THE INFLUENCE OF THERMAL LOAD ON THE PRINT QUALITY OF SCREEN PRINTED KNITTED FABRICS

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High surface texture of textile materials appears rougher and more porous than other printing substrates which can cause excessive ink penetration. Also, high temperature thermal loads affect the characteristics of printed ink and cause structural changes of the textile substrate material as well. The aim of this paper is to determine the influence of thermal load on the print quality of cotton based fabrics with different knitting types via surface macro non-uniformity and line quality determination of the printed samples. The research results indicated that the thermal load had a negative influence on the line quality parameter and a positive effect on the macro non-uniformity parameter.

Keywords: print mottle, screen printing, line quality, knitted cotton fabric, different knitting type

Introduction

Colour creates an important visual impression which can provide the basis for decisions in virtually every walk of life. With textile products, the colour often first attracts the consumer and plays an important role in a buying decision [1]. For clothes it is no longer enough to meet only basic functions, such as body protection and functionality, but also to meet the aesthetic and fashion requirements so it can better depict a personal character and lifestyle of the individual [2]. Textile printing can be best described as art and science of decorating a fabric with a colourful pattern or design. The vast majority of textile materials are printed using a screen printing technique. Besides screen printing, textiles can be printed using digital printing and thermal transfer. However, traditional screen printing is the most important printing technique for textile printing [3-5] intended for high productivity and large print circulation which significantly reduce the production costs [6,7]. In screen printing, a knitting of screen mesh i.e. a number of threads per cm is the most relevant factor which defines the printing quality [8]. Mesh number per unit area affects the pattern quality of the printing process. The information about screen mesh density is usually used for determination of the ink volume transfer to the substrate material. Coarse mesh causes some handicaps such as lack of fixing on stencil and the excessive paste transfer onto the fabric [9, 10]. The increase in mesh thread count causes certain changes of the substrate material surface, because during the printing process the ink paste fills a textile material structure which results in the surface roughness change [9]. Textile material is often exposed to various influences such as thermal load, washing process, friction, UV light, etc. It has been proved that thermal load application on textile materials, as well as this process frequency influence the print quality change [11]. The heat treatment of printed textile products is usually applied during the manufacturing process in order to achieve better visual effects. Heat can be applied by any heating element, such as a hand held or an industrial iron. In these processes, the applied heat affects printed ink as well as textile fibres of the substrate material [12]. In this investigation, the attention is placed onto the print mottle and the line quality analysis, as the print quality parameters. The print mottle or solid-tone print uniformity, as a print quality parameter, usually occurs in the manner of systematically structured patterns which the human vision system notices very easily due to its perfect responsiveness to pattern detection [13]. The causes of print mottle are various: inadequate printing pressure, printing speed, substrate material surface roughness, ink transfer and absorption etc. [14]. Print mottle assessment in this research was conducted by GLCM (Grey Level Co-occurrence Matrix) image processing method also known as the grey level spatial dependence matrix. It is a table that keeps track of how often different combinations, pairs of pixel intensities (grey level values) occur in a specific spatial relationship and distance in an analysed image [15]. It was found that contrast, correlation, entropy, energy and homogeneity parameters can be used for the print mottle assessment [15-17]. Low contrast, low correlation, low entropy, high energy and high homogeneity values correspond to the uniform grey

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level distribution, i.e., indicate a uniform, smooth surface [15, 18]. Gebeješ et al. found that the entropy parameter correlates best with the human texture perception and if the entropy value is high, a particular texture becomes more visible and more noticeable. Therefore, it can be concluded that higher entropy values indicate stronger texture patterns which are perceived more easily [19]. The correlation determines a linear dependency of grey levels with those of neighbouring pixels, and it is a quite different calculation of other texture measures described above. As a result, it is independent of them (gives different information) and can often be used profitably in combination with another texture measure. It also has a more intuitive meaning to the actual calculated values: 0 is uncorrelated, 1 is perfectly correlated [20]. The ISO-13660 standard suggests blurriness and raggedness as quantifiers of the printed line quality [21]. The most important printed line quality attributes are line width, raggedness and blurriness [22]. Line raggedness indicates the straightness of a printed line. Any geometric distortion is identified as an undesired property of a line, and consequently degrades the quality of the printed image [23]. A ragged edge appears rough or wavy rather than smooth or straight. The lower the raggedness, the better is the line quality [21]. The line quality of less than 12 units of raggedness has a visually unnoticeable difference [23]. An ideal line edge profile should be perfectly straight along the length of a line; any deviation from this gives the appearance of a ragged, jagged or scalloped line [24]. The excessive line raggedness results in lower print sharpness and can also cause an unclear or thicker text [11] which is independent of the line width characteristic [25]. The blurriness is the appearance of being hazy or indistinct in outline. The lower the blurriness, the better is the line quality [21]. The measure of blurriness corresponds to the width of the transition zone between the field and the line. Blurriness increases with the increase of the line width [25].

The aim of this research is to investigate the influence of thermal load and screen mesh tread count on the print quality of the screen printed cotton knitted fabrics with different knitting types. The assessment of the print quality included print mottle and line quality analysis which was performed after the printing process, as well as after the application of the thermal load.

Experimental part

Three different cotton based textile materials with different knitting types: single, pike and interlock were used. The material characterization was done according to the following standards: material composition (ISO 1833), fabric weight (ISO 3801) and thread count (ISO 7211-2). These substrate material properties are presented in Table 1.

Table 1. Characteristics of the material used in testing

Tests	Type of knitting	Material composition (%)	Fabric weight (g/m²)	Thread count (cm^{-1}) G_v	G_h
Material A	Single	Cotton 100 %	138	14	19
Material B	Pike	Cotton 100 %	185	15	16
Material C	Interlock	Cotton 100 %	207	12	18
Method		ISO 1833	ISO 3801	ISO 7211-2	

A special test chart was developed using the Adobe Illustrator CS 5 application. The test chart size was 297 x 420 mm and it consisted of various elements of the print quality analysis. The areas sized 2.54 x 2.54 cm, 100% tone values of the yellow process colour and 1 pt horizontal black lines were analysed. The samples were printed using the screen printing technique, M&R Sportsman E Series six-colour printing machine. Pan et al. found that four main parameters had a crucial effect on the screen print quality [26]. These parameters were kept constant during the printing process of all samples. The printing speed was 15 cm/sec; squeegee hardness was 80 Shore Type A, printing pressure 275.8 x 103 Pa and 4 mm snap-off distance. Sericol Texopaque Classic OP Plastisol (OP058 and OP021) ink was used. Ink fixation was done at the temperature of 160 °C and the exposure time of 150 seconds.

The printing form was made using printing screen mesh counts of 90, 120, 140 and 160 threads per cm on aluminium tubing frames (58 x 84 cm). The size of the stencil without a frame was 50 x 76 cm. The conventional exposure was conducted using linear positive films. The optical density of transparent areas of the film was 0.3 and 4.1 of opaque areas. The film scanning resolution was five times smaller than printing screen mesh count. Photosensitive Sericol Dirasol 915 emulsion was used. The light exposure was done using metal-halogen UV lamp (1000 W) at the 1 m distance from the mesh. The exposure time for each stencil was calculated using the control tape Autotype Exposure Calculator by Sericol Company. The light exposure time for each stencil is presented in Table 2.

Table 2. Exposure time of stencils

Thread count (threads/cm)	Light Exposure time (min)
90	3
120	2,6
140	1,6
160	1,3

The samples were heat treated according to standard ISO 105-X11:1994, using a thermal press MAGNET RV. Time (15 s) and contact pressure (850 daN) were constant during the experiment. The samples were exposed to the temperature of 130 °C. All the samples were scanned and measured repeatedly two times, before and after thermal load. The samples were scanned using flatbed scanner Canon CanoScan 5600F. Scanning resolution was set at 600 spi and auto correction was turned off. Image elements of the significance to this measurement were saved as separate TIFF files and they were analysed afterwards. Scanned samples were subjected to GLCM analysis for obtaining quantitative solid-tone print uniformity results. Applied MATLAB function proposed by Uppuluri [27] provides information about 22 GLCM parameters, out of which the most relevant and used in literature, as well as in this investigation are: contrast, correlation, entropy, energy and homogeneity, as suggested in references [15, 18, 28]. Those five parameters should be interpreted as follows: low values of contrast, correlation and entropy parameters, while high values of energy and homogeneity parameters correspond to a uniform grey level distribution, indicating a uniform solid-tone print surface [15, 18]. Line measurements were performed with the Personal IAS Image Analysis System, recently introduced by QEA. This device quantifies comprehensive print quality attributes according to ISO 13660:2001 [29].

Results and discussion

This section of the paper will present obtained GLCM analysis results of different solid-tone patches printed on different knitting type cotton textile materials with yellow ink, using four different mesh thread counts. After the printing process, the printed samples were exposed to high temperature thermal load.

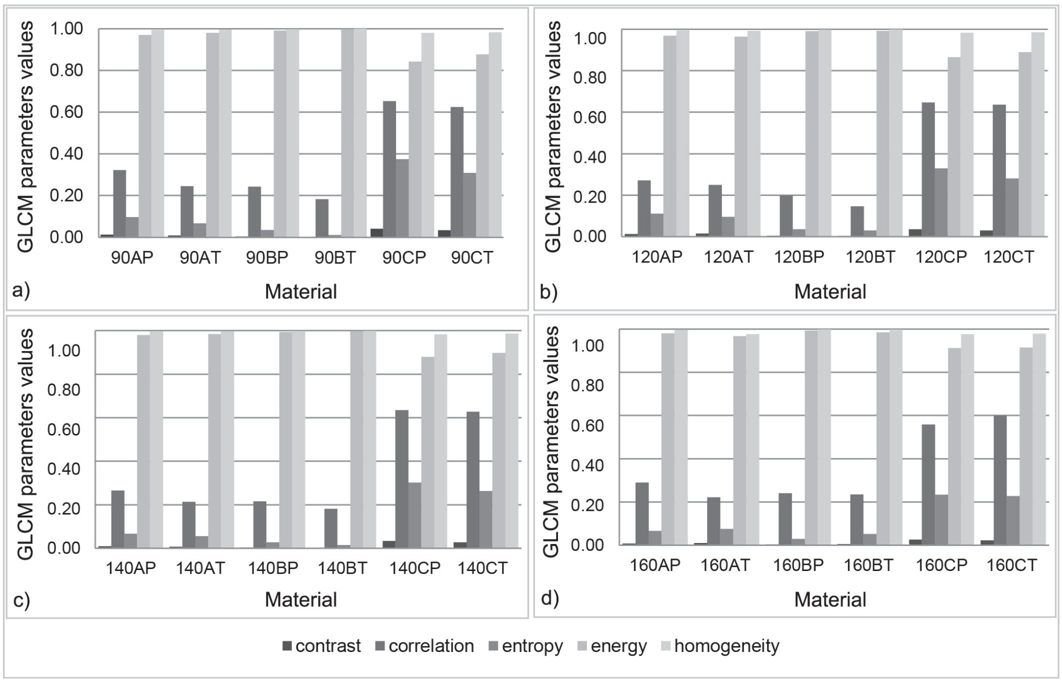

Figure 1. GLCM parameters comparison for the samples printed using four different thread counts on cotton textile materials with different knitting and exposed to high temperature: a) 90 threads/cm, b) 120 threads/cm, c) 140 threads/cm, d) 160 threads/cm.
Note: Numbers 90/120/140/160 represent the thread count; A/B/C represent materials with different knitting; P is a mark of the printed sample; T is a mark of the sample measured after thermal load.

In Figure 1 the results of GLCM Matlab function application on scanned samples are presented. Based on these results, all samples have low contrast, correlation and entropy and high energy and homogeneity values which leads to the conclusion that these samples have a good solid-tone print uniformity, i.e. low print mottle. It can be noticed that material C possesses significantly higher values of contrast, correlation and entropy parameters and lower ones concerning energy and homogeneity parameters. This indicates the higher print mottle presence on the samples printed with each screen mesh thread count on this material. Comparing the samples before and after thermal load, certain differences for all GLCM parameters can be noticed which indicates that high temperature has an impact on the printed samples structural arrangement of the surface. Contrast, correlation and entropy parameter values declined for all substrate materials and three out of four mesh thread counts were used (90 threads/cm, 120 threads/cm and 140 threads/cm) after thermal load, while energy and homogeneity parameter values increased. It leads to the conclusion that after high temperature and pressure impact, the texture becomes less visible resulting in print mottle diminishing. Exceptions are the samples printed using 160 threads/cm mesh, where GLCM parameter values have a reverse trend i.e. thermal load contributes to a higher print mottle level. It can be assumed that due to the high viscosity of screen printing inks, a lower amount of ink fills the area between the yarns of the fabric and the ink mostly retains on the fabric surface. Therefore, the use of higher mesh thread count will produce a lower amount of ink and thus a thinner layer of ink will be transfered onto the fabric surface, which leads to higher non uniformity of the surface. The lowest mesh thread count will produce the thickest ink layer, thus best filling the holes in the cotton fabric. However, in this case the problem of excessive thickness of ink causes a poor vertical lift of the screen in the zone after printing, which usually results in an uneven surface. Therefore, it is evident from the results that the medium screen printing mesh thread count gives the best results.

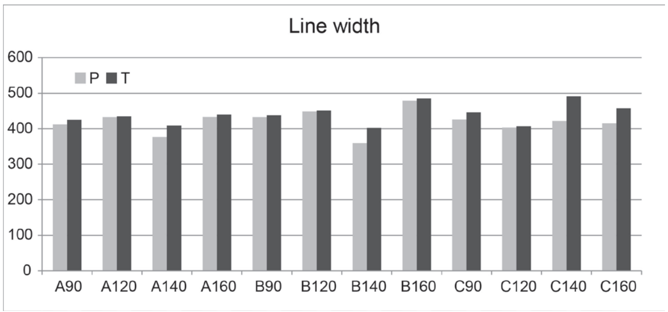

Figure 2. Line width comparison for the samples printed using four different thread counts on cotton textile materials with different knitting and exposed to high temperature
Note: Numbers 90/120/140/160 represent the thread count; A/B/C represent materials with different knitting; P is the mark of the printed sample; T is the mark of the sample measured after thermal load.

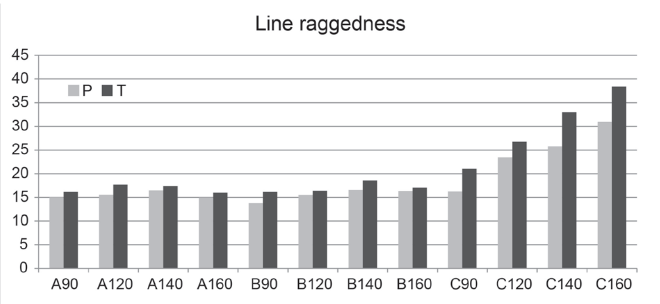

Figure 3. Line raggedness comparison for the samples printed using four different thread counts on cotton textile materials with different knitting and exposed to high temperature
Note: Numbers 90/120/140/160 represent the thread count; A/B/C represent materials with different knitting; P is the mark of the printed sample; T is the mark of the sample measured after thermal load.

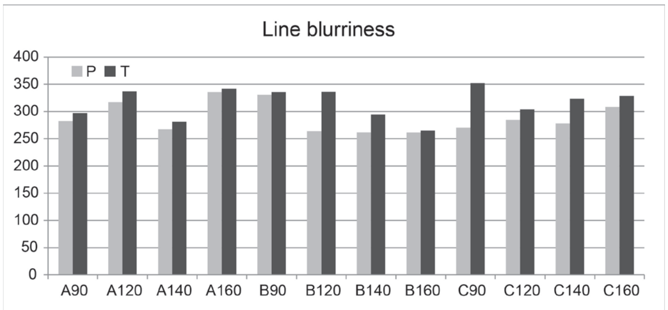

Figure 4. Line blurriness comparison for the samples printed using four different thread counts on cotton textile materials with different knitting and exposed to high temperature
Note: Numbers 90/120/140/160 represent the thread count; A/B/C represent materials with different knitting; P is the mark of the printed sample; T is the mark of the sample measured after thermal load.

In Figures 2-4 the line quality parameters results of the printed samples before and after thermal load are shown. It can be noticed that the values of all considered line quality parameters (line width, raggedness and blurriness) are higher after thermal load.

Conclusion

After the analysis of the thermal load impact on the print quality parameters of cotton material with different knitting, certain conclusions can be made. The aim of the investigation was to compare the same printed samples before and after thermal load, to reveal to what extent a high temperature affects the line quality and the uniformity of the solid-tone print area. Yellow process colour by itself is very complex, with a highly pronounced brightness that could be sensitive to external stimuli as light and heat. Also, it is the colour with the highest pigment content in comparison to other process colours. Based on the print mottle analysis results, all samples have low parameter values for contrast, correlation and entropy, and high energy and homogeneity which lead to the conclusion that these samples have relatively low non-uniformity. After subjecting the samples to the thermal load, the parameter values change are noticeable. Those changes brought better results of the printed surface uniformity characteristic, which leads to the conclusion that high temperature lowers the print mottle. The only difference that should be pointed out is that high thread count mesh let through the lower amount of ink during the printing process and this is what caused the transfer of the lower ink layer to the substrate surface. This caused a high amount of the print mottle on the printed sample which the subsequent thermal load diminished. Regarding the knitting type of the substrate materials it can be concluded that material B possessed the lowest level of print mottle, while the highest print mottle level was recorded on material C. This can be related to the material surface structure, specifically the material C had "very rough" knitting, which contributed to its higher surface roughness.

The comparison of the line quality parameter values before and after subjecting the samples to thermal load showed that line width, raggedness and blurriness have higher values after thermal load, i.e. the line quality after thermal load drops. Line raggedness for all samples is higher than 12, which indicates that these print imperfections are visible. The reduction of line sharpness occurs due to bleeding of inks caused by ink melting, which is influenced by high temperatures.

In order to broaden current knowledge in this scientific area, our plan is to conduct the investigations that include the washing influence on different textile material substrates, which will provide insight into the effect of structural characteristics of a textile substrate material on the print quality. Future research should be directed to utilization of different process colours, different thermal load temperatures, another printing technique (e.g. ink-jet) as well as the introduction of pre-treatment of textile materials, which may provide better results.

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Izvod

UTICAJ TOPLOTNOG DEJSTVA NA KVALITET OTISKA DOBIJENIH TEHNIKOM SITO ŠTAMPE NA TRIKOTAŽI

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Gruba tekstura površine, kao i velika poroznost tekstilnih materijala, u odnosu na ostale vrste štamparskih podloga, mogu dovesti do pretjeranog prodora boje. Pored toga, visoke temperature toplotne obrade utiču na karakteristike boje odštampanih uzoraka, kao i na strukturne promjene u tekstilnoj podlozi. Cilj ovog rada je utvrđivanje uticaja toplotne obrade na kvalitet štampe pamučnih pletenina različitih vrsta prepletaja putem određivanja makroneuniformnosti i kvaliteta linija odštampanih uzoraka. Rezultati istraživanja su pokazali da toplotna obrada negativno utiče na kvalitet linija, ali ima pozitivan uticaj na makroneuniformnost.

Ključne riječi: makro neuniformnost, sito štampa, kvalitet linija, pamučne pletenine, različit tip prepletaja