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Improvement of abrasion resistance by over-varnishing in the case of water-based flexographic printing

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Abstract

The objective of the research was to analyse the abrasion resistance in flexographic printing with water-based inks, covered with different water-based varnishes. Print rub-off tests in the Ink Rub Tester were performed for one water-based ink and three different water-based varnishes used in flexographic printing. The rub-off resistance was evaluated by spectrophotometric methods and visual observations. The ΔE^*_{ab} parameter was used in evaluation. The 3D optical microscope was used to analyse the obtained test results. It was observed that the varnishing process significantly improves the abrasion resistance of the prints. The type of the varnish used in the research does not have such an influence on improvement of abrasion resistance as that of the varnishing process itself. Considering the average surface roughness it could be deduced that the varnishing process increases the surface roughness for both the paper base and for the polyethylene foil. The greater the surface roughness the better is the resistance to abrasion.

Keywords: water-based ink, water-based varnish, surface roughness, spectrophotometric measurement, ΔE^*_{ab} colour difference

1. Introduction and background

Flexography is a very rapidly developing printing technology, therefore it is very important to solve existing problems, search for new materials and improve their properties and also environmental friendliness to obtain high quality prints. That was the reason to become involved in the subject of water-based flexographic inks and varnishes.

It was observed that the popularity of water-based inks has increased significantly in recent years because water is the major component of these products. It was undoubtedly due to their properties such as environmental friendliness, inexpensiveness, non-flammability, work friendliness, etc., especially due to legal requirements on environmental friendliness. Nevertheless, water-based inks can cause problems in the printing process, despite given advantages. The high surface tension of water-based flexographic inks significantly reduces their adhesion to plastic substrates. Their adhesion is much lower than that of other inks used in this printing technology. Many authors, e.g. Mesic et al. (2005) and Mesic, Lestelius and Engström (2006) have addressed the subject of water-based inks and of the surface free energy of the substrate and the ink, but the findings presented in our research on the quality of water-based flexographic inks may also contribute to development and improvement of these environmentally friendly inks. It is, therefore, important to investigate such properties as ink adhesion to the printing substrate or ink resistance to abrasion processes.

The issue of abrasion resistance improvement is within the scope of interests of the authors of the presented article (Gajadhur, 2012; Gajadhur, 2013; Gajadhur, 2014; Gajadhur and Wysokińska, 2013; Gajadhur and Jaszczuk, 2012). The detailed review of international standards for abrasion testing resistance was performed (American Society for Testing and Materials, 2004; International Organization for Standardization, 1997, 1997a, 1999, 1999a, 2000, 2003, 2009; Technical Association of the Pulp and Paper Industry, 1999) to define the existing knowledge base. The published papers on abrasion resistance (Ridgway, Gane and Gliese, 2006; Podhajny, 2005; Zhou et al., 2012; Zhao et al., 2012; Podhajny, 2000; Gane, Kozlik and Schoelkopf, 2005; Koivula, Gane and Toivakka, 2008; Mesic et al., 2005; Mesic, Lestelius and Engström, 2006; Salesin and Burge, 2011; Salesin et al., 2008; Hartus and Gane, 2012; Rentzhog and Fogden, 2006) were also analysed.

Podhajny (2005) indicates that in order to obtain a good scratch and abrasion resistance, an ink of appropriate composition is required. Ink containing an adequate amount of silicones or waxes can be more scratch and abrasion resistant. Zhao et al. (2012) considered the impact of varnishes on abrasion and scratch resistance. They studied how different waxes and resins and their respective content in the varnish can influence scratch and abrasion resistance. It was proved that the type of the resin and wax as well as their amount has a significant effect on resistance to abrasion and scratching. Evaluation of the 'rub off' resistance was based on the measurement of the gloss value before and after the abrasion process. A difference in gloss values of 1.5–6 % was found for different types of resins and waxes.

Zhou et al. (2012) addresses the influence of the substrate on the abrasion resistance of prints. The study involved seven different coated substrates – both glossy and matte – of various grammage. The abrasion resistance of printed matter was assessed, based on the change in optical density and changes in the ΔE^*_{ab} parameter. The research was based on one type of ink, namely the cyan offset ink. Viscosity modification was also included in the research. Prints were obtained from the IGT AIC-2-5 device. Abrasion resistance tests were performed with a Sutherland ink rub tester. The printed paper was rubbed in dry conditions with unprinted paper of the same type. Prints executed using different viscosity inks were also tested for rub off resistance. It was found that the absorption by the substrate and its smoothness has a great impact on abrasion resistance, whereas the viscosity of the ink has no significant effect on this parameter.

In their study, Chen and Liu (2008) presented abrasion resistance of a new type of UV inks designed for flexographic technology. Apart from abrasion resistance, other types of tests were performed, such as scratch resistance, 'Tessa® tape' tests on adhesion, and resistance to chemical agents. Abrasion tests were performed also on a Sutherland device. Polypropylene, polyester and polycarbonate foils were used in the studies. The study was performed to compare environmentally friendly UV inks with conventional UV inks.

Reduced resistance to abrasion may be caused by the low or insufficient surface free energy of the substrate. Surface wettability is characterised by direct contact angle measurements and spreading coefficient. The matter concerning the surface energy problem was presented by Mesic, Lestelius and Engström (2006). The print quality of water-borne inks applied on the LDPE (low density polyethylene) coated paperboard was studied. The LDPE layer was corona treated and the contact angle measurements were performed. The prints were made with an IGT F1 device, 432 hours after the corona treatment. The print properties such as print density, dot gain and mottling of cyan ink applied on the surface were examined.

In previous study by Mesic et al. (2005) it was shown that the surface roughness and corona treatment of polyethylene coated paperboard printed with water-borne flexographic inks significantly influence the rub off resistance of the printed sample. It was also proved that the surface free energy of the ink does not influence the print quality. The set of LDPE materials with different surface free energy and different surface roughness were examined in this study. The rub resistance was evaluated via such parameters as print density, white areas, dot gain and mottling. The cyan ink of 30 s Zahn cup # 2 viscosity was used in this study, and 1 % of surfactant was applied into the ink to reduce its surface energy. Prints were made both with modified and unmodified inks. It was proved that the corona treated samples display better abrasion resistance. Abrasion resistance was evaluated with the use of image analysis software. No influence of surfactant on the rub resistance of tested inks was observed. It was, however, observed that the surface roughness increased after corona treatment.

The problem of adhesion in the printing process studied by Mesic et al. (2005), and Mesic, Lestelius and Engström (2006), was considered also by Wolf (2010) in his research.

The problem of water-based flexographic inks applied on polymers was analysed in detailed studies by Rentzhog (2004), Rentzhog and Fogden (2006), and Rentzhog (2006). Three different printing materials, LDPE, oriented polypropylene (OPP) and polypropylene (PP), and differet inks were analysed by Rentzhog and Fogden, (2006). Wet rub and scratch resistance were evaluated. It was proved that the addition of silicone to the ink worsens the rub resistance, whereas the surface treatment of the substrate improves it. Moreover, it was proved that the rub resistance decreases from LDPE to PP to OPP substrates.

In the research of Zhao et al. (2012), the influence of different water-based varnishes in the printing production was studied only in the case of gloss value changes due to the influence of the abrasion process, but not in the case of abrasion resistance of the prints in respect to colorimetric properties.

The abrasion resistance of different varnishes (cellulosic, synthetic, polyurethane, water-borne and acid hardening) dedicated to wood technology was studied by Keskin and Tekin (2011). however not concerning the printing materials such as paper or foils. The rotation disc was used in these studies. The abrasion resistance was evaluated visually. If 50 % destruction of the sample was observed, the number of rotations was recognised as the measure for abrasion resistance.

2. Methods

This chapter describes materials and devices used in the research, preparation of the samples, as well as the detailed analysis of rub-off tests and evaluation of the abrasion resistance of the tested samples. The surface evaluation of the prepared samples is also discussed in this section.

2.1 Materials and devices

For the purpose of the study, water-based Pantone orange PMS 164 C ink was used. This ink was chosen for the research because of the previously identified poor abrasion resistance (Tomaszek, 2012).

Three different water-based varnishes intended for flexographic printing were also used in the study, namely:
- high-gloss (Varnish 1),
- standard gloss (Varnish 2),
- matt (Varnish 3).

The following substrate materials and tools were used in the study:
- polyethylene (PE) foil Flexipack M3L white, three-layered (25 %, 50 %, 25 %),
- gloss coated paper (illustrated in Figure 1),
- sand paper made of silicon carbide of granulation P-180, in accordance with the recommendations of ISO 5470-1 (International Organization for Standardization, 1999a),
- grey scales for assessing the change in colour (Figure 2a) and grey scales for assessing the staining (Figure 2b),
- anilox roller with screen ruling 80 l/cm and ink capacity of 10.2 cm^3/m^2,
- anilox roller with screen ruling 22 l/cm and ink capacity of 50.1 cm^3/m^2,
- anilox roller with screen ruling 40 l/cm and ink capacity of 39.1 cm^3/m^2.

layer coating 2
layer coating 1
pre-coating layer
bleached pulp (TCF)
pre-coating layer
layer coating 1
layer coating 2

Figure 1: Structure of gloss coated paper base used in the studies

To perform the research it was necessary to use:
- Ford cup ø 4 mm,
- RK Print K-lox manual device (Figure 3),
- TMI Ink Rub Tester with test block weighing 1.81 kg,
- Gretag Macbeth Spectrolino, and SpectroEye spectrophotometer,
- X-Rite KeyWizard software,
- HP LJ100 M175 scanner,
- Bruker Contour GT K1 3D optical microscope.

2.2 Sample preparation

Activated PE foil and gloss-coated paper base were printed with water-based orange PMS 164C Pantone ink in ambient conditions (23 °C and 50 % RH). Prints on PE foil and on coated paper base were obtained with the use of a K-lox RK Print manual device (Kontech). One anilox roller with screen ruling of 80 l/cm and ink capacity of 10.2 cm^3/m^2 was used for obtaining the prints. The K-lox manual device was moved under constant load of approx. 816 g. The width of obtained prints did not exceed 115 mm (Kontech, n.d.). The flat colour print was obtained using the method described.

In the next step, the prints were evaluated visually for the quality of the ink transferred onto the paper or

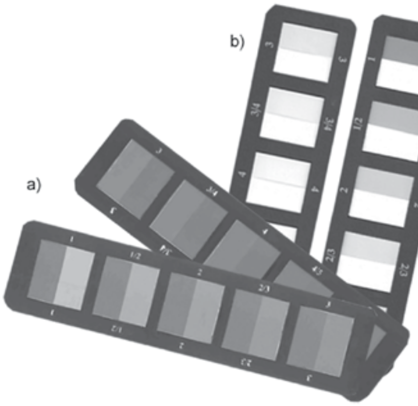


Figure 2: a) Grey scales for assessing the change in colour, b) grey scales for assessing the staining (grey scales prepared by the authors)

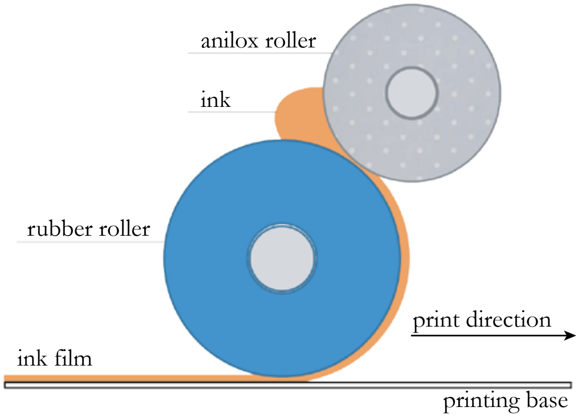


Figure 3: K-lox RK Print device (Kontech)

foil. Only those with a high quality obtained ink layer were selected for further research. After 24 hours, prints were coated with the appropriate layer of the varnish.

The varnish layer was applied to the prints also by means of the K-lox manual device. Two different thicknesses of varnish layer were applied to the prints, using two different anilox rollers, the one with screen ruling of 22 l/cm and ink capacity of 50.1 cm^3/m^2 and the one with screen ruling of 40 l/cm and ink capacity of 39.1 cm^3/m^2. The varnish viscosity was measured using Ford cup ø 4 mm.

2.3 3D surface morphology studies

To analyse the surface morphology of obtained samples, the Bruker Conour GT K1 3D optical microscope was used in the studies (Bruker, 2013). Only the samples varnished with the 40 l/cm anilox roller were analysed.

2.4 Abrasion resistance tests

Varnished prints were tested for abrasion resistance after 24 hours of conditioning in the Ink Rub Tester device, according to the Sutherland method (American Society for Testing and Materials, 2004) and to the method developed in the Department of Printing Technology, WUT (Gajadhur, 2014). The total number of cycles performed in the Ink Rub Tester device was 60 070 cycles. Tests were performed in "dry" conditions, which means that the sample prepared on PE substrate was subjected to rub resistance with contact against the unprinted PE foil (named as PE receptor) and with abrasive paper made of silicon carbide of granulation P-180, according to the recommendations of ISO 5470-1 (International Organization for Standardization, 1999a), whereas the sample prepared on gloss-coated paper base was abrasion tested with contact against the unprinted gloss-coated paper (named as paper receptor). The test block weighing 1.81 kg was used. The device speed of 100 cycles/min was applied in the research.

Samples for the Ink Rub Tester device (TMI, 2015) were prepared in the following manner: the backing material of 152 mm × 76 mm size was attached to the Ink Rub Tester device table using adhesive tape; then the printed sample of 152 mm × 60 mm size was attached to the backing also with adhesive tape; finally, the receptor – unprinted material (film, paper or abrasive paper) with dimensions of 178 mm × 51 mm – was bent and placed on the test block. Each sample was tested for 5 000 abrasion cycles.

A visual assessment of abrasion and spectrodensitometric measurements were performed every 100 cycles from 0 to 500, then every 500 cycles up to 5 000 cycles. Also, the sample was scanned at each stage of the abrasion tests in order to register occurring changes. The spectrophotometric measurements were collected with the use of KeyWizard X-Rite software. At each stage of abrasion, CIELAB values, CIELCH, and the main partial optical density of process colours were measured on the sample and the receptor. Three measurements were taken both for the sample and for the receptor, i.e. a polyethylene foil or unprinted gloss-coated paper base, at every stage of the abrasion tests, respectively. These measurements were performed each time in the same square 5 mm × 5 mm that was marked both on the receptor and on the sample.

The colour coordinates CIELAB, the colour attributes CIELCH and the main partial optical density were measured under the following conditions:

- illuminant D50,
- 2° colorimetric observer,
- density standard DIN NB,
- absolute reflectance,
- no polarization filter.

Firstly, the mean of measured parameters and then the value of the ΔE^*_{ab} parameter ware calculated on the basis of Equation 1,

$$\Delta E^*_{ab} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \qquad [1]$$

where ΔL^*, Δa^* and Δb^* are differences between the coordinates L^*, a^*, and b^* of measured colour and reference.

The results obtained for samples covered with films of different varnish layers were compared to the results obtained for unprotected samples.

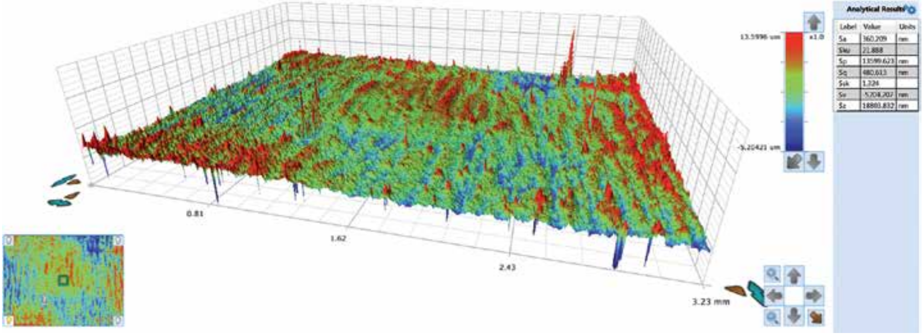
The grey scale for assessing the change in colour and the grey scale for assessing the staining (Figure 2) were used in the evaluation of samples.

3. Results

3.1 Surface morphology results

Three-dimensional images of the surface morphology are presented for the PE substrate (Figures 4 and 5) and for the paper base (Figures 6 and 7).

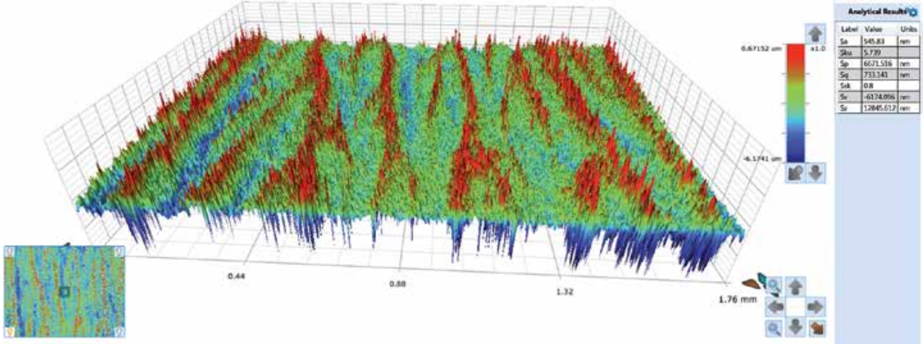
In Figures 4 and 5, the ribbing of the ink and also of the varnish layer is observed on the 3D microscopy maps, changing from short wavelength to longer wavelength in the case of the PE substrate. The similar effect is observed on the paper (Figures 6 and 7), but some-



Analytical Results

Label	Value	Units
Sa	360.209	nm
Sku	21.888	
Sp	13599.623	nm
Sq	480.613	nm
Ssk	1.324	
Sv	-5204.207	nm
Sz	18803.830	nm

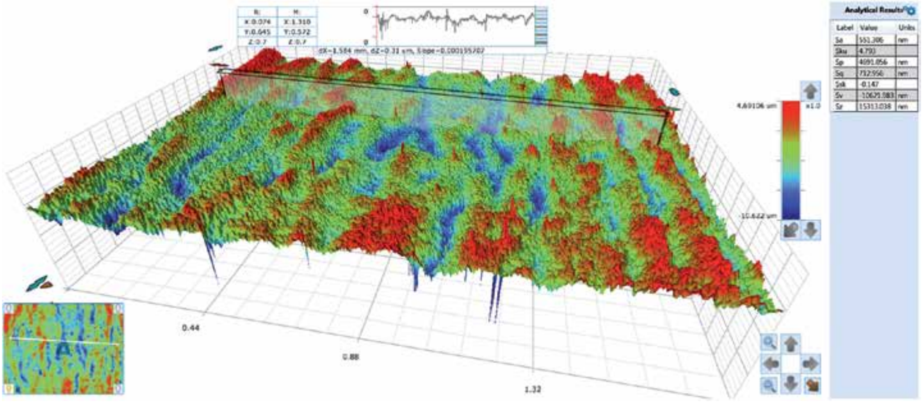
Figure 4: Three-dimensional image of the PE foil surface with the ink layer



Analytical Results

Label	Value	Units
Sa	545.83	nm
Sku	5.739	
Sp	6671.536	nm
Sq	733.141	nm
Ssk	0.8	
Sv	-6174.096	nm
Sz	12845.632	nm

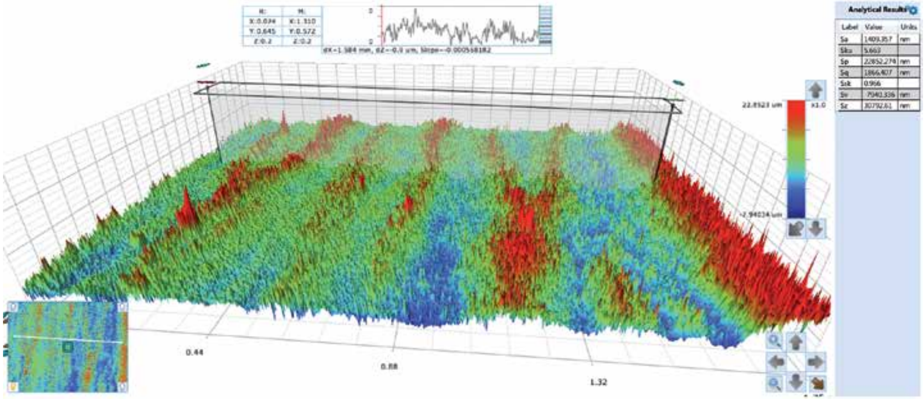
Figure 5: Three-dimensional image of the PE foil surface with the ink and Varnish 3 layer



Analytical Results

Label	Value	Units
Sa	551.306	nm
Sku	4.793	
Sp	4691.056	nm
Sq	732.956	nm
Ssk	-0.147	
Sv	-10621.983	nm
Sz	15313.038	nm

Figure 6: Three-dimensional image of gloss coated paper base surface with the ink layer



Analytical Results

Label	Value	Units
Sa	1409.357	nm
Sku	5.663	
Sp	22852.274	nm
Sq	1866.407	nm
Ssk	0.956	
Sv	-7940.336	nm
Sz	30792.61	nm

Figure 7: Three-dimensional image of gloss coated paper base with the ink and Varnish 3 layer

what less well formed. Perhaps it is related to a possible different viscoelastic behaviour between the ink and varnish used, leading to a material dependent elastic recovery after the film split.

In Figure 8, the average surface roughness (arithmetic mean height, S_a) is compared in a graphical form both for the paper base and for the PE foil.

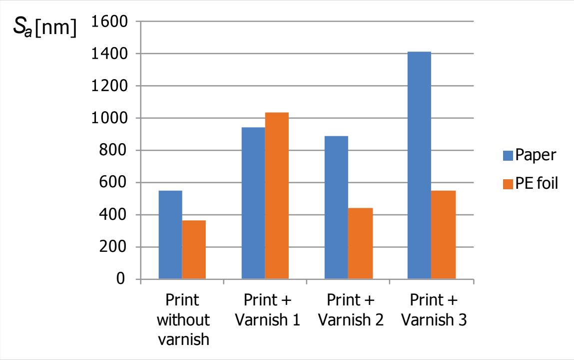


Figure 8: Average surface roughness (S_a) of all tested materials

In Figure 8 it is observed that average surface roughness of the paper samples is roughly twice the value compared to the average surface roughness of the PE samples except for the print coated with Varnish 1. The S_a value for the varnished and unvarnished PE substrate remains at a quite similar level, again with the exception of the print coated with Varnish 1, which has the highest S_a value measured.

3.2 Viscosity of varnish

The results of viscosity measurements with the use of Ford cup ø 4 mm of all varnishes tested in this research are presented in Table 1.

3.3 Abrasion resistance

The ΔE^*_{ab} parameter (colour differences) changes due to abrasion of the prints on PE foil, both varnished with three different varnishes and without varnishing, are presented in Figure 9a for the PE foil sample and in Figure 9b for the PE foil receptor. The varnish layer in this case was obtained with the use of the 22 l/cm anilox roller.

The influence of the varnish layer thickness applied over the print on the rub-off resistance is demonstrated in Figures 10 and 11. Results for three different varnishes are presented. The thicker varnish layer was obtained with the use of the 22 l/cm anilox roller, whereas the thinner with the use of the 40 l/cm anilox roller. The results for both screen rulings are presented. Figure 10 compares results obtained for the printed samples, whereas Figure 11 shows the results of the transfer onto the PE unprinted receptors. Similarly, the results obtained on the gloss coated paper substrate are presented in Figures 12 and 13. In this case the varnish layer was applied only with the use of the 40 l/cm anilox roller. Figure 12 presents the results obtained on the samples, whereas Figure 13 the results obtained on unprinted gloss coated base receptors. Further, printed

Table 1: Viscosity of varnishes measured with Ford cup ø 4 mm (three measurements per sample)

Sample	**Viscosity [s]**			
	1	**2**	**3**	**Average**
Varnish 1	124	111	112	116 (1 min 56 s)
Varnish 2	212	180	195	196 (3 min 16 s)
Varnish 3	43	43	43	43

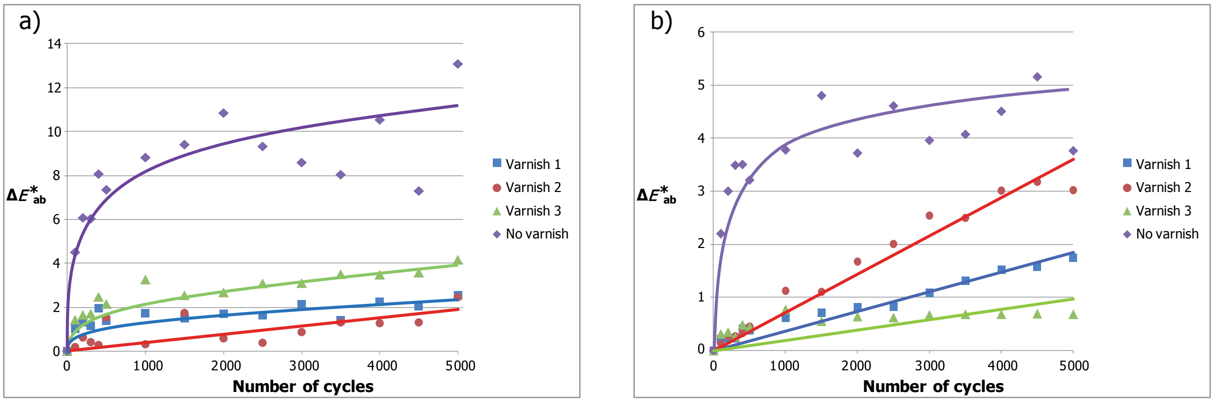


Figure 9: ΔE^*_{ab} parameter changes due to the abrasion resistance process for PE foil a) samples and b) receptors; varnish applied with 22 l/cm anilox roller

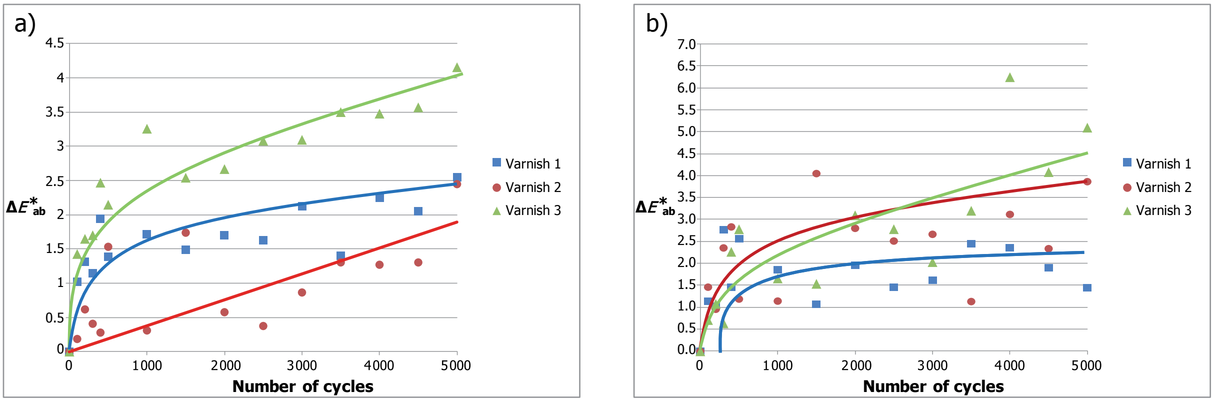


Figure 10: Comparison of ΔE^*_{ab} parameter changes due to the abrasion resistance process for varnishes applied with different anilox rollers, for PE foil samples: a) 22 l/cm, b) 40 l/cm anilox roller

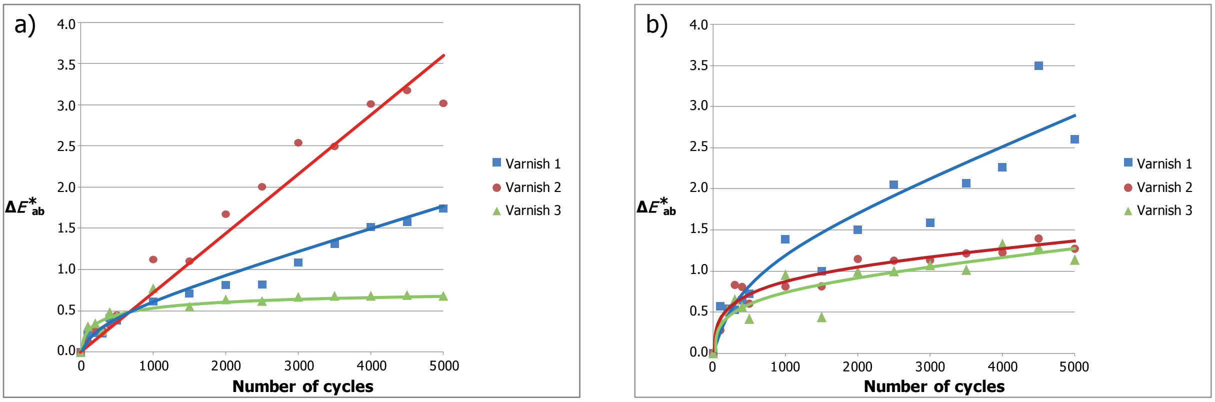


Figure 11: Comparison of ΔE^*_{ab} parameter changes due to the abrasion resistance process for varnishes applied with different anilox rollers, for PE foil receptors: a) 22 l/cm, b) 40 l/cm anilox roller

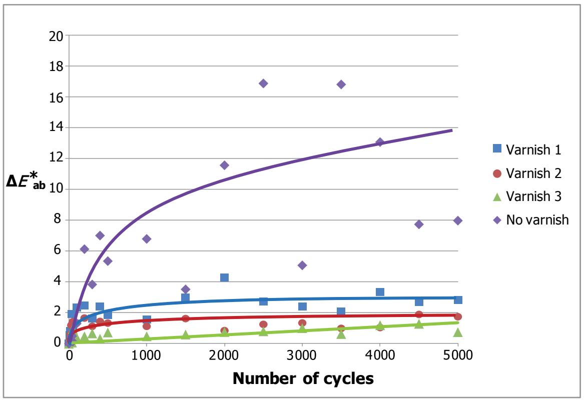


Figure 12: ΔE^*_{ab} parameter changes due to abrasion resistance process, for gloss coated paper samples, varnish applied with 40 l/cm anilox roller

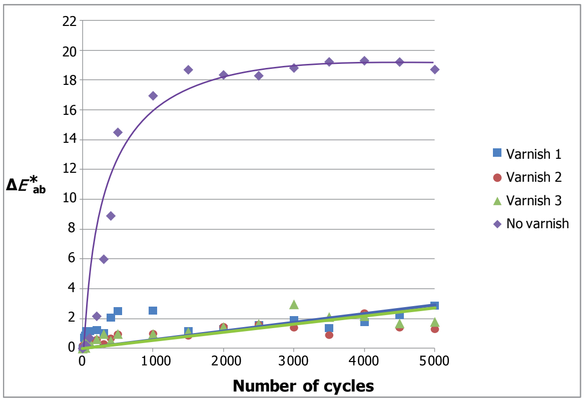


Figure 13: ΔE^*_{ab} parameter changes due to abrasion resistance process, for gloss coated paper receptors, varnish applied with 40 l/cm anilox roller

samples were tested for abrasion resistance with different materials. The results of the abrasion tests with sand paper are presented in Figure 14. Only the samples printed on PE foil were tested by this means.

Table 2 was created on the basis of the grey scale patch measurements both for assessing the change in colour and staining. The measurements were performed using two different GretagMacbeth spectrophotometers, i.e. Spectrolino and SpectroEye, with the following measuring conditions: illuminant D50 and 2° colorimetric observer. It should be noted that the values of the ΔE^*_{ab} parameter changes described in the standards (International Organization for Standardization, 1993; International

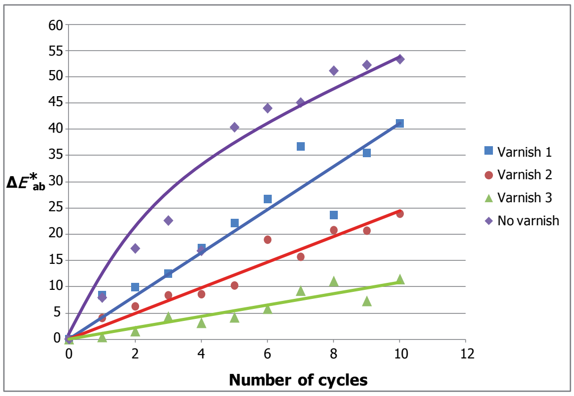


Figure 14: ΔE^*_{ab} parameter changes due to abrasion resistance process with abrasive paper, for PE foil samples, varnish applied with 40 l/cm anilox roller

Organization for Standardization, 1993a) apply only to the measuring conditions involving illuminant D65 and 10° colorimetric observer. The methodology for assessing abrasion resistance is described by Gajadhur (2014).

Evaluation of abrasion resistance (Tables 3–5) was performed on the basis of samples and receptors measurements (materials used for sample abrasion), by monitoring the changes with respect to grey scale grades for assessing change in colour and grey scale, for determining the transfer staining, respectively. The evaluation was, thus, based on the ΔE^*_{ab} parameter value after 500 cycles of abrasion on the sample with respect to the grey scale for assessing change in colour and in case of receptors with respect to the grey scale for assessing staining (Table 2).

Table 2: ΔE^*_{ab} changes according to grey scale for assessing the change in colour and grey scale for assessing the staining

Grey scale for assessing the change in colour grade		**Grey scale for assessing the staining grade**	
Grey scale grade	ΔE^*_{ab}	**Grey scale grade**	ΔE^*_{ab}
5.0	0–0.5	5.0	0–2
4.5	0.5–1.5	4.5	2–4
4.0	1.5–2	4.0	4–6
3.5	2–3	3.5	6–9
3.0	3–4	3.0	9–12
2.5	4–6	2.5	12–17
2.0	6–9.5	2.0	17–24
1.5	9.5–13.0	1.5	24–36
1.0	>13	1.0	>36

Table 3: ΔE^*_{ab} parameter changes due to the abrasion process on the PE foil after 500 rub-off cycles and evaluation of abrasion resistance according to grey scale for assessing the change in colour and grey scale for assessing the staining (varnish applied with 22 l/cm anilox roller)

PE foil substrate	**Sample**		**Receptor**		**Average grey scale grade**
	ΔE^*_{ab}	**Grey scale grade**	ΔE^*_{ab}	**Grey scale grade**	
Print without varnish	7.34	2.0	3.21	4.5	3.25
Print + Varnish 1	1.38	4.5	0.38	5.0	4.75
Print + Varnish 2	1.53	4.0	0.45	5.0	4.50
Print + Varnish 3	2.15	3.5	0.44	5.0	4.25

Table 4: ΔE^*_{ab} parameter changes due to the abrasion process on the PE foil after 500 rub-off cycles and evaluation of abrasion resistance according to grey scale for assessing the change in colour and grey scale for assessing the staining (varnish applied with 40 l/cm anilox roller)

PE foil substrate	**Sample**		**Receptor**		**Average grey scale grade**
	ΔE^*_{ab}	**Grey scale grade**	ΔE^*_{ab}	**Grey scale grade**	
Print without varnish	7.34	2.0	3.21	4.5	3.25
Print + Varnish 1	2.57	3.5	0.72	5.0	4.25
Print + Varnish 2	1.19	4.5	0.60	5.0	4.75
Print + Varnish 3	2.78	3.5	0.42	5.0	4.25

Table 5: ΔE^*_{ab} parameter changes due to the abrasion process on the gloss coated paper after 500 rub-off cycles and evaluation of abrasion resistance according to grey scale for assessing the change in colour and grey scale for assessing the staining (varnish applied with 40 l/cm anilox roller)

Gloss coated paper substrate	**Sample**		**Receptor**		**Average grey scale grade**
	ΔE^*_{ab}	**Grey scale grade**	**ΔE^*_{ab}**	**Grey scale grade**	
Print without varnish	5.36	2.5	14.49	1.0	1.75
Print + varnish 1	1.85	4.0	2.52	3.5	3.75
print + varnish 2	1.34	4.5	0.95	4.5	4.50
print + varnish 3	0.73	4.5	0.97	4.5	4.50

An average abrasion resistance grade according to the grey scale for assessing staining and grey scale for assessing change in colour is presented in Figure 15 both for the printed paper substrate varnished with the 40 l/cm anilox roller and for the PE printed foil varnished with the 22 and 40 l/cm anilox roller. The values for samples without varnishing are also presented.

The pictures of abrasion tested samples before and after 500 and 5000 rub-off tests are presented in the Figures 16 and 17. Figure 16 shows the samples on PE substrate whereas Figure 17 the pictures taken from gloss coated paper substrate, both varnished with the 40 l/cm anilox roller.

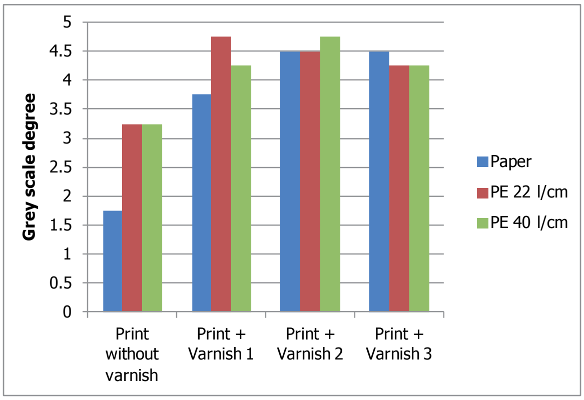


Figure 15: An average grey degree for the sample and receptor of abrasion resistance tested substrates

0 cycles	500 cycles	5 000 cycles
Sample without varnishing		
		
Varnish 1		
		
Varnish 2		
		
Varnish 3		
		

Figure 16: Pictures of abrasion tested samples of PE foil (varnish applied with 40 l/cm anilox roller)

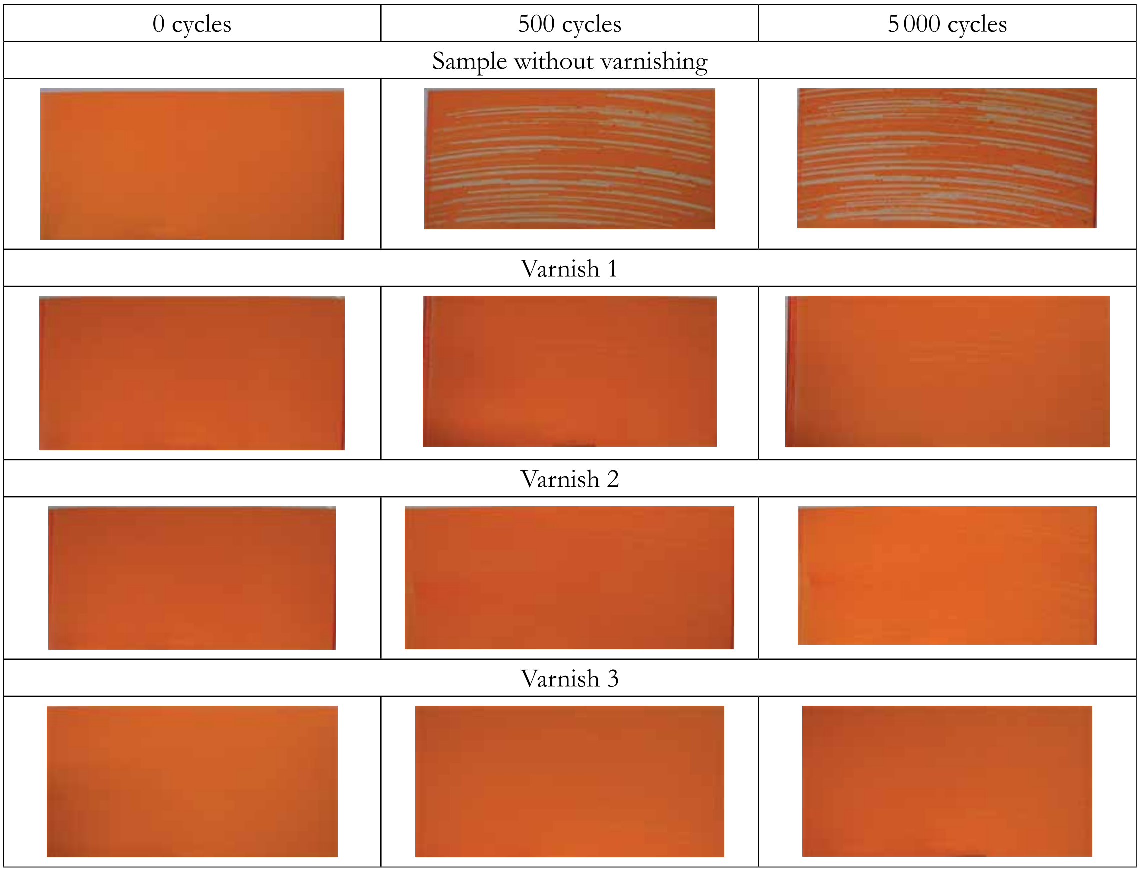


Figure 17: Pictures of abrasion tested samples of gloss coated paper base (varnish applied with 40 l/cm anilox roller)

4. Discussion

It was observed that the varnishing process significantly improves the abrasion resistance of the prints. It may be noted that an improvement of at least two grades of grey scale in the abrasion resistance due to varnish layer applied onto the prints is observed.

A triple abrasion resistance improvement obtained in comparison to the prints, which were not protected by the varnish, was observed for the PE foil substrate. In the case of gloss-coated paper substrate an approximate 8–9 times abrasion resistance increase was observed relative to the prints not protected by the varnish. It was also observed that changes in the parameter ΔE^*_{ab} are significantly greater on a paper rather than on a PE foil substrate in the case of samples not protected by the varnish. It was also found that the type of varnish, the thickness of the applied varnish film (using anilox rollers with 22 and 40 l/cm) and the differences in viscosity of the varnishes used in the study do not have such a significant impact on the improvement of abrasion resistance as the varnishing process itself. The differences in viscosities of applied varnishes resulted in different layer thicknesses. Presumably the thinner varnish layer was obtained for the matt sample (Varnish 3) with the lowest viscosity whereas the thickest for the Varnish 2 with the highest viscosity. Slightly better abrasion resistance results were observed for Varnish 2. Perhaps applying an even thicker layer of varnish than that obtained with the anilox roller with screen ruling of 22 l/cm might result in greater abrasion resistance improvement.

The wide variation of the results for 'no varnish' PE foil prints (Figure 9a, 9b) as well as for 'no varnish' paper substrate prints (Figure 12) could be caused by poor, stochastic adhesion of the ink. In Figure 13, representing the receptor of the paper base, such a phenomenon of variation is not observed. The problem also is not seen in the Figure 14, where a strongly abrasive contact receptor such as sand paper was used in the studies.

Considering the average surface roughness it could be deduced that the varnishing process increases the surface roughness for both the gloss paper substrate and for the PE foil. According to Mesic et al. (2005) it could be noticed that the greater the surface roughness then the better is the resistance to abrasion. Reduced abrasion resistance of the printed paper substrate without varnish layer on it despite the high roughness coefficient in reference to PE printed, but not varnished foil, may be caused by the ink penetration into the paper base. In the case of PE foil, the greater amount of the ink and varnish remained on the surface of the tested material causing the better surface abrasion resistance. Reduced abrasion resistance may be also caused by the uneven coverage by the ink due to its penetration into the paper base and insufficient adhesion to the covered substrate.

5. Conclusions

The need for improved resistance to abrasion and scratch resistance of water-based flexographic prints has become ever more relevant recently. It may be noted that an improvement of at least two grades of grey scale in the abrasion resistance by applying a varnish layer onto the prints is observed. In the case of the paper substrate even three grades improvement was observed due to the varnish application. The surface roughness of the tested material is also of great importance in the abrasion resistance process.

The type of the varnish used in the research does not have such an influence on improvement of abrasion resistance as that of the varnishing process itself.

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