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The Effect of Washing Treatment and Washing Temperature on Print Quality of Screen Printed Cotton Knitted Fabrics

Yıkama İşleminin ve Yıkama Sıcaklığının Pamuklu Örme Kumaşların Baskı Kalitesi Üzerine Etkileri

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THE EFFECT OF WASHING TREATMENT AND WASHING TEMPERATURE ON PRINT QUALITY OF SCREEN PRINTED COTTON KNITTED FABRICS

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ABSTRACT: During exploitation different effects influence printed textile products and one of the most common is washing treatment. It causes modification of textile structure and textile fibres. The aim of this research is to determine the influence of the washing treatment, the washing treatment temperature and characteristics of printed material on print quality parameters of screen printed cotton knitted textile materials. It will be obtained using spectrophotometric analysis and macro non-uniformity analysis via the mottling index. The research results show that increasing the number of washing treatments, and also increasing of washing temperature, causes an increase of colour difference between washed and unwashed samples. It also shows that substrate characteristics have great influence on colour differences. Besides that, washing treatment also causes noticeable changes of print mottle, which are, again, also dependent on substrate characteristics.

Keywords: Screen printing, Cotton, Washing, Colour difference, Print mottle

YIKAMA İŞLEMİNİN VE YIKAMA SICAKLIĞININ PAMUKLU ÖRME KUMAŞLARIN BASKI KALİTESİ ÜZERİNE ETKİLERİ

ÖZET: Kullanım sırasında farklı işlemler baskılı tekstil ürünlerini etkiler ve bu işlemlerden en yaygın olanlarından biri yıkama işlemidir. Yıkama işlemi tekstil yapısının ve tekstil liflerinin modifikasyonuna neden olur. Bu araştırmanın amacı, elyaf baskılı pamuklu örme tekstil malzemelerinin baskı kalitesi parametrelerine yıkama işleminin, yıkama işlem sıcaklığının ve baskılı malzemenin özelliklerinin etkilerini belirlemektir. Renk indeksi üzerinden spektrofotometrik analiz ve makro dağınıklık analizi kullanılarak etkiler belirlenecektir. Araştırma sonuçları, yıkama işlemlerinin sayısının arttırılmasının ve aynı zamanda yıkama sıcaklığının arttırılmasının, yıkanmış ve yıkanmamış numuneler arasındaki renk farkının artmasına neden olduğunu göstermektedir. Aynı zamanda, substrat özelliklerin renk farklılıkları üzerinde büyük etkisi olduğunu da gösterir. Bunun yanında, yıkama işlemi aynı zamanda baskı kalitesinde gözle görülür değişikliklere neden olur ki bu yine substrat özelliklerine bağlıdır.

Anahtar Kelimeler: El baskısı, Pamuk, Yıkama, Renk farkı, Baskı kalitesi

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1. INTRODUCTION

Today it is not enough that clothes meet just basic function, it is expected to fulfil personal requirements, such as visual attractiveness. Thus, clothes should meet both the aesthetic and fashionable requirements [1, 2]. Printing in easy way contributes to the aesthetic value of clothes [3].

There are a lot different types of textile materials in use as well as different printing techniques [4-8]. The most represented among them are conventional screen and digital ink-jet printing [8]. Screen printing is considered to be dominant printing technique in textile world [7-12]. As the advantages of this printing technique stand out costs and productivity. Compared to other printing techniques equipment is commonly less expensive and simpler. It is also convenient for long print runs [13, 14]. One more advantage of this technique is usability on different types and shapes of substrates. For screen printing is characteristic usage of different ink types [15]. Textile screen printing uses special ink type called plastisol inks. They represent dispersion of PVC particles in a plasticizer, which dissolve each other on temperature higher than 150^{o}C and create strong layer of ink. Plastisol inks infiltrate into textile material and after drying strongly merge with cloth. Textile material printed with these colours is extremely resistant to numerous washing and drying treatments. Also, these colours have great covering capacity and behaviour during printing [15].

The screen print quality is influenced by various factors that are closely dependent on each other [7, 8, 16]. Some of them are process parameters as print speed, squeegee hardness, squeegee pressure and the distance between the screen and printing substrate, i.e. snap-off distance [7, 8]. According to Pan et al [17] squeegee hardness and print speed have the largest influence on the print quality. Printing screen mesh counts and fibre thickness have great influence on ink density and reproduction of colour tone [7, 8]. Ingram concluded that reproduction quality of lines and dots largely depends on printing form, ink and substrate.

Cotton has outstanding properties: air permeability, diffusion of moisture and heat, softness, hypoallergenic and antistatic properties. That is why the furthermost part of printed textile material belongs to cotton substrate printing [19]. Besides that, it is an inexpensive material, which brings to its prevalence, and long-lasting, washable material that does not demand any special attention [7].

Different effects influence printed textile materials during exploitation – washing, heating, chemical agents, light, etc. [6, 7, 8, 10, 20]. Prime factor that influence the print quality of textile materials is a washing treatment. As Kalantzi [21] founded, washing treatment modifies physical and chemical characteristics of textile. It also affects micro mechanical properties (air permeability, tearing resistance, rigidity) [22]. Besides that, according to Xiang [23] washing treatment has an effect on printed colours and causes its modification. All mentioned modifications are dependent on washing process, washing temperature, water hardness and washing period. Also, chemicals like bleach suspensions, enzyme catalysts and ink transfer inhibitors are contained in modern detergents and they can affect printed colours and change them [24].

Smaller colour difference corresponds to higher print quality. Graphic industry founded colour management standards that comprise objective methods for describing colour and its difference [6]. Spectrophotometry is most common used technique for analyzing colour and quality control in printing process [6, 7]. The CIE L*a*b* colour coordinates and spectral reflectance curves are being used for describing colour reproduction. These colour coordinates enable evaluation of colour differences between two samples, or between standard and sample, and obtaining objective data about reproduction quality [25]. It is expressed as a numerical value that corresponds to differences of colour space coordinates (ΔL, Δa, Δb) [7, 25].

There are various equations in use for determination value of colour difference, for instance CMC [26], BFD [27], CIE 94 [28] and latest CIE $\Delta E2000$ [29]. Obtained values of colour differences can be divided in next groups: $\Delta E < 0,2$ (the colour difference is not perceptible), ΔE between 0,2 and 1 (the colour difference is noticeable), ΔE between 1 and 3 (the colour difference is perceptible), ΔE between 3 and 6 (the colour difference is easy perceptible) and ΔE over 6 (obvious colours difference) [30].

Evaluation of image colour and tone value reproduction is simple using appropriate measuring device, since tone and colour are easily perceptible, but they are not sufficient for assessment of print quality [31, 32]. In a couple of experiments so far, it was discovered that print quality is not a monotonic function of hue, saturation and brightness [33-36]. There are several quality attributes such as contrast, sharpness, macro-uniformity, etc, which are not directly linked with tone and colour, but have a large effect on print quality. They are directly linked with structural elements of any image, i.e. lines and dots [32]. Until now many research have been done that indicate the significance of different quality attributes, but still none of them has been highlighted as the prime [7, 37, 38]. It is conditioned on multidimensionality and complexity of image quality [38].

Print mottle and colour gamut, as well as colour shift and sharpness, firmly influence the perception of the image quality, according to Lindberg [39]. Thus, amount of quality attributes can be decreased to four mentioned, which corresponds to Engeldrum's statement that observer is not capable to detect more than five quality attributes at the same time [37, 40].

The importance of print mottle in print quality, as well as colour gamut, colour shift and sharpness was also pointed out by Petterson [41]. Some studies highlighted the print mottle as one of the most annoying printing problem, which has great impact on overall print quality [42, 43]. It can show up in solid tones or smooth image areas, and is described as a term that explains optical heterogeneity, unevenness in optical density and print gloss [37].

This research is engaged in the influence of washing series and washing temperature on colour reproduction and macro non-uniformity of screen printed cotton knitted fabrics. Analysis of colour reproduction integrated solid tones reproduction measurements and calculating the colour differences (ΔE). Macro non-uniformity analysis was conducted via the mottling index, or so called non-uniformity number (NU), which is calculated from averages of dot intensity above the median (Ux) and those under the median (Lx) as in equation (1) [44]:

$$NU = Ux - Lx \tag{1}$$

Since the level of print non-uniformity is connected with an intensity width span of picture dots, the larger the NU value is, the larger the mottling [45].

2. MATERIALS AND METHODS

This research included three different textile materials, all of them cotton based, with different weave type: single, interlock and single pique were used. Material characterization was done according to following standards: material composition (ISO 1833), fabric weight (ISO 3801) and thread count (ISO 7211-2). These properties are presented in Table 1.

Special test chart, used in research, was created using Adobe Illustrator CS5 software. Test chart dimensions were 210 x 297 mm and it contained different elements for print quality analysis. Elements used for obtaining the results were 2.54 x 2.54 cm 100% tone values of black process colour. The samples were printed using screen printing technique, M&R Sportsman E Series six-colour printing machine. Various researchers have determined that the print quality largely depends on four main parameters [17, 46]. These parameters were kept constant during the printing of all samples. Printing speed was 15 cm/sec; squeegee hardness was 80 Shore Type A, printing pressure 275.8 x 10^3 Pa and 4 mm snap-off distance. Sericol Texopaque Classic OP Plastisol OP001 (S) - Black ink was used. Ink fixation was done under the temperature of 160^o C, with the exposure time of 150 seconds.

Printing form was made using printing screen mesh count of 90 threads per cm on aluminium tubing frames (58 x 84 cm). Size of the stencil, without frame, was 50 x 76 cm. Conventional exposure was conducted using linear positive films. The optical density of transparent areas of the film was 0.3 and 4.1 of the opaque areas. Film liniature was five times smaller than printing screen mesh count. Photosensitive Sericol Dirasol 915 emulsion was used. Light exposure was done using metal-halogen UV lamp (1000 W) at a 1 m distance from the mesh. The exposure time was set to 3 minutes. That was determined using an Autotype Exposure Calculator (Sericol) control strip.

The samples were treated according to ISO 105-C10:2006 standard [47]. The process was repeated 10 times on washing temperatures at 30°C, 60°C and 90°C. All the print quality parameters as well as colourfastness to washing were measured repeatedly four times: before washing treatment, after first, fifth and tenth washing treatment.

Print quality analysis included colour difference analysis and print mottle analysis. Colour differences (ΔE) between the samples with same material composition and different fabric weight and thread count were calculated using measured CIE L* a* b* coordinates of solid-tone patches printed with black ink. CIE L* a* b* coordinates of the printed ink colour were determined using spectrophotometer HP 200 (Illumination types D65, standard observer angle 10^o, measurement geometry d/8, measurement aperture 16 mm). Measurements were repeated and as measurement results were taken arithmetic means of ten times measured numerical values.

Macro non-uniformity was determined by digital analysis of image using Image J software, with plug-in developed and described by Muck et al [44]. Samples were scanned on flatbed scanner Canon CanoScan 5600F. Scanning resolution was set to 600 spi and all auto functions were turned off. Image elements of the significance to this measurement were 2.54 x 2.54 cm solid tone patches, that were cropped to size 500 x 500 pixels, saved as separate TIFF files and analysed afterwards.

3 RESULTS AND DISCUSSION

3.1 Colour reproduction analysis

In Table 2 are shown measured CIE L*a*b* colour coordinates and colour differences after printing and after series of washing treatments at three different temperatures. As reference values for calculating the colour differences (ΔE) were taken L*a*b* values of printed samples. The colour differences after each series of washing treatment have been calculated related to these values.

Table 1. Characteristics of materials used in research

Tests	Type of weaves	Material composition (%) (ISO 1833)	Fabric weight (g m^{-2}) (ISO 3801)	Thread count (cm^{-1}) (ISO 7211-2)	
				Course	Weft
Material A	Single	Cotton 100%	138	14	19
Material B	Interlock	Cotton 100%	185	15	16
Material C	Single pique	Cotton 100%	207	12	18

Table 2. CIE L*a*b* colour coordinates and colour differences after printing and washing treatments

Sample	L*	a*	b*	ΔE_{2000}
90A-P	22,94	0,08	-0,22	-
90A-W1-30	22,83	0,01	-0,41	**0,23**
90A-W1-60	24,47	0,06	-0,33	**1,11**
90A-W1-90	26,45	-0,1	-0,46	**2,58**
90A-W5-30	27,14	-0,29	-0,36	**3,13**
90A-W5-60	29,65	-0,02	-0,48	**4,98**
90A-W5-90	30,17	-0,55	-0,39	**5,46**
90A-W10-30	28,16	-0,30	-0,58	**3,90**
90A-W10-60	30,29	-0,33	-0,31	**5,50**
90A-W10-90	34,05	-0,29	-0,57	**8,47**
90B-P	24,06	-0,02	-0,35	-
90B-W1-30	24,43	0,04	0,44	**0,83**
90B-W1-60	26,11	-0,11	0,20	**1,60**
90B-W1-90	27,96	-0,13	-0,32	**2,88**
90B-W5-30	27,62	-0,27	-0,48	**2,65**
90B-W5-60	29,30	-0,11	-0,52	**3,91**
90B-W5-90	33,21	-0,34	-0,75	**6,99**
90B-W10-30	27,48	-0,20	-0,63	**2,54**
90B-W10-60	30,51	-0,23	-0,46	**4,84**
90B-W10-90	33,04	-0,20	-0,58	**6,84**
90C-P	23,93	-0,01	-0,24	-
90C-W1-30	24,03	0,14	-0,36	**0,26**
90C-W1-60	26,25	0,02	0,42	**1,82**
90C-W1-90	28,18	-0,19	-0,39	**3,15**
90C-W5-30	27,02	-0,27	-0,36	**2,30**
90C-W5-60	29,01	-0,05	-0,30	**3,77**
90C-W5-90	30,12	-0,20	-0,50	**4,64**
90C-W10-30	28,99	-0,36	-0,61	**3,81**
90C-W10-60	29,93	-0,27	-0,57	**4,50**
90C-W10-90	31,82	-0,29	-0,54	**5,98**

Note: first number of the sample name represents screen mesh counts; letters A, B and C represent materials; P is the mark of printed sample; W1 is the mark of the sample after the first washing treatment, W5 - after the fifth washing treatment and W10 - the tenth washing treatment; and the last number represents washing temperature.

Results shown in Table 2 reveal that with increasing number of washing treatment colour difference is also being increased. Also, it can be noticed that with increasing the washing temperature colour difference is also being increased. This is noticeable for every material.

Colour difference value for every sample after first washing treatment at temperature of 30°C is below 1, which is defined as noticeable colour difference. After first washing treatment at temperature of 60°C colour difference value is between 1 and 3 for every sample, which is defined as perceptible colour difference. When washing temperature is set to 90°C after first washing treatment colour difference value is between 1 and 3 for material A and B, which is defined as perceptible colour difference, and between 3 and 6 for material C, which is defined as easy perceptible colour difference.

After fifth washing treatment on temperature of 30°C colour difference is between 1 and 3 for material B and C, which is defined as perceptible colour difference, and between 3 and 6 for material A, which is defined as easy perceptible colour difference. After fifth washing treatment on temperature of 60°C colour difference is between 3 and 6 for every material, which is defined as easy perceptible colour difference. And, after fifth washing treatment on temperature of 90°C colour difference is between 3 and 6 for material A and C, which is defined as easy perceptible colour difference, and over 6 for material B, which is defined as obvious colour difference.

After tenth washing treatment on temperature of 30°C colour difference is between 1 and 3 for material B, which is defined as perceptible colour difference, and between 3 and 6 for material A and C, which is defined as easy perceptible colour difference. After tenth washing treatment on temperature of 60°C colour difference is between 3 and 6 for every material, which is defined as easy perceptible colour difference. When washing temperature is set to 90°C after tenth washing treatment colour difference value is between 3 and 6 for material C, which is defined as easy perceptible colour difference, and over 6 for material A and B, which is defined as obvious colour difference.

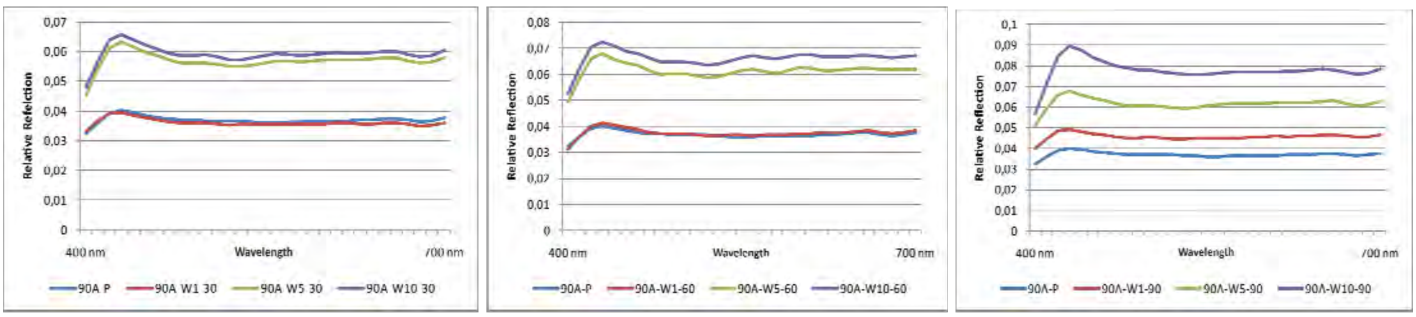
From the obtained results it can be concluded that during washing treatment ink particles are being washed off. Reducing the layer of the ink on printed substrate leads to different absorption, as well as reflection of incoming light and thus, to the change of visual perception of printed colour. Increasing the number of washing treatments leads to wash off of higher amount of ink particles, and thus to the bigger change of reproduced colours, which results in higher colour difference ΔE. Also, increasing the washing temperature breaks fibres of textile substrate and leads to colour fading, and therefore to the bigger change of reproduced colours and higher colour difference ΔE.

It can be noticed that Material C shows smallest deviations in colour reproduction with increasing number of washing treatment and also with increasing the washing temperature. The smallest colour difference is noticeable for material A after first washing treatment on temperature of 30°C and the highest colour difference appears also on material A after tenth washing treatment on temperature of 90°C. Deviations in colour reproduction are not same for every material. It can be concluded that material characteristics, actually its surface structure, as well as number of washing treatments and its temperature influence colour reproduction of printed cotton knitted fabrics.

Materials were printed using Sericol Texopaque Classic OP Plastisol OP001 (S) - Black ink. According to ink properties colour should be consistent on washing temperature of 60°C and less, but results show that there is significant difference of colour after repeated washing cycles even on temperature of 30°C. This can be cause of fibrillation, the process which is influenced by fibre break through the ink film on top of the garment. Thus, it can be concluded that increasing of ink film on top of the material could decrease colour difference.

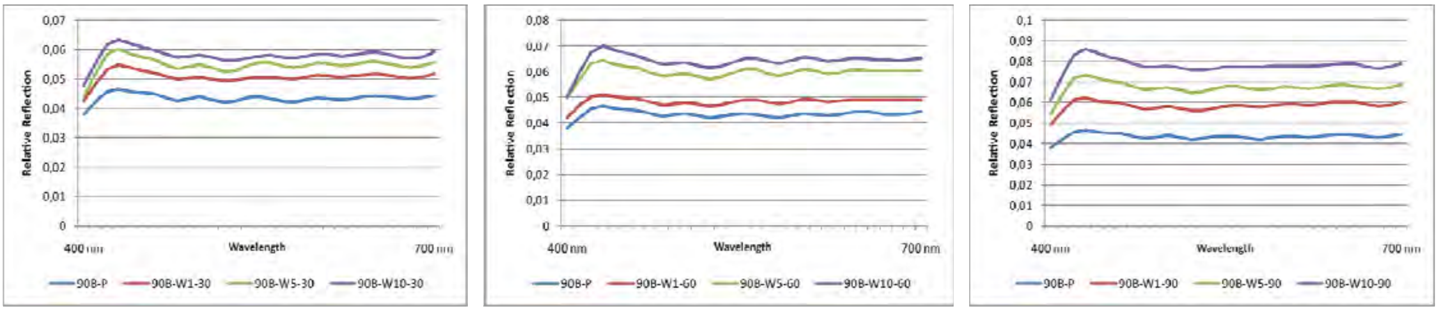
Measurements of printed samples reflectance before and after series of washing treatments were conducted, after which the spectral curves were created. The influence of material, washing treatment and washing temperature on the printed surface reflection characteristic was examined. Figure 1 presents spectral curves of the sample A printed with 90 threads cm^{-1} after printing and washing treatments on temperature of 30°C, 60°C and 90°C. It can be noticed that spectral curve shapes remain the same after washing for every washing temperature. This leads to conclusion that washing treatment resulted in insignificant change of tone of the colour, but change of intensity of the reflected light occurred, as the result of brightening of printed colour. With increasing the number of washing treatments, the intensity of the reflected light is also being increased. It can also be noticed that with increasing of washing temperature the intensity of the reflected light is also being increased.

Figure 2 presents spectral curves of the sample B printed with 90 threads cm^{-1} after printing and washing treatments on temperature of 30°C, 60°C and 90°C. Everything is pretty much the same as for material A. Spectral curve shapes remain the same after washing for every washing temperature. With increasing the number of washing treatments, the intensity of the reflected light is also being increased. It can also be noticed that with increasing of washing temperature the intensity of the reflected light is also being increased.



a) *b)* *c)*

Figure 1. Spectral curves of the sample A printed with 90 threads cm^{-1} after printing and washing treatments: (a) Washing temperature 30°C; (b) Washing temperature 60°C; (c) Washing temperature 90°C; (Note: first number of the sample name represents screen mesh counts; letters A, B and C represent materials; P is the mark of printed sample; W1 is the mark of the sample after the first washing treatment, W5 - after the fifth washing treatment and W10 - the tenth washing treatment; 30, 60 and 90 are marks of washing temperature.)



a) *b)* *c)*

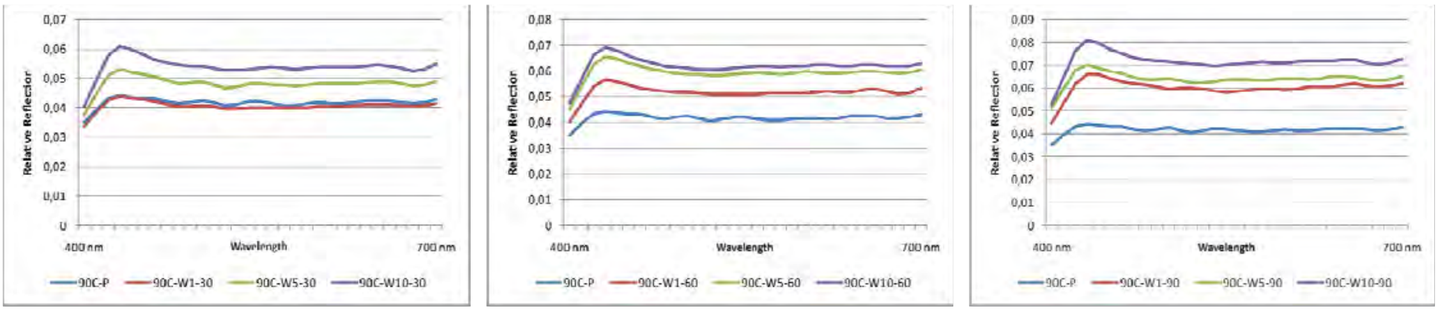
Figure 2: Spectral curves of the sample B printed with 90 threads cm^{-1} after printing and washing treatments: (a) Washing temperature 30^{o}C; (b) Washing temperature 60^{o}C; (c) Washing temperature 90^{o}C; (Note: first number of the sample name represents screen mesh counts; letters A, B and C represent materials; P is the mark of printed sample; W1 is the mark of the sample after the first washing treatment, W5 - after the fifth washing treatment and W10 - the tenth washing treatment; 30, 60 and 90 are marks of washing temperature.)

Figure 3 presents spectral curves of the sample C printed with 90 threads cm-1 after printing and washing treatments on temperature of 30°C, 60°C and 90°C. Everything is pretty much the same as for material A and B. Spectral curve shapes remain the same after washing for every washing temperature. With increasing the number of washing treatments, the intensity of the reflected light is also being increased. It can also be noticed that with increasing of washing temperature the intensity of the reflected light is also being increased.

Summing the result of spectral curve analysis up, it can be concluded that increased number of washing treatments and increased washing temperature provoke the rise of spectral reflection for all samples printed with 90 threads cm^{-1}. This can be explained by the fact that during the washing process the ink particles, actually pigment particles, are being washed off. Since they absorb the light, after washing treatment a higher amount of light is being reflected from the surface of the sample, which the human eye perceives as a lighter shade of colour. The change that occurs with increased washing temperature can be explained by the fact that higher temperature breaks fibres of textile substrate and leads to colour fading. At the same time, all samples showed insignificant changes of shape of spectral curve. It means that there is no big difference in tone of the colour. There is also no big difference between materials and the intensity of reflected light is closely to each other.

3.2. Print Mottle Analysis

The level of macro non-uniformity is defined by non-uniformity index. Figure 4 a) represents values of macro non-uniformity analysed on materials A, B and C after printing with 90 threads cm^{-1} before and after series of washing treatments on temperature of 30 °C. Material A showed that increased number of washing treatments leads to increase of macro non-uniformity index value. It can be assumed that washing treatments lead to uneven wash off effect of the ink particles and results in uneven and non-uniform surface, which results in higher print mottle. For material B macro non-uniformity value increased after the first and also after fifth washing treatment, and then decreased after tenth washing treatment. This improvement of print uniformity after few washing treatments can be explained by levelling out of the ink amount on the surface of material with further washing treatments. In case of material C macro non-



a) *b)* *c)*

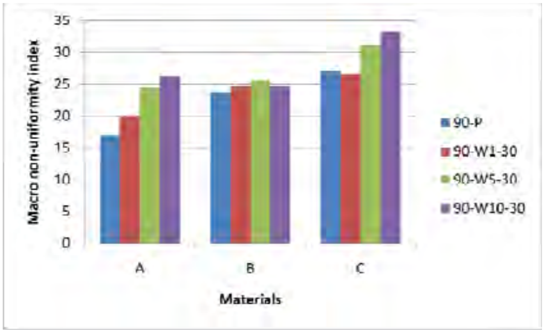
Figure 3. Spectral curves of the sample C printed with 90 threads cm^{-1} after printing and washing treatments: (a) Washing temperature 30^{o}C; (b) Washing temperature 60^{o}C; (c) Washing temperature 90^{o}C; (Note: first number of the sample name represents screen mesh counts; letters A, B and C represent materials; P is the mark of printed sample; W1 is the mark of the sample after the first washing treatment, W5 - after the fifth washing treatment and W10 - the tenth washing treatment; 30, 60 and 90 are marks of washing temperature.)

uniformity value decreased after the first washing treatment compared to the unwashed sample. Further increasing in number of washing treatments increased the value of macro non-uniformity index above. It can be assumed that after washing treatment ink amount on the surface of material is being levelled out, then with further washing treatment uneven wash off effect of the ink particles results in uneven and non-uniform surface, which leads to higher print mottle.

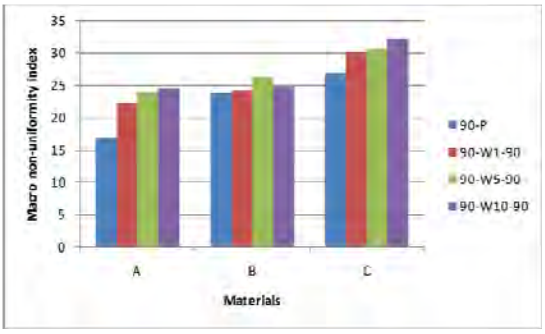
Figure 4 b) represents values of macro non-uniformity analysed on materials A, B and C after printing with 90 threads cm^{-1} before and after series of washing treatments on temperature of 60 °C. For material A macro non-uniformity value increased after the first and also after fifth washing treatment, and then decreased after tenth washing treatment. In case of material B macro non-uniformity value decreased after the first washing treatment compared to the unwashed sample. Further increasing in number of washing treatments increased the value of macro non-uniformity index above. Material C showed that increased number of washing treatments leads to increase of macro non-uniformity index value.

Figure 4 c) represents values of macro non-uniformity analysed on materials A, B and C after printing with 90 threads cm^{-1} before and after series of washing treatments on temperature of 90 °C. Material A showed that increased number of washing treatments leads to increase of macro non-uniformity index value. For material B macro non-uniformity value increased after the first and also after fifth washing treatment, and then decreased after tenth washing treatment. Material C showed that increased number of washing treatments leads to increase of macro non-uniformity index value.

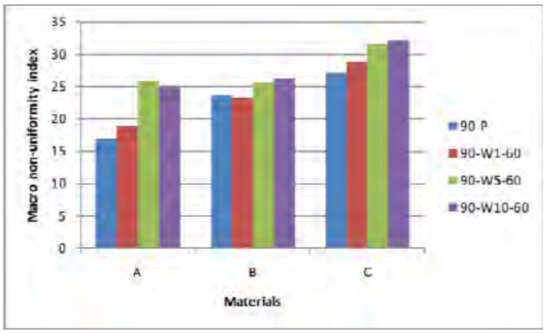
If macro non-uniformity between materials is being compared, it can be noticed that material C generally shows the largest values of macro non-uniformity index. Macro non-uniformity index value is smallest for material A, but after washing treatments it shows big changes and equals with material B. It can also be concluded that material B shows smallest deviations of macro non-uniformity index value after washing treatments. From figure 5 differences in surface structure of materials can be noticed. Material A and B have smooth and soft structure unlike material C which surface structure is very rough. These differences in surface structure leads to different surface of ink on material after printing, which influences macro non-uniformity index. Material A have more compact structure than material B, which is reason for smaller value of macro non-uniformity index for material A, because ink is able to form more uniform layer on the material after printing. In case of material B, since surface is less compact and pores are more noticeable, ink is not able to create so uniform layer. Since surface of material C is very rough and texturised, ink is not able to fill in gaps in best way, so macro non-uniformity index have large values. Thus, it can be concluded that material type influences macro non-uniformity.



a)



b)



c)

Figure 4. Macro non-uniformity index value of textile materials printed with 90 threads cm^{-1} after printing and washing treatments: (a) Washing temperature 30^{o}C; (b) Washing temperature 60^{o}C; (c) Washing temperature 90^{o}C; (Note: first number of the sample name represents screen mesh counts; letters A, B and C represent materials; P is the mark of printed sample; W1 is the mark of the sample after the first washing treatment, W5 - after the fifth washing treatment and W10 - the tenth washing treatment; 30, 60 and 90 are marks of washing temperature.)

a) b) c)

Figure 5. Textile materials printed with 90 threads cm^{-1} with black ink: (a) Material A; (b) Material B; (c) Material C

When washing temperatures and macro non-uniformity are being observed it can be noticed that there is no significant difference when materials are being washed on different temperature. There are some smaller differences that can be explained by temperature effect on textile fibres. It breaks fibres and thus leads to some differences in print mottle, since surface of material is changing.

4. CONCLUSIONS

The aim of this paper was comparison of cotton based textile imprints printed with screen printing technology before and after washing treatment on different temperatures, to determine how it influences colour reproduction and the uniformity of solid tone areas. Three different types of cotton materials were printed. After printing samples were subjected to series of washing treatment on different washing temperatures.

Spectrophotometric analysis showed that with increasing number of washing treatment, and also increasing of washing temperature, colour difference is also being increased. This is noticeable for every material. It can be concluded that with every washing treatment part of the ink layer is being washed off and increased temperature breaks fibres of textile substrate and leads to colour fading. Material C showed smallest deviations in colour reproduction with increasing number of washing treatment and also with increasing the washing temperature.

Print mottle analysis showed that washing treatment influences macro non-uniformity index value. This value is dependent on type of material. Material C generally showed the largest values of macro non-uniformity index. Material B showed smallest deviations of macro non-uniformity index value after washing treatments. Macro non-uniformity index value is smallest for material A, but after washing treatments it shows big changes and equals with material B. Smallest deviations appeared on material B when washed on temperature of $30^{o}C$. Generally, there is no significant difference when materials are being washed on different temperature. There are some smaller differences, caused by fibres breaking on higher temperature, since surface of material is changing.

From spectral reflectance analysis results since spectral curve shapes remain the same after washing for every washing temperature it can be concluded that there is no significant change of tone of the colour. However, intensity of the reflected light changed and it is result of brightened colour. Intensity of reflected light is being increased with increased number of washing treatments and also with increased temperature. This can be explained by wash off of the ink particles from the material surface, so higher amount of the light is being reflected from the surface of the sample. Higher temperature breaks fibres of textile substrate and leads to colour fading, so this explains increased intensity of reflected light when higher washing temperature is used. There is no significant difference between materials and the intensity of reflected light is closely to each other.

In order to expand knowledge from this area, plan for future researches is to analyze influence of printing with more screen mesh counts, include analysis of different process colours and different material substrates. Also, experiments should include imprints printed with digital ink-jet printing technique, since this technique is rapidly expanding in textile printing.

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