality_assessment.pdf[Accessed 7th June 2013].
4. Engeldrum, P. G. (2004) A Theory of Image Quality: The Image Quality Circle. Journal of Imaging Science and Technology, 48 (5), 446-456.
5. Fedorovskaya,E. A., Blommaert, F., De Ridder, H. (1993) Perceptual quality of colour images of natural scenes transformed into CIELUV colour space. Proceedings of IS&T & SID's Colour Imaging Conference, 7-11 November 1993, Scottsdale, Arizona, USA.Society for Imaging Science and Technology. pp. 37-40.
6. Fedorovskaya, E. A., De Ridder, H., Blommaert. F. (1997) Chroma variations and perceived quality of colour images of natural scenes. Color research and application, 22 (2), 96-110.
7. Kašiković, N., Novaković, D., Vladić, G., Klančnik, M. (2011) Influence of heat treathment on caracteristics of inkjet prints on textile material. Journal of Graphic Engineering and Design, 2 (1), 24-30.
8. Kašiković, N., Novaković, D., Karlović, I., Vladić, G. (2012) Influence of ink layers on the quality of ink jet printed textile materials. Tekstil ve Konfeksiyon, 22 (2), 115-124.
9. Kočevar, N. T. (2006) Kolorimetrisjka analiza i vizuelna ocjena boja na dvobojnoj tkanini. Tekstil, 55 (3), 127-134 (in Croatian)
10. Krebs, F., Jørgensen, M., Norrman, K., Hagemann, O., Alstrup, J., Nielsen, T., Fyenbo, J., Larsen, K., Kristensen, J. (2009) A complete process for production of flexible large area polymer solar cells entirely using

screen printing- First public demonstration. Solar Energy Materials and Solar Cells, 93 (4), 422-441.
11. Lee, T. M., Choi, Y. J., Nam, S. Y., You, C. W., Na, D. Y., Choi, H. C., Shin, D. Y., Kim, K. Y., Jung, K. I. (2008) Color filter patterned by screen printing. Thin Solid Films, 21 (516), 7875-7880.
12. Lindberg, S. (2004) Perceptual determinants of print quality. PhD thesis. Stockholm, Department of Psychology, StockholmUniversity.
13. Majnarić, I., Bolanča, S., Golubović, K. (2010) Some characteristics of ink jet transfer foils and their influence on the print quality of cotton fabric. Tekstil, 59 (10), 456-462.
14. Mao, N., Russell, S. J. (2007) The Thermal Insulation Properties of Spacer Fabrics with a Mechanically Integrated Wool Fiber Surface. Textile Research Journal, 77 (12), 914-922.
15. Michalak, M., Felczak, M., Więcek, B. (2009) Evaluation of the thermal parameters of Textile materials using the thermographic methods. Fibres and Textiles In Eastern Europe, 17(3), 84-89.
16. Momin, N. H. (2008) Chitosan and improved pigment ink jet printing on textiles. PhD thesis. Melbourne, RMIT University.
17. Muck, T., Hladnik, A., Stanić, M. (2009) Analiza tiskovne kakovosti z orodjem ImageJ = Analysis of print quality with ImageJ. Zbornik Prispevkov, Naravoslovnotehniška fakulteta, Oddelek za tekstilstvo. [Online] Available from: http://www.ot.ntf.uni-lj.si/simpozij2009/zbornik.pdf[Accessed 20th May 2013].
18. Novaković, D., Kašiković, N., Vladić, G. (2010) Integrating internet application in to the workflow for costumisation of textile products. Proceednigs of the International Joint Conference on Environmental and Light Industry Technologies, 18-19 November 2010, Budapest, Hungary. Óbuda University. pp. 471-476.
19. Novaković, D., Kašiković, N., Zeljković, Ž., Agić, D., Gojo, M. (2010) Thermographic analysis of thermal effects on the change of colour differences on the digitally printed textile materials. Tekstil, 59(7), 297-306.
20. OnarÇatal, D., Özgüney, A. T., Akçakoca Kumbasar, E. P. (2012) The influence of rheological properties of the pretreatment thickeners on ink-jet printing quality. Tekstil ve Konfeksiyon, 22 (4), 309-316.
21. Pedersen, M., Bonnier, N., Hardeberg, J., Albregtsen, F. (2009) Attributes of a new image quality model for color prints. Proceedings of Color Imaging Conference, 9-13 November 2009, Albuquerque, New Mexico, USA, Society for Imaging Science and Technology. pp. 204-209.
22. Stančić, M., Novaković, D., Kašiković, N., Vukmirović, V., Ružičić, B. (2013) Influence of material composition on print quality digitally printed textile substrates. Tekstilna industrija, 60 (1), 37-43.
23. Tippet, B. G. (2002) The Evolution and Progression Of Digital Textile Printing. [Online] Available from: http://www.brookstippett.com/docs/Print2002-BGT.pdf [Accessed 5th June 2013].