ISSN 1392 – 1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 11, No. 3. 2000

Investigation of Quality Parameters of Digital Printing Technologies

Edmundas KIBIRKŠTIS[1]*, Vytautas JUŠKAITIS[2], Kęstutis VAITASIUS[1], Artūras DABKEVIČIUS[1], Lina ZUBRICKAITĖ[1]

[1]*Faculty of Design and Technology, Kaunas University of Technology, Studentų 56, LT-51424 Kaunas, Lithuania*
[2]*EAN Lithuania, J. Tumo-Vaižganto 9/1, Vilnius, Lithuania*

Received 12 November 2004; accepted 30 April 2005

In order to evaluate the stability of the characteristics of digitally printed graphic image symbols, the resistance of graphic element prints to the temperature changes and mechanical friction was studied. During investigation, prints of graphic elements printed by direct and indirect thermographic methods, digital and offset printing were used. Papers with different temperature sensitivity, surface morphology and hydrophobic properties were used for the specimens printing. It was show that thermographically produced specimens, subjected to temperature changes under mechanical wear, showed a different optical density decrease. The highest optical density decrease (from 2.05 to 0.30) was noticed in the element printed on COAT PC paper by indirect thermographic method, using Wax ink transfer ribbon. The prints on PP White paper, using Wax ink transfer ribbon, also showed significant decrease of wear resistance. In this case the print quality did not meet the standard requirements. The prints on PP White paper, using resin-based ink transfer ribbon, got wear much less (the optical density changed from 1.71 to 1.43, thus meeting the standard requirements). When offset prints were subjected to mechanical wear after a jump temperature change, the highest decrease in optical density was found in prints on Gloss paper (from 1.63 to 1.37), and the lowest – on offset paper (from 1.19 to 1.12). The resistance of digital prints to mechanical wear after a cyclic temperature change is similar to that of prints, which were not subjected to temperature changes. In this case the highest decrease of optical density is found in prints on Ensobulky paper – from 1.02 to 0.67. The optical density of prints on offset, Gloss and Silk papers decreased as follows: offset – from 1.20 to 0.96; Gloss – from 1.73 to 1.46; Silk – from 1.90 to 1.65.

Keywords: bar codes, print resistance to mechanical wear, printing technology.

1. INTRODUCTION

The printing quality of graphic image symbols and stability of parameters are highly varied by the chosen printing method, used materials [1] and operational conditions. Roughness of print surfaces or instability of technical parameters of the scanning system may cause errors in reading [2, 3]. In order to eliminate them, methods of reading of BC of high resolution, which do not focus on the influence of operational conditions, are created [4 – 6]. A high-resolution image is then formed by interleaving the pixel values from rows where the offset is nearest to the new pixel spacing. By modeling the image capture system, the point spread function may be estimated and then removed by using inverse filtering in the frequency domain. The offset between the rows is then removed by using a linear phase filter. This allows the rows within the resultant image to be averaged to reduce noise [4]. Magnetic bar codes can be used in dirty environments instead of optical bar codes or as invisible codes in order to enhance the security of prepaid cards [5]. A new two-dimensional bar-code detection system using two visible-light laser diodes driven by complementary light emission and pulse modulation with a bias current near the threshold has been developed for applications such as goods management in production lines requiring high-speed detection [6]. It has been shown, however, that these conditions affect the stability of parameters of BC symbol elements [7, 8].

The present paper is a continuation of the study discussed in previous papers [7, 8]. In this paper results of evaluation of stability of the characteristics of digitally printed graphic image symbols upon operational conditions are presented.

2. RESEARCH METHODS AND EQUIPMENT

The principal scheme of experimental device, which was used to study the resistance of graphic element prints to mechanical wear, is presented in details in [7, 8]. The prints were subjected to pressure, and the optical density of the specimen was measured at fixed time intervals. During the tests permanent linear velocity of 0.47 m/s and permanent load of $441.45 \cdot 10^{-3}$ N/cm^2 were maintained. During the first five minutes the optical density was measured every minute, during the following first hour it was measured every 10 minutes, the second hour – every 20 minutes, the third – every 30 minutes.

The following devices were used for the metrological analysis of the specimens: Profilometer *Mod. 283* was used for determining the paper surface morphology; The hydrophobic properties were evaluated by measuring the wetting angle with *Biometrija* device; Densitometers *X-Rite 408* and *X-RiteColor* were used for measuring the optical density of the prints.

The specimens were prepared as follows: first, a square of 15×15 mm^2 was cut out with a special printed area of 10×10 mm^2 and adjacent base material without imprint (Fig. 1). Then the specimen was fixed on the specimen disk with a two-sided adhesive tape.

*Corresponding author. Tel.: + 370-37-300236; fax:+ 370-37-451684.
E-mail address: *edmundas.kibirkstis@ktu.lt* (E. Kibirkštis)

The geometrical parameters of the specimens were predetermined by the standard terms of *Oser* method, i.e., load of 25 g/cm^2, and by the geometrical dimensions of the specimen disk.

The optical density was measured in five points within the print and five points on the base. Positions 1 – 5, shown in Fig. 1, are the points where the optical density of the print was measured, while 1' – 5' are the positions where the optical density of the base was measured. The optical density of the base was measured in order to determine the contrast level between the print and the base.

The dependence of optical density on the reflectance can be expressed by the following relation:

$$D = \lg \frac{1}{R} \ , \quad (1)$$

where D is the optical density, R is the reflectance.

In accordance with Standard [9], Appendix E, the reflectance from a symbol is acceptable if the reflectance from the light spaces is identical to the size of reflectance from dark spaces, according to the following equation:

$$\log_{10} R_D \le 2.6(\log_{10} R_L) - 0.3 \ , \quad (2)$$

where R_L is the reflectance of the light spaces and R_D is the reflectance of dark bars.

This parameter is more important than individual reflectance parameters from bars and spaces.

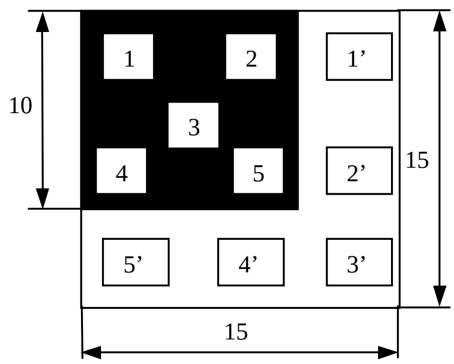

Fig. 1. Scheme of experimental areas for studying resistance of the prints and the base to mechanical wear: 1 – 5 are the points where the optical density of the print was measured, 1' – 5' are the points where the optical density of the base was measured

As the optical density measurements of the prints and the base are carried out, the contrast level of the print can be calculated:

$$PC = \frac{R_L - R_D}{R_L} \times 100 = \frac{10^{D_D} - 10^{D_L}}{10^{D_D}} \times 100 \quad (3)$$

where PC is the contrast level of the print, %; D_L is the optical density of the light base and D_D is the optical density of the dark bars.

Different BC-identified goods have different storage and shipping standards. Depending on the geographical location and the atmospheric conditions, the mentioned goods may be subjected to quite a wide range of temperatures for a shorter or longer period of time. Therefore, the temperature change range from +42 °C to –37 °C was chosen for the prints' temperature change test, it to be close to the maintenance conditions and corresponding to Standard [10] requirements.

During the maintenance, bar codes are subjected not only to temperature changes, but also to the mechanical wear, therefore after a cyclic jump temperature change (cycle duration t_Σ = 387 s) the specimens were subjected to pressure according to the methodology described in [8], followed by measuring the optical density changes.

3. RESULTS AND DISCUSSION

3.1. Study of the resistance of prints on thermopaper to mechanical wear (after a cyclic jump temperature change)

The specimens were printed with thermal printer *Zebra Z4M* which is capable of changing discretely the printing speed and the temperature of the heating head. The printing was performed at five different speeds: 0.051, 0.076, 0.102, 0.127, 0.152 m/s and at four different temperatures of the heating head, marked by arbitrary units *R15*, *R20*, *R25*, *R30* (corresponding to the temperature interval 90 – 130 °C).

For direct thermographic printing three types of thermosensitive paper were used: low sensitivity KLS-44, medium sensitivity KPO-440 and high sensitivity ECO RHI HG65.

When using indirect thermography for printing, experiments were carried out with four types of paper: COAT PC, PP White, PharmaGloss RP-45 and writing paper, using two types of ink transfer ribbons: resin-based Resin and wax-based Wax.

The experimental results are shown in Fig. 2 and Fig. 3.

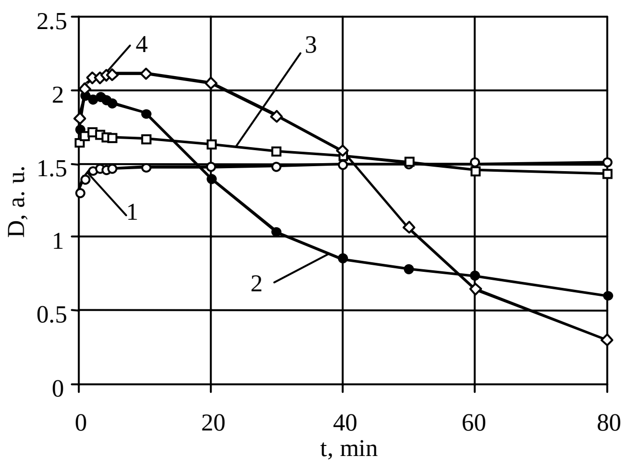

Fig. 2. Dependence of optical density on the wearing duration after a cyclic temperature change: 1 – direct thermography: paper KLS-44, heating head temperature *R25*, printing speed v_{sp} = 0.102 m/s; 2 – indirect thermography: paper PP White, ink transfer ribbon Wax, *R30*, v_{sp} = 0.051 m/s; 3 – indirect thermography: paper COAT PC, ink transfer ribbon Wax, *R30*, v_{sp} = 0.051 m/s; 4 – indirect thermography: paper COAT PC, ink transfer ribbon Wax, *R30*, v_{sp} = 0.051 m/s; v_1 = 0.47 m/s, P = 441.45 × 10^{-3} N/cm^2

The results show that when bar codes are subjected to mechanical force after cyclic temperature changes, their optical density decreases. During the experiments the highest optical density decrease (from 2.05 to 0.30) was noted in the element printed on COAT PC paper using indirect thermography method and Wax ink transfer ribbon (Fig. 2, curve 4). A significant scuff was also evident in prints on PP White paper, using Wax ink transfer ribbon (Fig. 2, curve 2). The prints made on this paper using Resin ink transfer ribbon scuffed less (optical density changed from 1.71 to 1.43).

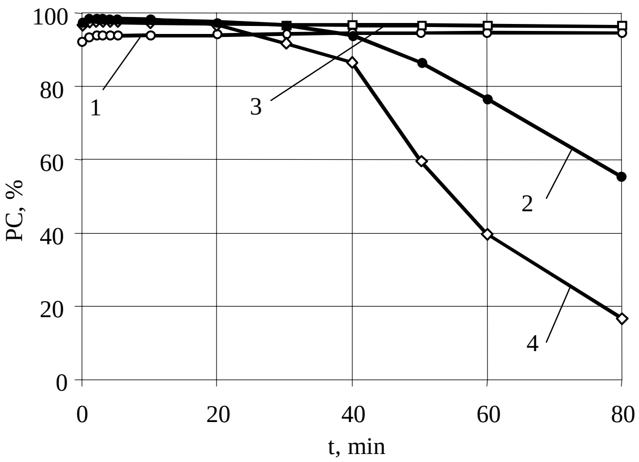

Fig. 3. Dependence of printing contrast level on the wearing duration: 1 – direct thermography: paper KLS-44, heating head temperature *R25*, printing speed $v_{sp} = 0.102$ m/s; 2 – indirect thermography: paper PP White, ink transfer ribbon Wax, *R30*, $v_{sp} = 0.051$ m/s; 3 – indirect thermography: paper PP White, ink transfer ribbon Resin, *R30*, $v_{sp} = 0.051$ m/s; 4 – indirect thermography: paper COAT PC, ink transfer ribbon Wax, *R30*, $v_{sp} = 0.051$ m/s; $v_1 = 0.47$ m/s, $P = 441.45 \times 10^{-3}$ N/cm^2

As can be seen from the graph (Fig. 3, curve 4), the highest change in the contrast level (from 98.9 % to 25.9 %) occurred in the element printed on the COAT PC paper using indirect thermography and Wax ink transfer ribbon, although a significant change in *PC* (from 98.5 % to 56.3 %) can also be found in prints on PP White paper using Wax ink transfer ribbon (Fig. 3, curve 2). In order to meet Condition (2), in the first case (Fig. 3, curve 4) *PC* has to be higher than 73.7 % ($D_D > 0.75$), while in the second case (Fig. 3, curve 2) $PC > 79\%$ ($D_D > 0.9$). Prints on this paper (Fig. 3, curve 3), using Resin ink transfer ribbon, wore only slightly (*PC* changed from 97.2 to 93.8). *PC* of prints using direct thermography on KLS-44 thermopaper changed insignificantly° (it increased from 92.9 to 95.4).

3.2. Study of the resistance of offset and digital prints to mechanical wear (after a jump temperature change)

The experimental specimens were printed with a sheet offset four-colour printing machine “Planeta” and printing ink “Logo 2000 process”. The ink, based on seed oil, is characterised by high pigmentation and good adhesion properties.

Other experimental specimens were printed with a sheet digital printing machine “Indigo E-Print 1000+” which operates on the principle of liquid electrography. “ElectroInk Mark III – Black” ink was applied.

In order to obtain more reliable experimental outcomes, papers with different surface morphology ($R_a = 0.11 – 1.97$ μm) and different hydrophobic properties ($\Theta = 50° – 107°$) were selected for printing experimental specimens. The characteristics of paper specimens are presented in the Table 1.

The morphology of the paper surface depends on the machine direction during manufacturing. For some types of paper this difference may be quite prominent, as proved by the measurement results presented in the table. During the printing process this factor undoubtedly affects the quality of prints.

While defining the hydrophobic paper properties, the wetting angle was measured for five times and the arithmetical mean of the results was used.

The digital printing machine “Indigo E-Print 1000+” can print only on the paper with the weight not less than 130 g/m^2, therefore the same types of paper were used for this printing method as for offset printing, only with higher weight. As can be seen from the table, only two types of paper differ: G-Print (traditional offset printing) and Silk (digital printing). However, comparing the values of the material surface morphology and surface hydrophobics, seems that the data are similar, thus it can be stated that almost identical materials were used for printing and the results can be comparable.

The results of the experiments are presented in Fig. 4 – 7. Fig. 4 shows that the optical density of the prints made by the traditional offset method on Ensobulky paper ($R_a = 1.68$) changed insignificantly ($\Delta D = 0.14$) during mechanical wear (friction) after a cyclic temperature change.

Table 1. Characteristics of paper samples

Paper type	Weight, g/m^2	Paper morphology R_a, μm		Wetting angle Θ, °	Printing type
		In printing direction	Perpendicular to printing direction		
G-print	90	0.42	0.52	70	Traditional offset, Printing machine “Planeta”
Offset	90	1.32	1.42	104	Traditional offset, Printing machine “Planeta”
Ensobulky	60	1.38	1.97	50	Traditional offset, Printing machine “Planeta”
Offset	130	1.26	1.37	107	Digital offset, "Indigo E-Print 1000+"
Ensobulky	120	1.42	1.78	72	Digital offset, "Indigo E-Print 1000+"
Silk	130	0.45	0.46	68	Digital offset, "Indigo E-Print 1000+"
Glass	130	0.11	0.13	63	Traditional offset, Printing machine “Planeta” Digital offset, "Indigo E-Print 1000+"

During the tests with offset paper it was noticed that the optical density actually did not change and demonstrated the lowest change (ΔD = 0.07) among all the samples under study. During the traditional offset printing on Gloss paper (initial D = 1.57), the optical density slightly increases at the beginning (ΔD = 0.06), but after 40 minutes of friction the optical density starts decreasing sharply and finally decreases up to D = 1.37 (ΔD = 0.26).

Testing the resistance to mechanical wear of prints printed by the traditional offset method on G-Print paper has shown that at the beginning of friction the optical density slightly increases, and then again decreases. During the whole process only insignificant change of optical density has been observed (ΔD = 0.09).

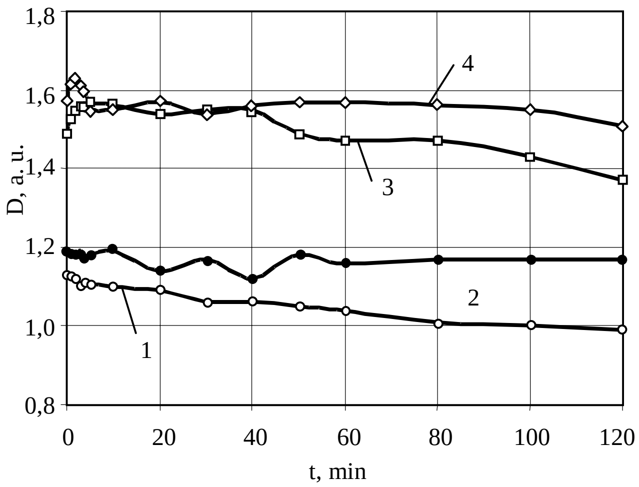

Fig. 4. Dependence of optical density on the wearing duration in prints made using the traditional offset method after a cyclic temperature change: 1 – Ensobulky paper; 2 – offset paper; 3 – Gloss paper; 4 – G-Print paper

Fig. 5 shows that after a cyclic temperature change the optical density of digital prints decreases under the wear of pressure. The highest optical density decrease occurred in the element printed on Ensobulky paper (D varied from 1.0 to 0.67; ΔD = 0.43). However, the rest of the prints, printed on Offset, Gloss and Silk papers, also were significantly (optical density decreased for Offset ΔD = 0.24, Gloss ΔD = 0.27 and Silk ΔD = 0.25).

In Fig. 6 we can see that for traditional offset prints subjected to mechanical forces after a cyclic temperature change, the print contrast level was the highest and almost unchanged on Gloss and G-print paper (ΔPC = 3 %). Meanwhile, the print contrast level was lower and decreased in the case of prints on Ensobulky and Offset paper (Offset paper ΔPC = 3 %, Ensobulky paper ΔPC = 7 %).

However, contrast level of final print on Ensobulky paper after two hours of mechanical and temperature treatment decreases, the minimum print contrast level agrees requirements of standard (final PC = 83.78 %, while the permissible PC = 81.8 %, with the print optical density (D = 0.99).

Fig. 7 shows the dependence between of the print contrast level on the duration of mechanical wear after temperature change in the case of digital prints. It has been stated that after temperature changes, the highest decrease of print contrast level occurred under the wear of pressure on Ensobulky paper (from PC = 86.82 % to PC = 57.34 %; ΔPC = 29.48 %).

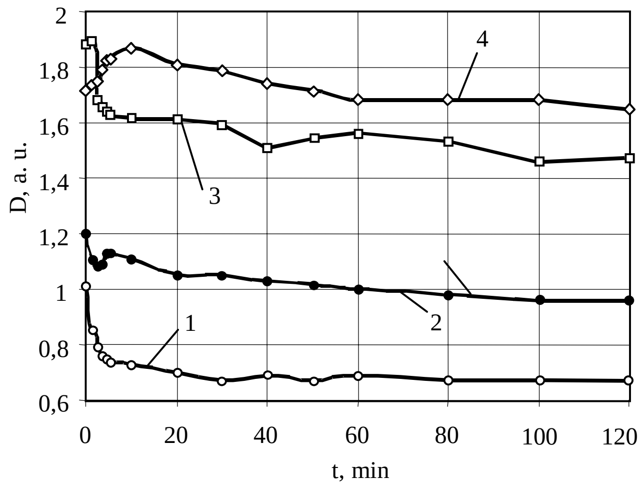

Fig. 5. Dependence of optical density on the wearing duration in the case of digital prints: 1 – Ensobulky paper, 2 – Offset paper, 3 - Gloss paper, 4 – Silk paper

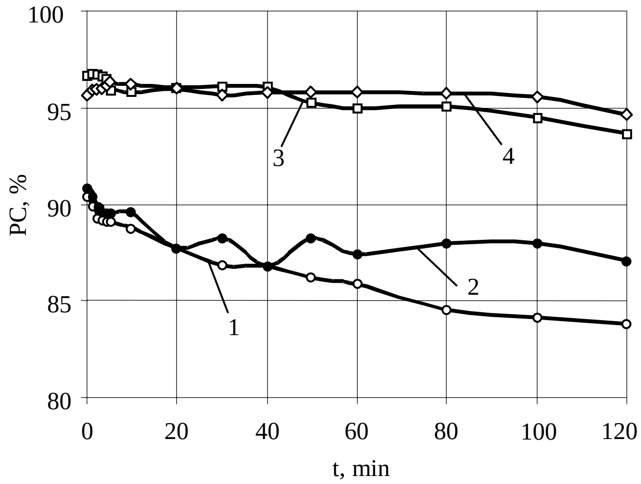

Fig. 6. Dependence of print contrast level on the wearing duration in the case of traditional offset prints: 1 – Ensobulky paper, 2 – Offset paper, 3 – Gloss paper, 4 – G-Print paper

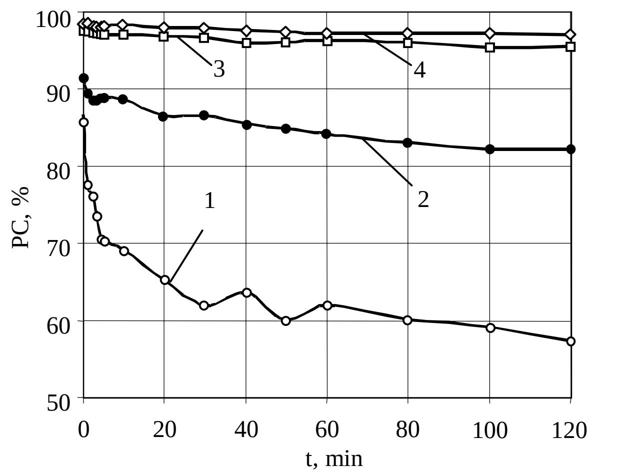

Fig. 7. Dependence of print contrast level on the wearing duration in the case of digital prints: 1 – Ensobulky paper, 2 – Offset paper, 3 – Gloss paper, 4 – Silk paper

The print contrast level in the other samples, printed on Offset, Gloss and Silk paper, underwent significantly smaller changes (the print contrast level decreased for Offset $\Delta PC = 9.66$ %, Gloss $\Delta PC = 2.27$ and Silk $\Delta PC = 1.47$ %). At the initial stage of friction (after the first minute of mechanical wear), the print contrast level on Ensobulky paper decreases so much that it does not meet the minimum requirements of print contrast level (after the first minute Ensobulky paper ($D = 0.85$) $PC = 77.61$ %, while the requirement is $PC = 78.10$ %), and continues to decline.

CONCLUSIONS

1. The different optical density changes were observed for the specimens obtained by thermographic method after its subjection to mechanical treatment and cyclic temperature changes. The highest decrease (from 2.05 to 0.30) occurred in the element printed on COAT PC paper using indirect thermographic method and Wax ink transfer ribbon. Although prints on PP White paper using Wax transfer ribbon also wore significantly. In this case the print quality does not meet the requirements quality of Standard. The samples printed on PP White paper using Resin ink transfer ribbon wore much less (the optical density changed from 1.71 to 1.43, thus meeting the Standard requirements).
2. It has been determined that in the case of offset prints, after a cyclic temperature change, the highest decrease in optical density (from 1.63 to 1.37) under the mechanical wear occurred on Gloss paper and the lowest – on Offset paper (decreased from 1.19 to 1.12).
3. In the case of digital prints, resistance to mechanical wear after temperature changes is similar to the resistance of prints without temperature changes. The highest decrease in optical density was noticed in prints on Ensobulky paper (from 1.02 to 0.67). The optical density of prints on Offset, Gloss and Silk papers decreased, following: Offset from 1.20 to 0.96, Gloss from 1.73 to 1.46 and Silk from 1.90 to 1.65.
4. Among traditional offset prints, after a cyclic temperature change and a mechanical wear, the highest contrast level, which significantly changed at all, was in prints on Gloss and G-Print paper (*PC* changed from 95.53 % to 94.63 %). The print contrast level was lower and slightly decreased in prints on Ensobulky and Offset papers (*PC* changed from 90.45 % to 83.78 %). All these prints meet the contrast level requirements of Standard.
5. The print contrast level while subjecting digital prints to mechanical wear (after a cyclic temperature change) decreased more significantly on Ensobulky paper (*PC* changed from 86.82 % to 57.34 %). White the print contrast level on Offset, Gloss and Silk papers changed only insignificantly (the print contrast level decreased from 98.45 % to 96.98 %). After friction (already after the first minute of mechanical wear) the contrast level of the print on Ensobulky paper so much that it did not meet the minimum requirements of print contrast level ($PC = 77.61$ %, while the required $PC = 78.10$ %). In this case the print contrast level does not met requirements of Standard.

REFERENCES

1. **Ness, C., Gottsching, L.** The Reproduction of Small Details on Various Graphic Papers in Offset Printing *Papier* 47 (10A) 1993: V63 – V73.
2. **Marom, E., Kresic-Juric, S., Bergstein, L.** Analysis of Speckle Noise in Bar-Code Scanning Systems *Journal of the Optical Society of America A-Optics Image Science and Vision* 18 (4) 2001: pp. 888 – 901.
3. **Boie, R. A., Turin, W.** Noise-Limited Reading of Bar Codes *IEEE Transactions on Industrial Electronics* 44 (6) 1997: pp. 816 – 824.
4. **Bailey, D. G.** Super-Resolution of Bar Codes *Journal of Electronic Imaging* 10 (1) 2001: pp. 213 – 220.
5. **Watanabe, N., Sasada, I., Asuke, N.** A New High Density Magnetic Bar Code System *Journal of Applied Physics* 85 (8) Part 2B 1999: pp. 5462 – 5464.
6. **Wakaumi, H., Ajiki, H.** Two-Dimensional Bar-Code Detection System Using a Complementary Laser Light Emission Method *Sensors and Materials* 10 (1) 1998: pp. 47 – 61.
7. **Kibirkštis, E., Margelevičius, J., Vaitasius, K., Kabelkaitė, A.** Impact of maintenance conditions upon the print quality of graphic elements *The 1st International Meeting of Science and Technology of Design, Senses and Sensibility in Technology– Linking Tradition to Innovation through Design* 25-26 September 2003, Lisbon, Portugal: Visual Arts, Design and Marketing Institute, 2003: pp. 248 – 250.
8. **Kibirkštis, E., Margelevičius, J., Vaitasius, K., Kabelkaitė, A.** Impact of Environment Temperature Changes upon Print Durability *Materials Science* (*Medžiagotyra*) *ISSN 1392-1320* 10 (1) 2004: pp. 105 – 108.
9. **LST EN 797+AC:1998 lt.** Bar Coding – Symbology specification – “EAN/UPC”.
10. **ISO 2233:2000**. Packaging – Complete, filled transport packages and unit loads – Conditioning for testing.