Preliminary report UDC: 655.326.1:655.28.062

Correlation between plastic films properties and flexographic prints quality

ABSTRACT

The article presents a preliminary study of the correlation between films properties and flexographic print quality defined as the optical density of full tone. It is also an attempt to answer the question whether traditional plastic films can be replaced by biodegradable and compostable films as printing substrates and as materials for packaging. Four kinds of films were used in the experiments – two plastic films (PP and PET) and two biodegradable films (PLA and cellulose). The permeability to water vapour and oxygen, as well as the tensile strength and elongation at break of the material were investigated for all samples. The measurements of the contact angle with water, diiodomethane and printing ink were also conducted for these films, and their surface free energy was determined. All samples were printed on laboratory equipment by a flexographic technique using water-based inks and the optical density of copies was measured. It has been found that the print quality was determined by the type of film used. Furthermore, the correlation between optical density and wettability defined as the contact angle between film and water or printing ink turned out to be significant. Other important parameter is surface free energy, albeit to a little lesser extent. The barrier and mechanical properties of the material have an even weaker impact on optical density. In addition, it is possible to choose the biodegradable film with properties corresponding to conventional, commonly used films which enable high quality prints.

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First recieved: 23.07.2015.
Accepted: 09.10.2015.

KEY WORDS
plastic films, biodegradable films, flexographic printing, print quality

Introduction

The importance of plastic packaging is significant and growing every year. According to data from Plastics Europe, over 50% of products packed in Europe utilize packaging made of plastics (Plastics Europe, 2014). Films are the largest group of products made of plastic, mainly used in the packaging market. A nominal thickness of films does not exceed 250 µm, meanwhile typically their thickness is from over a dozen to several tens of micrometers (Rosato, 2000). To manufacture a film for printing purposes 3 kinds of traditional plastic are primarily used: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) (Abdel-Bary, 2003; Ebnesajjad, 2012; Maretić, Bates & Modrić, 2014).

Nowadays, because of the environment, an attempt to reduce waste caused by packaging by replacing the plastic films with films based on the biodegradable polymer. The most important among biodegradable polymers are: polylactide (PLA), cellulose and products based on starch. Their physical, physico-chemical, chemical and mechanical properties may be comparable to conventional plastics (Izdebska, 2016b; Rudnik, 2008).

The properties of the film are important both because of the implementation of the basic function of the package, which is the product protection, and its printability. Almost all packages are printed at least with an informative text, but most of them are decorated with full colour image due to their marketing function.

There are many properties of plastic films, which have a major impact on the quality of prints. These properties can include in particular: yield stress, tensile strength, film deformation due to the temperature, gloss, transparency, adhesion to other materials and wettability, polarity and electrostatic properties (Abdel-Bary, 2003).

The most common techniques for films printing are flexography and gravure. Materials are printed using web-fed high-speed machines, hence elongation and tensile strength are especially important parameters. Increased substrate stretch (mainly non-oriented PE and softened PVC) can cause difficulties during the colour registration. Insufficient strength may lead to breaking of the material during printing and stop the production (Panak, 2005; Maretić, Bates & Modrić, 2014).

The films are non-absorbent materials, which means that they are more difficult to print on than absorbent substrates such as paper. Problems with printing are mainly caused by: poor wettability, lack of absorbency, low surface free energy, lack of dimensional stability during stretching and temperature changes. Because of problems with wettability and adhesion most films (particularly non-polar PP and PE) require the preparation of the surface by its treatment before the printing process. The main purpose of activation is to make the functional groups with high binding capacity create interactions and bonds with other functional groups which can increase the surface free energy, but also modify surface morphology by increasing or reducing its roughness and crystallinity, as well as remove dirt and weak boundary layers. The corona treatment is of the most extensive industrial use currently, often performed immediately before printing with a printing press or during the film production (Izdebska, 2016b; Yuan & Lee, 2013).

Flexographic printing technique is crucial for the printing of plastics. It is an example of a direct relief printing for printing both on absorbent and non-absorbent bases. Liquid inks with low viscosity are used for printing. There are three kinds of inks: water-based, solvent-based and UV-cured. Solvent and UV inks are most commonly used inks for flexographic films printing. However, share of water-based inks in flexographic ink market has been growing for several years. It is related primarily to the environmental aspect of these inks – usage of the solvents is limited and solvents are replaced with water. The use of water-based ink also eliminates such problems as flammable volatile compounds which occurred in case of solvents, restrictions on transportation or storage conditions. Currently flexography is one of the most dynamically developing sectors of the printing industry especially in the area of packaging printing (Dreher, 2007; FFTA, 2014; Leach, 2007; Shapiro, 2001).

Print quality is determined by many factors connected with printing process, kind and properties of substrates and inks. It can be described by many parameters such as: colour coordinates, optical density, dot shape, dot gain, ink trapping, doubling, evenness of ink distribution, sharpness, gradation, tone value range, etc. Among these parameters optical density of full tone is one of the most popular and basic. In printing industry the value of optical density measured in reflection light is recognized as the description of the applied ink thickness. Value of optical density depends on the type of ink, on its pigment and concentration, on printed substrate and on printing technique (Eldred,2001; Johnson, 2008; Kipphan, 2001; Rentzhog & Fogden, 2006).

Due to the increasing importance of biodegradable films and their application as an alternative to conventional plastic films the correlation between the properties of the substrate - in this case the film and the optical density of full tone has been studied. The results are an initial attempt to determine these relationships. Available literature (Jacobson et al., 2009; Izdebska & Nesterowicz, 2013; Izdebska, Podsiadło & Harii, 2012; Vásquez Quintero et al., 2014; Tanley, 2007; Rong & Keif, 2007) describes the biodegradable film printing quite well and even compares the quality of prints on the films made of a biodegradable plastic material and conventional one. However, the approach presented in this paper in contrast to previous work takes into account the correlation between the multiple chosen parameters (barrier and mechanical properties, wettability and surface free energy) of the film and is not limited to only one – kind of polymer.

Methods

Studies on the effect of various film properties on optical density of full tone fields printed with flexographic water-based ink on different kind of films were carried out. Within the frame of the experiments, four films as well as copies printed on these films were examined. The relationship between optical density and selected parameters, such as contact angle, the surface free energy or barrier and mechanical properties of the films were determined.

Materials

Samples of four films were used. The properties of the films are shown in Table 1. Two of them (PP and PET) are traditional films commonly used on the packaging market, whereas the next two (PLA and NK) are the examples of biodegradable films. Both of them are biodegradable, compostable materials according to standard EN 13432.

The printing process was performed with black, water-based ink – PMS Process Black (Michael Huber, Poland). This printing ink is recommended for flexographic printing on plastic films.

Table 1

Films specification (Flexpol, 2013a; Flexpol, 2013b; Innovia Films, 2013; Sidaplax, 2012).

	PP	PET	PLA	NK
Trade name	BIFOL BG	BOPET CA	EARTHFIRST® PLA BCP	Nature Flex NK
Producer	Flexpol	Flexpol	Sidaplax	Innovia Films
Type of polymer	polypropylene	polyethylene terephthalate	polylactide	cellulose
Thickness [μm]	20	12	20	30
Film orientation	biaxial	biaxial	mono	mono
Surface activation	yes	yes	no	no
Type of material	role	role	sheet	sheet
Role width [mm]	560	560	-	-
Sheet size [mm]	-	-	210x297	210x297
Haze [%]	2	4	3,8	4,5
Gloss (geometry)	90 (45°)	-	125 (60°)	105 (60°)

Ink test

The viscosity of the printing ink was determined by the flow time in a flow cup (Ford cup, capacity of 100 ml, the diameter of the outflow opening – 4 mm) according to the standard ISO 2431 (2011). The kinematic viscosity of the ink was 18 ± 0.5 s.

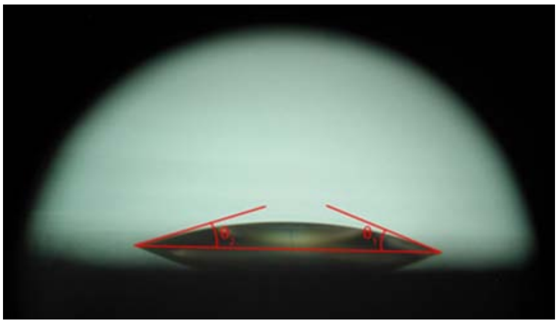
Films tests

The permeability of water vapour was obtained according to the modified standard ASTM E96 (ASTM, 1995; Turhan & Şahbaz, 2004). The sample of the investigated film was used to seal a vessel containing freshly activated molecular sieves of type 4 Å (Union Carbide). The vessel was kept in a desiccator at a fixed temperature and humidity (30°C, RH 95%). The water vapour transferred through the film was determined by four times weighting at intervals of 24 hours.

The permeability of oxygen was performed using a gas dialyser with oxygen and helium (WCh PW, Poland). 3 samples of each film were tested. The measurements took place after 24 hours from placement of the sample in device at a temperature of 30 ± 0.1°C.

Testing of the mechanical properties of the plastic films was performed using a Zwick T1105-563 tensometer (Zwick Roell, Germany). 5 samples for each film in each direction of material (machine and traverse direction) were prepared according to standard ISO 527-1 (2012). The width of the strip was 15 mm and the length was 200 mm for all tested films, and initial distance of the clamps was set to 50 mm. The speed of stretching was 100 mm/min. Tensile stress and elongation at break properties were determined.

The contact angle of diiodomethane and distilled water as well as the printing ink was measured for the films. Therefore photographs of magnified drops of these liquids on the surface of each film by means of camera coupled with stereoscopic optical microscope SZ-STU2 (Olympus, USA) were taken. The ambient conditions were: temperature: 19.1°C; RH 24%. The contact angle was measured with the aid of Iris software. An example of measuring of the contact angle of diiodomethane on PET film is shown in Figure 1. Surface free energy of the films was determined according to the Owens-Wendt method which is the most commonly used (Izdebska, Podsiadło & Harri, 2012; Yuan & Lee, 2013; Zielecka, 2004; Żenkiewicz, 2007).



» **Figure 1:** *Photograph of diiodomethane droplet on PET film*

Printing process

The copies were made using of a Flexiproof 100 (RK, United Kingdom) laboratory printing device. This device is comparable to a single-colour flexographic printing machine. The printing plate was prepared by a digital laser-photochemical method. The screen frequency of the plate was 36 l/cm (91 lpi) and the anilox roller was 200.6 l/cm (509.6 lpi). The carrying capacity of the cell was 5 cm^3/m^2 and the angle of the cells was 60°. The plate was mounted on the print cylinder using soft tesa plate mounting tape with a thickness of 0.5 mm. Printing took place at a constant speed – 60 m/min. Pressure between the anilox roller and plate cylinder was 98 units for all prints, and between the plate cylinder and impression cylinder it depends on the printed film and was appropriately 32 units for PET, 54 units for PLA and PP, and 61 units for NK. The pressure was determined based on the thickness of the material. The ambient conditions were: temperature: 18.6 ± 0.3°C; RH 34.5 ± 0.6%.

Copies test

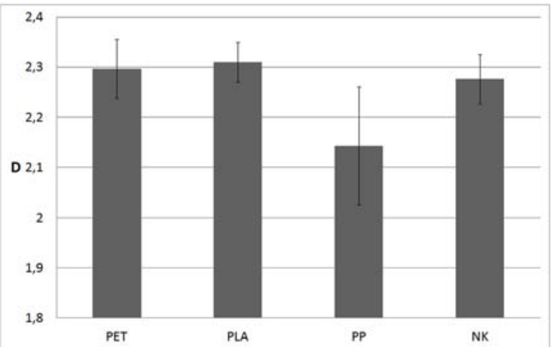
After drying of copies, densitometry measurements were done using Spectro Eye spectrophotometer (GretagMacbeth, Switzerland). The optical density of full tone fields were measured. 15 measurements for each film with reflected light were taken. For this purpose the tested samples were placed on a proofing paper (Matchprint Proofing Paper) as a white background and measurements were carried out with D65 illuminant for 2° observer, with polarisation filters and paper as a base.

Statistical analysis

The results were expressed as the mean ± standard deviation. They were analyzed using Excel software. A confidence interval of 95% was used.

Results and discussion

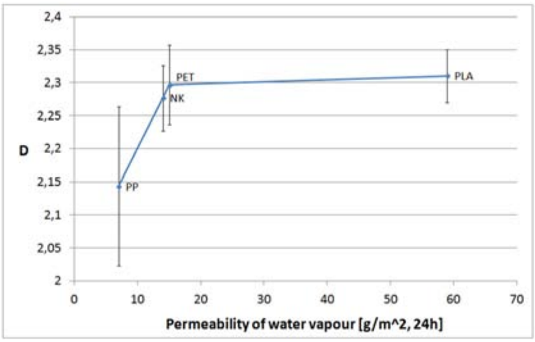
The results of the preliminary study of the correlation between films properties and flexographic print quality described by the optical density of solids are presented in this article. Based on the analysis of the obtained results we try to answer the question whether traditional plastic films can be replaced by biodegradable, compostable films as printing substrates and materials for packaging.



» **Figure 2:** *Optical density of fully coated fields printed on different films*

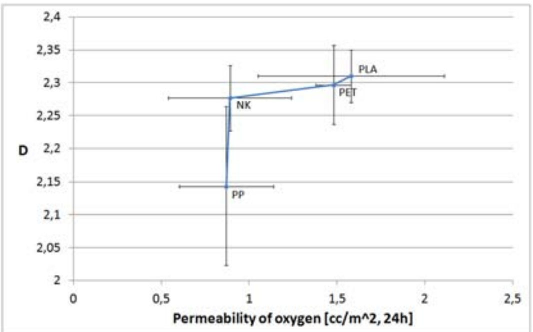
Measurements of the optical density of fully coated fields depending on the kind of film are displayed in Figure 2. Optical density is the most useful parameter which determines the quality of the copies. The thickness of the ink layer deposited on the non-absorbing base depends on the surface properties, its surface free energy, the kinds of ink used and many other parameters of the printing process. There were no substantial differences in the optical density of three films (PET, PLA and NK), while for PP we reported a lower value of optical density. Moreover, standard deviation was much higher, which indicates lower print uniformity and worse quality. However, optical density value was very high for all copies regardless of the kind of printed film. Foundation of Flexographic Technical Association assumes that the value of 1.33-1.47 makes it possible to obtain high-quality prints (FFTA, 2003). It is therefore advisable to use an anilox roll with a smaller cell volume during the future experiments using the same ink.

Higher values than the FIRST standard were obtained in this study. Despite the fact that the ink was dedicated to the PET and PP film, the results obtained for the biodegradable film were very good and comparable or even better. These results are comparable to those obtained by Jacobson, et al. (2009).



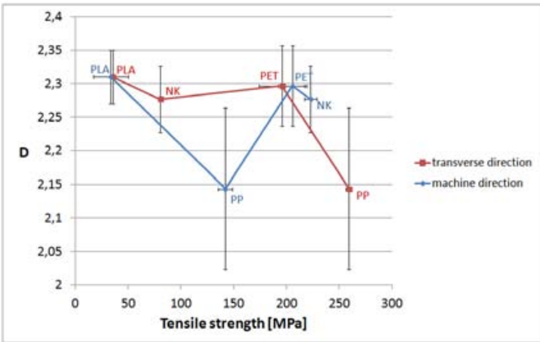
» **Figure 3:** *The relationship between the optical density of the copy and permeability of water vapour of printed film*

The permeability of water vapour of the investigated films was the lowest for PP film and the highest for PLA film. Medial results, close to each other were obtained for PET and NK film (Figure 3). The relationship between optical density and the water vapour permeability of materials is middling (R = 0.59).



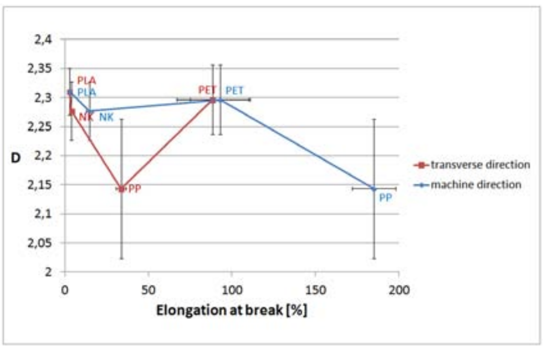
» **Figure 4:** *The relationship between the optical density of the copy and permeability of oxygen of printed film*

The oxygen permeability of each film was as follows: PP <NK <PET <PLA (Figure 4). With respect to the cellulose (NK) film oxygen barrier is comparable to those characteristic of polypropylene film (PP). Furthermore, NK barrier is almost twice higher than PET film barrier, which is similar to the one of PLA film. Moreover, the most consistent results were obtained for PET film. The correlation coefficient was 0.72, which indicates a relatively high relationship.



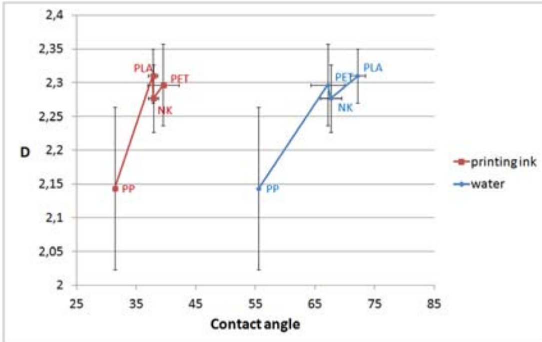
» **Figure 5:** *The relationship between the optical density of the copy and tensile strength of printed film*

Tensile strength depends on the film direction (Figure 5). The highest values both in traverse and machine direction were obtained for PLA film. Moreover, these values are almost independent of the direction of the material. The direction of the material also has no significant impact on the strength of PET film. PP and NK films have different mechanical properties depending on their direction. For PP tensile strength in machine direction is almost two times lower than in transverse direction. In case of NK film, relationship is reversed – tensile strength in machine direction is almost three times higher than in transverse direction. The results did not show a significant correlation between the optical density and the tensile strength.



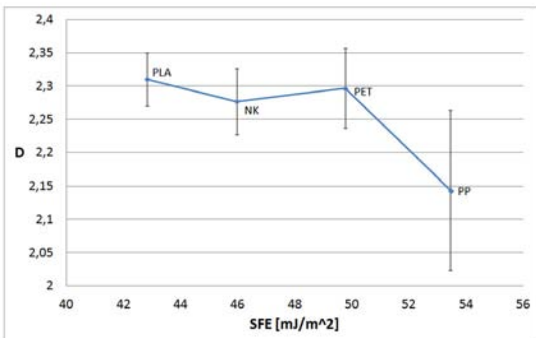
» **Figure 6:** *The relationship between the optical density of the copy and the elongation at break of printed film*

Elongation at break as a tensile strength depends on the film direction (Figure 6). The smallest, only a few percent elongation was obtained for PLA film and a little bit higher for NK films. For these two materials direction is not critical to the elongation. The greatest elongation was observed for PET film in the transverse direction and for PP film in the machine direction. As for tensile strength, no significant relationship with the mechanical properties of the film was observed. However, it is important to point out, that excessive stretching of the film may cause problems with the colour register of the prints, while too low tension strength may cause the material bursting during the printing.



» **Figure 7:** *The relationship between the optical density of the copy and contact angels of water and printing ink on printed film*

The close relationship between a contact angle of water and water-based ink on the tested film is shown (Figure 7). The smallest angles for both liquid was obtained on PP film, which indicates good wettability of this material. The results are not reflected in the value of optical density, which is higher than standard (it is 2.14 where the standard is about 1.4), but lower than for other materials. It can be affected by many other factors, such as the ink distribution in printing unit, the surface roughness obtained as a result of the corona treatment or very high density related to very high ink film thickness on the print. The results indicate a high correlation between the contact angle and the optical density for both the printing ink and water. This is evidenced by the obtained statistic values – for the printing ink it was: $R = 0.961$, $F = 24.66$, $p = 0.010$, and for water: $R = 0.975$, $F = 38.96$, $p = 0.005$.



» **Figure 8:** *The relationship between the optical density of the copy and surface free energy of printed film*

The test shows that the natural surface free energy of biodegradable films was high and exceed 40 mJ/m^2, which value is usually regarded as sufficient for printing (Figure 8). PLA film has the lowest SFE (about 43 mJ/m^2), but prints prepared on those films has the highest optical density value. The cellulose films has slightly higher SFE – about 46 mJ/m^2. PET film has almost 50 mJ/m^2 and PP more than 53 mJ/m^2.

It is thought that higher SFE value means a better substrate wettability and better adhesion which has not been confirmed in the performed tests (Zielecka, 2004; Żenkiewicz, 2007). This may be due to the fact that only plastic films were corona treated. Both biodegradable films had relatively high natural SFE value and have not been subject to modification. In addition, all of the films had high SFE and prints printed on them have very high optical density. Based on this research it can be concluded that untreated substrate have greater reproducibility of printing – the smaller standard deviations. The obtained relationship is high (R = 0.81). However, due to the data and its nature a much broader research is required for the proper determination of the correlation.

Conclusions

The value of optical density of copies printed on biodegradable films were comparable to those printed on traditional plastic films and even surpassed it. Films based on polylactide and cellulose can successfully be an alternative to traditional polymer films such as PP or PET used for printed packaging materials. Commercially available water-based flexographic ink dedicated to films printing allow to achieve high-quality prints on biodegradable film.

The number of results is limited, besides their variation is small, so further research is required to determine the detailed relationships. However, based on the measured values of different parameters the following correlation were observed. It has been confirmed that the type of film determined the print quality. The correlation between optical density and wettability defined as the contact angle between film and water or printing ink turned out to be significant. Influence of surface free energy was also significant, but to a noticeably lower degree. The barrier and mechanical properties of the material have weaker impact on optical density.

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