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ANALYSIS OF INK PENETRATION DEPTH INSIDE SUBSTRATES FOR SECONDARY PACKAGING

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Abstract. Today, the packaging industry is experiencing growth, which in turn leads to an increased amount of packaging waste. To reduce packaging waste, it is necessary to reduce the use of packaging and combine primary and secondary packaging into one. For secondary packaging, which is usually made of paper or cardboard, to replace primary packaging, the penetration depth of the ink into the substrate must be checked, as this is the most important indicator that the product it protects is not affected. The low penetration depth of the printing ink into the interior of the paper printing substrate is crucial for the safety of using this packaging. The penetration depth of the ink into the printing substrate is a very important factor in primary and secondary packaging, as it affects the overall efficiency of the packaging, health, safety, and print quality. The most important factors influencing the ink penetration depth are the porosity of the substrate, the composition of the substrate, the surface energy of the substrate, and the viscosity of the ink. This research is based on analysing and comparing the ink penetration depth in different printing materials most commonly used for secondary packaging. Based on the microscopic analysis of cross-sections of offset prints produced with cyan ink, the maximum ink penetration depth was estimated and observed in parallel with the ink coverage of the substrate. Microscopic images of the printed parts, calculated using image analysis software, were used to determine the coverage of the printing substrate. This research aims to determine which secondary packaging material achieves the lowest penetration depth of the printing ink into the substrate, which opens up the possibility of using these substrates as primary packaging substrates. In this way, the use of polymeric, ecologically unacceptable materials, which are most commonly used as primary packaging substrates, is reduced, and the use of paper or cardboard materials for primary packaging is increased. The results obtained show that the GT2 and GC2 substrates printed with higher cyan ink halftone values contain the lowest ink penetration values into the printing substrate. When printing with a 40% halftone value of cyan ink, the lowest values were achieved when printing on the substrates KD silk and GC2. The ink penetration from the unprinted side of the print was also observed and measured. Ink penetration from the unprinted side of the print occurs when the prints are output after printing, with the unprinted side of the print placed in a stack on top of the printed side.

Keywords: cross-sections of prints, ink penetration, secondary packaging substrates

Introduction

Packaging that surrounds individual products or primary packaging in order to group them for easier handling, transportation, and presentation is referred to as secondary packaging. In contrast to tertiary packaging, secondary packaging has a logistical and marketing function, while all packaging has a protective function (Pirsa, 2024). Primary packaging that comes into direct contact with food is usually made of foil or foil-laminated materials that have good barrier properties, while the use of paper and cardboard is only possible for dry food (Ščetar et al., 2009). Secondary and tertiary packaging requires fewer barrier properties as they do not come into direct contact with food. To attract consumers, more and more printing inks, varnishes, coatings, and foils are printed on the packaging to make it look expensive and high quality, while the consumption of natural resources and the accumulation of non-biodegradable waste and pollution are increasing (Pauer et al., 2019). The latest data shows that each European produced more than 188 kg of packaging waste on average in 2021, so the amount of packaging waste is expected to increase by a further 19% by 2030 (European Council, n.d.).

Hardwoods are particularly important for the pulp and paper industry. The reason for this interest lies in their occurrence in many parts of the world, their rapid growth, and their fibre properties. The use of hardwoods such as eucalyptus, aspen, birch, and acacia is now widespread in the pulp and paper industry, with pulping technologies having been developed in many different directions (Xu et al., 2007). Materials made from chemical, mechanical, or recycled pulp are generally used as substrates for secondary packaging (Mboowa, 2021; Şimşeker, 2021; Stark et al., 2021). Pulp production technology can be divided into three groups: mechanical pulp production, chemical pulp production, and mechanical-chemical pulp production. In mechanical pulp production, mechanical energy is used to separate the fibres and develop the properties of the pulp. In chemical pulp production, chemical energy from chemical reactions is used to separate the fibres and develop the basic properties of the pulp. Chemical mechanical pulping, on the other hand, is a combination of chemical and mechanical pulping, i.e., it uses chemical and mechanical energy. In chemical pulp production, two types of chemical treatments are most commonly used, namely alkaline sulfite and alkaline peroxide (Xu et al., 2007), and there are also two major mechanical pulp productions: thermomechanical pulping (TMP) and mechanical pulping (GW). Chemical pulp focuses on cleanliness, which is important for food or pharmaceutical packaging. Chemical pulp provides a very suitable printing surface, especially when coated, due to the inherent whiteness of the bleached cellulose. Mechanical pulp differs from chemical pulp in that it contains impurities such as lignin and offers a great advantage with high stiffness values (Marttila, 2012; Xu, n.d.). In addition to the main component, which is cellulose fibres, the printing materials consist of additional materials such as fillers, sizing additives, and colorants. A distinction is made between coated and uncoated printing substrates.

Offset printing, the most widely used printing technique for absorbent substrates, is a printing technique that has evolved from lithography. Lithography is a printing technique that was invented by Alois Senefelder in 1796. This technique involves printing over a stone that has been moistened with water before the ink is applied. Offset printing is an indirect printing technique in which the printing and non-printing parts of the printing plate are at the same height. The dampening solution is applied in a very thin layer to the printing plate on the hydrophilic parts, while the printing ink is applied to the oleophilic parts; in this way, the dampening solution film prevents the ink from leaking. (Kipphan, 2001). Offset printing is a technology in which the ink is transferred from the printing plate to the printing substrate using a roller system (Aydemir et al., 2020; Pavlović et al., 2015).

The quality of the print depends on many parameters, the most important of which are printing substrate and printing ink (Havlínová et al., 2020). During printing, a certain amount of ink spreads directly on the surface of the substrate, and a certain amount penetrates the printing substrate itself during the secondary drying of the print. (Bates et al., 2021.) The penetration of the ink into the substrate is a complex problem that depends on the composition of the printing material and the printing ink. There are several methods for determining the penetration of ink into the interior of the paper, which are divided into non-destructive and destructive methods. Common destructive methods are based on microtomy and microscopic analysis, scanning electron microscopy (SEM) or secondary ion mass spectroscopy (SIMS), or focused ion beam (FIB) instruments, or confocal laser scanning microscopes (CLSM). The most commonly used non-destructive method for determining the penetration depth of ink is based on the Kubelka–Munk theory, which uses spectral reflectance (Li et al., 2015).

This paper aims to compare the maximum penetration depth of ink into a printing substrate with the parameter of covering the substrate with ink. The most commonly used offset printing substrates are printed with cyan, low-migration ink, which is used for food packaging.

The analysis

Paper substrate and printing inks

This study used nine different printing substrates, with their characteristics listed in Table 1. The main difference among them lies in their composition, specifically the type of pulp, which is the primary component of each substrate. Three substrates are made from mechanical pulp, two from chemical pulp, while for four substrates, the main component is pulp made from recycled pulps. The printing substrates, which primarily contain chemical and mechanical pulp, their abbreviations used are GC and KD, while the materials made only from recycled fibres have abbreviations GT and GD (Eckhart, 2021). Next to each abbreviation, a number is written that corresponds to the colour of the substrate background.

Table 1. Printing substrates – types and their characteristics

Paper substrate	Grammage (g/m^2)	Thickness (µm)	Brightness (%)	Composition
GT2	300	0,400 ± 0,02	80	recycled pulp
GD2	400	0,565 ± 0,016	82	recycled pulp
GT4 white	280	0, 380 ± 0,019	79	recycled pulp
GT4 brown	280	0,380 ± 0,019	/	recycled pulp
GC1	295	0,460 ± 0,018	91	mechanical pulp
GC2	250	0,406 ± 0,01	88	mechanical pulp
GC2_ barrier	245	0,400 ± 0,02	90	mechanical pulp
KD silk	250	0,220 ± 0,011	/	chemical pulp
KD gloss	250	0,183 ± 0,009	/	chemical pulp

The same offset sheetfed cyan ink was used - a low-migration and low-odour ink that dries by absorption. According to the technical specification, this ink is suitable for all types of printing substrates.

Printing of the paper substrates

All analysed printing substrates were printed using the offset printing technique under the same temperature and humidity conditions (T= 20–24 °C, RH= 40–60%). The printing press used was a Koenig&Beuer 105 with five printing units and an inline varnishing unit. The samples were printed with a prepared vector format, which was provided with a patch with 40% and 80% halftone values (Figure 1).

Fig. 1. Printed patches with 40% and 80% halftone values

Analysing the penetration depth of the ink

To analyse the penetration depth of the ink into each printing substrate, it is necessary to make a cross-section of all printed materials, which was made on the RM2235 Rotary Microtome, Leica. The cross-section samples were prepared by cutting 10 mm x 50 mm strips and embedding them in epoxy resin (Figure 2). The epoxy resin used is a mixture of resin and hardener in a ratio of 15:2. The mixture is prepared by mixing 8 ml of hardener in 60 ml of resin, and everything is gently mixed for 2 minutes and left for a further 2 minutes before pouring (Figure 3). After the epoxy resin has cured, the samples are ground and polished to obtain cross-sectional images for analysing the ink penetration depth of the ink. The cross-section of samples was observed at 200× magnification using an Olympus GX 51 light microscope, and the captured images were further analysed with ImageJ software (Figure 4). ImageJ is an image analysis program that was used to measure the penetration depth of the ink (Hp_m) from the cross-sectional images of the 25 sections. The results are presented as average values of maximum ink penetration depth in Figures 5 and 6.

Analysing the ink coverage

Prints with 40% and 80% halftone values were observed using a DinoLite digital microscope at 200x magnification to obtain images. The images were subjected to image analysis using ImageJ to determine ink coverage on the substrate (Figure 7) and particle count analysis to determine the halftone dot diameter in microns (Table 2).

Fig. 2. Prepared samples for epoxy resin

Fig. 3. Samples after pouring the epoxy resin

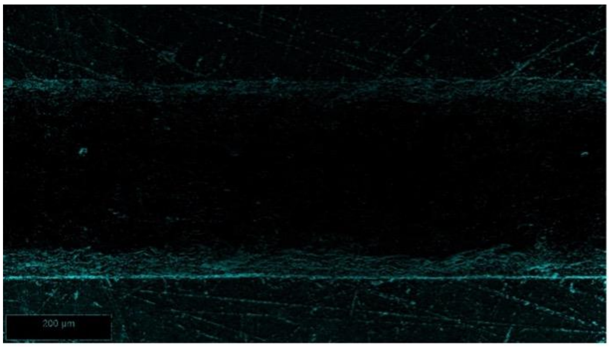

Fig. 4. Cross-section image of the printing substrate for analysis in ImageJ software

Results and Discussion

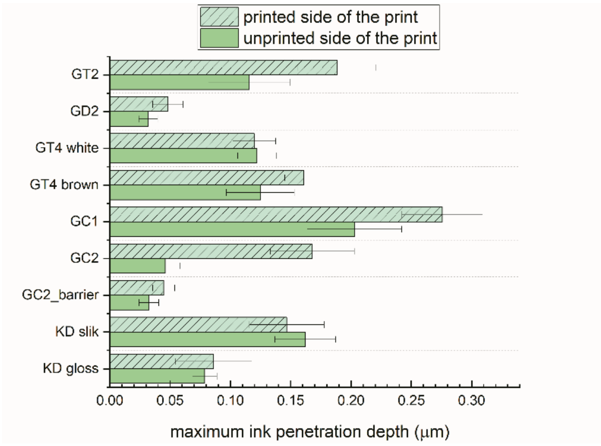

Fig. 5. Maximum ink penetration depth on the printed and unprinted side of prints with 80% halftone values

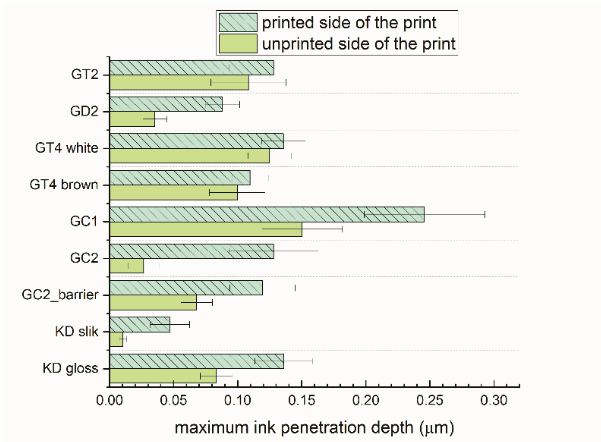

Fig. 6. Maximum ink penetration depth on the printed and unprinted side of prints with 40% halftone values

By observing the samples with 40% and 80% halftone values (Figures 5 and 6) obtained from the cross-section, it can be seen that the ink penetrates the substrate on both the printed and unprinted sides of the printing substrate; therefore, measurements were carried out on both sides of the printed substrate. From the results of the average values of the maximum ink penetration depth on the printed side of patches with 80% halftone value, it is evident that the values of the highest ink penetration depth was obtained on the print on the GC1 substrate. The lowest values of the maximum ink penetration depth on the printed side are contained in the prints on the GD2 and GC2 with barrier substrates. The lowest values of ink penetration within the printing substrate from the unprinted side were obtained on the print at the GC2 substrate with a barrier. On the samples with 40% halftone value, it is also evident that the values of the highest ink penetration depth were obtained on the print on the GC1 substrate. The lowest values of the maximum ink penetration depth on the printed side are contained in the prints on the KD silk and GD2. The lowest ink penetration depth on the unprinted side was obtained on the KD silk.

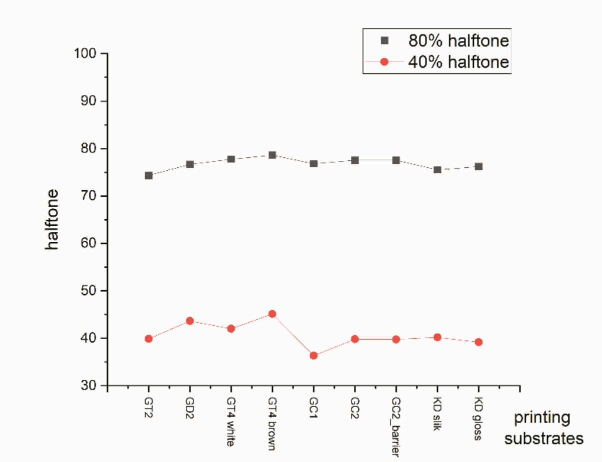

Fig. 7. Ink coverage on prints with 80% and 40% halftone values

From the results in Figure 7, it is evident that the ink coverage values on the patch with an 80% halftone value are very similar in all prints. They lie between 74.33 and 78.61%, while on a patch of 40% halftone value, the ink coverage values vary greatly from print to print. This means that they differ about the printing substrate used for printing. An additional analysis of the patch with a 40% halftone value was performed to confirm that the ink coverage depends on the printing substrate. Table 2 shows the diameter sizes of halftone dots are presented on.

Table 2. Size of the printed halftone dots at 40%

Printing substrates	GT2	GD2	GT4 white	GT4 brown	GC1	GC2	GC2_ barrier	KD slik	KD gloss
Diameter of the dots (µm)	0.392	0.431	0.418	0.464	0.363	0.390	0.384	0.389	0.380

To explain the difference in surface coverage on a particular material, a halftone dot analysis was performed, and the results of the diameter are shown in Table 2. In Table 2, one can see that the diameter of substrate GT4–brown is the biggest one, and according to this, the values of the coverage are higher. The screen dot is not reproduced in the same way on every material, but its reproduction depends on the composition and top layer of the printing substrate.

Measuring ink penetration from the top side of the printing substrate, penetration was also observed and measured on the back of the materials. This occurs when freshly printed sheets are stacked, with the unprinted side of one sheet placed directly on top of the printed side of another. The results indicate that ink penetrates through the backside of the printing substrate, and the amount of penetrated ink varies depending on the type of material, specifically the coating on the back side.

Conclusions

Microscopic analysis of cross-sections of prints made with cyan ink at 40% and 80% halftone values showed that the greatest ink penetration depth was achieved on the GC1 print. The lowest values of ink penetration depth varied depending on the motif on the print. When printing with 80% halftone values of cyan ink, the lowest values were achieved on the prints on GT2 and GC2 with barrier substrate, while when printing with 40% halftone values of cyan ink, the lowest values were achieved on the prints on KD silk and GC2 substrates. Of all the prints observed, KD silk is the only print with the lowest maximum ink penetration depth on the unprinted reverse side of the print, both at 80% and 40% halftone values. This opens up the possibility of using KD silk substrates as primary packaging substrates. To confirm that the ink coverage values depend on the printing substrate, the surface coverage was measured. The results showed a difference in ink coverage values for each material. It can also be concluded from this research that the amount of ink that penetrates depends on the composition of the material. The results also demonstrate that ink penetration occurs from the backside of the printed substrate, which should be taken into account to prevent ink migration and its potentially harmful effects.

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DAŽŲ ĮSISKVERBIMO Į ANTRINĖMS PAKUOTĖMS NAUDOJAMŲ MEDŽIAGŲ PAGRINDĄ GYLIO ANALIZĖ

Santrauka

Šiandien pakuočių pramonė sparčiai auga, todėl susidaro vis daugiau pakuočių atliekų. Siekiant sumažinti pakuočių atliekų kiekį, būtina mažinti pakuočių naudojimą ir sujungti pirminę ir antrinę pakuotę į vieną. Kad antrinė pakuotė, kuri dažniausiai gaminama iš popieriaus ar kartono, galėtų pakeisti pirminę pakuotę, būtina patikrinti dažų įsiskverbimo į medžiagą gylį, nes tai yra svarbiausias rodiklis, rodantis, jog produktas, kurį pakuotė saugo, nebus paveiktas. Mažas spaudos dažų įsiskverbimo į popierinę spaudos medžiagą gylis yra itin svarbus pakuotės naudojimo saugumui.
Dažų įsiskverbimo į spaudos pagrindą gylis yra labai svarbus veiksnys tiek pirminėje, tiek antrinėje pakuotėje, nes jis daro įtaką bendram pakuotės efektyvumui, sveikatai ir spaudos kokybei. Svarbiausi veiksniai, darantys įtaką dažų įsiskverbimo gyliui, yra pagrindo porėtumas, sudėtis, paviršiaus energija bei dažų klampumas.
Šis tyrimas pagrįstas skirtingų dažniausiai antrinėje pakuotėje naudojamų spaudos medžiagų dažų įsiskverbimo gylio analize ir palyginimu. Remiantis mikroskopine ofsetinių spaudinių, atliktų su žydrais dažais, skerspjūvių analize, buvo įvertintas maksimalus dažų įsiskverbimo gylis ir kartu stebėtas pagrindo padengimas dažais. Padengtų spaudinių vietų mikroskopiniai vaizdai, apdoroti vaizdų analizės programine įranga, buvo naudojami spaudos pagrindo padengimo kokybei nustatyti.
Šio tyrimo tikslas – nustatyti, kuri antrinės pakuotės medžiaga pasižymi mažiausiu spaudos dažų įsiskverbimo gyliu į pagrindą, o tai atveria galimybę šias medžiagas naudoti kaip pirminės pakuotės pagrindus. Tokiu būdu mažinamas polimerinių, ekologiškai nepriimtinų medžiagų, kurios vyrauja pirminėse pakuotėse, naudojimas ir didinamas popieriaus ar kartono medžiagų panaudojimas pirminėje pakuotėje.
Gauti rezultatai parodė, kad GT2 ir GC2 pagrindai, atspausdinti su didesnėmis žydros spalvos pustonių reikšmėmis, turėjo mažiausią dažų įsiskverbimą į spaudos pagrindą. Spausdinant su 40 % žydros spalvos pustoniu, mažiausios įsiskverbimo vertės buvo pasiektos spausdinant ant KD šilko ir GC2 pagrindų. Taip pat buvo stebėtas ir išmatuotas dažų įsiskverbimas į neatspausdintą spaudinio pusę. Dažų įsiskverbimas į neatspausdintą pusę atsiranda, kai spaudiniai po spausdinimo dedami į krūvą ir neatspausdinta pusė liečiasi su atspausdinta.

Reikšminiai žodžiai: spaudinių skerspjūviai, dažų prasiskverbimas, antrinės pakuotės pagrindas

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