Functionality in Digital Packaging Printing

Veronica Gidlöf[1], Johan Granås[2], Monica Dahlström[3]

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Abstract: More than ten years ago, the first digital print units were introduced on the market and since then, the technology has developed rapidly. Today there is an interest in trying digital printing also for packages. Digital printing on paperboard may, however, require slightly different criteria than digital printing on paper, due to different characteristics. A very important factor in the Packaging Industry is, for example, the functionality after printing. This study reports on an investigation of the packaging functionalities; taste and odor, creasing, toner adhesion and stability of whiteness in digital printed paperboard. Test printing has been performed in digital print units based on both electrophotography and liquid toner technology. Furthermore, three different board types, one sack paper and a fine paper for digital printing were used. Results show that, whiteness stability, taste and odor are marginally affected after printing, but in some cases the amounts of volatile substances increase substantially. Furthermore, toner adhesion is relatively good, but some problems occur in liquid toner technology. The appearance of folding cracks, during manual folding, occurred rarely.

Introduction

Packaging printing has developed rapidly over the last decade in order to meet the special demands raised by companies who want to protect their products as well as achieve promotional and attractive packaging. But the demands on packaging printing are often complex; low taint and odor, adequate toner adhesion, accurate color reproduction and light fastness are examples of demands that have become important today. Current trends point towards customized runs and shorter lead times and digital printing makes it possible to meet this trend. Digital printing offers a way to eliminate steps like films and plates and enables short series printing in colour and with "good enough" quality. So far digital printing has been a commercial printing method only, but there is an interest trying this printing technique also for packaging printing. For digital printing to be successful for packaging applications it must, however, live up to the requirements set by the traditional printing methods used by the packaging industry today.

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[1]Digital Printing Center, Mid Sweden University
[2]Iggesund Paperboard, [3]Korsnäs AB

The main objective of this paper is, to investigate if digital printing is a suitable method for packaging printing regards to: taste and odor neutrality, whiteness stability, toner adhesion and crease ability.

Digital packaging printing is today limited in comparison to traditional printing and few international functionality studies in this area have been published. Several reports have, however, indicated that digital packaging printing is a promising and increasing area (Jacobs, 2003) (Gilboa, 2002) (Politis, 2001) (Lamperth, 2001). Jacobs states that "Digital package packaging applications are less developed up till now, compared to digital label printing, but the opportunities are without doubt promising". He also states that successful printers use digital technology to provide a unique service to their customers. According to Sirviö (2001) digital printing makes it possible to save costs on obsolete packages and also on logistics and inventory costs. He also explains that there are great possibilities in, for example, small batch test marketing and in personalized packaging.

Earlier studies in digital printing have shown that certain paper properties influence the print result. Some of the important paper properties while printing in Xeikon printing systems are; very smooth surface, high stiffness, resistance towards high temperatures, correct surface energy and controlled moisture content (Lamperth, 2001). Some of the paper requirements for printing in hp indigo presses are: correct surface energy to the Electro Ink, good oil absorption, very smooth surface, low porosity and good surface strength (Lamperth, 2001). Several of these properties may become important due to functionality.

A key feature of chocolate and food packaging is taste and odor neutrality. The packaging material must not influence the taste or odor of the packaged product. Fine chocolate that tastes of wood or ink is not acceptable. Packaging materials that reduce the flavor of the product are equally unacceptable.

Transfer of taint is a critical sensory property from a legal point of view, but also odor is an equally important aspect from a marketing perspective (Levlin., 1999). According to Frisell (2002), it is important with low emissions of volatile organic compounds for packaging board products intended for use in packaging materials for foodstuff and sensitive products. Volatile organic compounds can negatively affect the packaged product with taint or off-flavor. A large number of volatile organic compounds have been shown to form from auto oxidation and photo oxidation of unsaturated fatty acids and corresponding derivates. For analysis of samples with regard to taint and odor using gas chromatograph techniques, hexanal has been considered to be a good indicator to which extent these reactions occurs (Frisell, 2002). The taste and odor of printed substrates were investigated in this study, together with gas chromatography analysis and sensory analysis.

Packages made of cellulose fibres will mostly undergo creasing, to receive a functional packaging shape (boxes or capsules etcetera). Therefore, it is very important to show how the substrate in combination with the printing layer reacts to creasing. Cracks and rupture in the printing layer and/or substrate will affect not only the function, but also the perception and appearance of the package. Consequently, good creaseability is a basic condition for functional and promotional packaging. According to Eklund (2002) digital printing is strongly dependent on successful finishing, today seen as the week link in digital printing that is necessary to improve.

Toner adhesion is a critical parameter in digital packaging printing, since damaged prints affect the appearance of packaging. Accordingly, it is important that packages are able to stand the strain from transportation and exposure so that scraping and friction do not cause damage. Good toner adhesion is achieved when dry- or liquid toner is strongly bonded to the surface which in turn minimizes the effect of external conditions like handling and storage. However, it is sometimes difficult attaching the toner onto the substrate, causing low toner adhesion.

Several results claim that correct surface energy is important in order to achieve good toner adhesion, in both liquid toner and dry toner technology. Lamperth (2001) indicates the importance of paper with correct surface energy in relation to the Electro Ink used in the hp indigo press.

According to an earlier study (Sipi, 2001), paper grades with a decreased surface energy printed in dry toner technology increases the toner adhesion. But, another result reports that toner adhesion approaches 100% when the surface energy of a polymer coating is higher than the dry toner (Lahti, 2003).

Toner adhesion can according to Sipi (2001) also depend on the roughness of the paper grade. Lathi (2003) explains that rougher surfaces have better abrasion durability and that smooth surfaces must have a high surface energy in order to achieve good toner adhesion. A rough surface does not need to have such a high surface energy to achieve good adhesion properties (Lathi, 2003).

Packaging is not only protection but also marketing. Packages that are visually appealing probably have a greater chance of success in selling the goods they contains. In order to achieve good print quality, and good contrast, a white background is often important. If the printing process decreases the whiteness, or the whiteness stability of the substrate it can be a problem. An earlier result indicates that uncharged or poorly charged toner particles tend to develop in the non-image areas of a latent xerographic image (Nash, 2000). This will not affect the whiteness stability of the paperboard, but it might affect the perceived whiteness of the paperboard.

Methods and materials

In order to investigate the functionality in digital printed paperboards, four different tests were performed; toner adhesion, whiteness stability, creasing and finally taste and odor tests. Before testing, printing trails were conducted in five different print units. Four of them were based on dry toner electrophotography and one on liquid toner technology. The techniques can be studied in the Handbook of Print Media (Kipphan, 2001).

During the printing trials each print technician was required to produce the best possible print quality. Meanwhile, the press settings were noted and the temperature and humidity were measured both in the substrates and in the printing room, with a hygroscope (Hygroscope S1, Rotronic, Basserdorf, Germany). The print units are specified in table A.

Presses	Feeding	Maximal Grammage	Fusing	Toner/Color
hp indigo press 1000	Sheet	300g/m^2	No unit	Liquid toner
DICOpack	Web	300g/m^2	Hot pressure 90-128°C [1]	Dry toner
DICOpress	Web	250g/m^2	Contact less IR 110-125°C [1]	Dry toner
Nexpress	Sheet	300g/m^2	Hot pressure, 157-170°C [1]	Dry toner
Xerox DC12	Sheet	250g/m^2	Hot pressure	Dry toner

Table A. The table shows the print units used during the printing trials.
[1]Temperatures used for fusing during printing.

The printings trials were performed at ten different substrates; five graphical solid bleached paperboards (G), one bleached and unbleached liquid packaging board (L), two bleached and unbleached white top craft liner (C), one sack paper (S) and finally a paper designed for digital printing (P) as benchmarking.

Substrates	Grammage	Surfaceenergy[1] (mN/m)	Coating	Thickness (µm)[2]	Whiteness (CIE)[3]
G1	250	40.4	Triple clay, $CaCO_3$	274 ±4	117 ±1.3
G2	220	43.1	Double clay, $CaCO_3$	256 ±4	111 ±0.4
G3	220	42.9	Double clay, $CaCO_3$	269 ±4	68 ±0.7
G4	210	-	Double clay, $CaCO_3$	264 ±3	72 ±0.7
G5	240	39.6	Triple clay, $CaCO_3$	291 ±3	105 ±1
L1	192	45.8	Double chalk, clay	260 ±2	65 ±1
C1	180	-	Single clay, $CaCO_3$	218 ±4	74 ±0.4
C2	120	-	Uncoated	152 ±4	67 ±0.1
S	80	-	Uncoated	172 ±9	63 ±0.7
P	130	-	Single, clay	113 ±2	121 ±1

Table B. The substrates used in the printing trials. [1]Calculated from measurements of contact angle with water and diiodomethane at one second. [2]Measured in a micrometer from Lorentzen&Wettre. [3]Measured in Elrepho SF450, according to the method of measuring whiteness and whiteness stability explained later.

Taste and odor neutrality

After the printing trials, the samples were packed in ten layers of aluminum foil and stored for three months. The taste and odor of printed substrates were later investigated, with gas chromatography- and sensory analysis.

In order to investigate the odor of the printed substrates a DIN odor test was preformed. The test (Modified DIN 10 955) was preformed by placing 20±2 gram substrate into a 250 ml e-flask, for a minimum of two hours in room temperature. Next, eight specially trained panelists (Swedac, lab no 1740) evaluated the odor intensity of the samples by smelling the e-flasks. The samples were judged according to the DIN odor test scale presented below.

0 = No perceptible odor, 1 = Odor just perceptible,
2 = Slight odor, 3 = Distinct odor, 4 = Strong odor

A Robinson test (Modified DIN 10 955) was performed in order to investigate the taste neutrality. The test was preformed by placing 20g of grated chocolate together with two A4 sheets of one printed substrate into a six liters glass container for 48 hours. Next, the chocolate was compared (Swedac, lab no 1740) with a reference chocolate, prepared in the same manner, but without any substrate. The taint of the chocolate was evaluated according to the Robinson test scale presented below.

0 = No deviation from reference sample (RS),
1 = Just perceptible deviation from RS, 2 = Weak deviation from RS,
3 = Distinct deviation from RS, 4 = Strong deviation from RS

A warm headspace gas chromatography analysis (Forsgren, 1999) was performed in order to investigate the amount of volatile substances in the printed substrates. First, a sample was placed in a sealed chamber and heated to 100ºC for 25 minutes. The heated gases (approximate 1 ml) were then transferred with a carrier gas (He) into the gas chromatograph (8700 Gas Chromatograph, Perkin Elmer Ltd. BeaconsField, Buckinghamshire, England).

In this study, only the amount of hexanal was investigated. Hexanal, has been considered to be a good indicator to which extent oxidation of unsaturated fatty acids occurs (Frisell, 2002). Oxidation of unsaturated fats causes rancid taint and odor, and all wood containing products contain unsaturated fatty acids, to some extent (Ljungberg, 2004).

Whiteness stability

Whiteness stability was evaluated by placing paperboard in Suntest XLS+ (ATLAS, Linsengericht, Germany), which simulates when samples are placed behind glass (3mm) and exposed to normal daylight, but with an accelerated intensity. The light was generated with a xenon lamp (600 W/m^2) and a 320nm cut off filter. Before exposure, the whiteness was measured in Elrepho SF450 (Data Color International, USA) under conditions D65/10° and calculated with, the generally excepted equation presented by CIE (*Pauler, 1998*).

$$W = Y_{10} + 800\,(x_{n10} - x_{10}) + 1700\,(y_{n10} - y_{10}) \qquad (1)$$

Y_{10} = Y-value
x_{10}, y_{10} = the chromaticity co-ordinates
x_{n10}, y_{n10} = the chromaticity co-ordinates for the D65-illuminat.

Before testing, all samples were cut to the same size (15x12 mm) and mounted on a white paperboard sheet. In order to prevent the whiteness of the sheet to affect the measurement, four identical samples were placed on the top of each other. During measurement, three white paperboards were also placed behind, in order to prevent light shining through.

After the first measurement the unexposed samples were placed in Suntest for one hour. Then they were left dark for 20 minutes before measuring in Elrepho. The samples were always left dark after an exposure because earlier experiences have indicated that the level of whiteness increases a short while after. Next, the samples were again placed in Suntest for an additional hour and then measured. Finally, the samples were exposed for two hours and then measured. Consequently, the samples were exposed for four hours. Whiteness and whiteness stability of the boards that had passed through the print units and those which had not were finally compared.

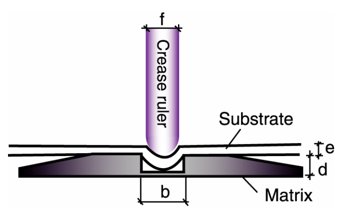
Creasing

An investigation of damage during creasing and folding was preformed by creasing eight samples (38x75mm) of each substrate (4 long- and 4 short grain) in a 400% covered black area, in a Marbach (Heilbonn, Germany). The substrates were, however, creased differently depending on the thickness of the substrate.

Equation 2 (BOBST, 2002) estimated the thickness of the matrix (d) and equation 3 determined the width of the groove (b) (BOBST). Equation 3 was adapted for creasing in short grain, but by using this equation even in long grain the damage would be less destructive. Equation 3 was, accordingly, used both for creasing in long grain and short grain. The thickness of the crease ruler (f) was constantly 0.7 millimeters, which is used for paperboards with thickness between 0.2 and 0.55 millimeters (Iggesund Paperboard, 1993). Creasing was preformed with zero penetration.

$$d = e + a \qquad (2)$$

$$b = 1.5e + f \qquad (3)$$



Picture B. The picture illustrates the creasing procedure.

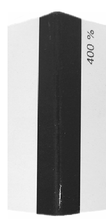
The thickness of the matrix (d) was set to 0.4 millimeters and the bottom of the matrix (a) 0.1 millimeter, but the width of the groove was varied. Table C, shows the width of the groove.

Substrate	G1	G2	G3	G4	G5	L1	C1	C2	S	P
b (mm)	1.2	1.1	1.1	1.1	1.2	1.1	1.1	1.0	1.0	0.9

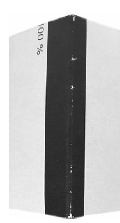
Table C. The table shows how the width of the groove was varied.

After creasing, the samples were stored dark for four months in approximately 20°C and 25-30%RH. The samples were then folded manually into the bead with human force to 180° and then expanded to 90°. Next, the substrates, whose folds were cracked, were evaluated by five observers in 5000K illumination. The study was based on category ranking (Engeldrum, 2000) and the observers were asked to decide if cracks were visible or not according to following scale.

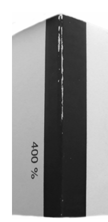
1 = Imperceptible cracks, 2 = Perceptible, but not annoying cracks
3 = Slightly annoying cracks, 4 = Annoying cracks 5 = Very annoying cracks



Picture C.
A typical grade 3.



Picture D.
A typical grade 3.

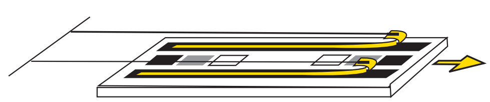


Picture E.
A typical grade 4-5.

Toner adhesion

Before investigation the samples were stored approximately one year. Toner adhesion was tested by first attaching tapes (Scotch magic™ Tape 810) with the same pressure on 100% printed black areas T1 and T2 (picture F). Next, the tape was peeled off with a constant speed (picture G). Three sheets were tested of each substrate and print unit combination.

Picture F. Test chart used for evaluation of toner adhesion.

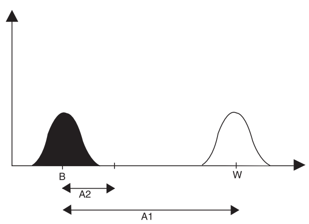


Picture G. The picture shows how the tape was peeled off. The sample was attached to a mobile plate and the ends of the tape were attached into a fixed position.

In order to investigate damage, the samples were scanned and analysed. Scanning was preformed in AGFA Duoscan HiD, in the areas where the tape had been attached and in a black and white paper reference (picture H). The following settings were used during scanning; 600ppi, grey scale, 8-bit, 100%.

The area coverage of T1 and T2 was calculated with the help of the black and white reference. First, the mean value of the black (B) and the white reference area (W) was calculated to decide the terminal points of the grey scale. Next, the mean value of the test areas (T1 and T2) in relation to the black and white reference areas determined the coverage. Finally, the mean value of three samples was calculated. A perfect adhesion was 100% area coverage.

$$\text{Adhesion (Grey scale)} = 1 - (A_2/A_1) \qquad (4)$$



Picture H. Illustration of how the adhesion was evaluated.

Results and Discussion

Taste and odor neutrality

Neither off-flavor nor taint were remarkably high according to the DIN odor and the Robinson test (diagram A and B). The test results did not deviate from similar measurements of unprinted substrates (Ljungberg, 2004). However, DICOpack emitted less off-flavor and taint than the other print units. But, it is important to consider that none of the print units will affect the packaged products negatively, regarding off-flavor or taint since the levels in general were low and are not deviant from unprinted substrates.

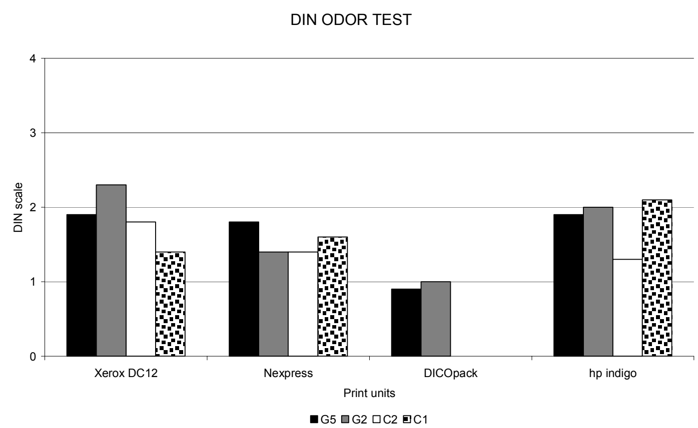


Diagram A. Digital printed substrates mostly were judged to emit less than slight odor. The substrates not shown were not deviant from the results mentioned above.

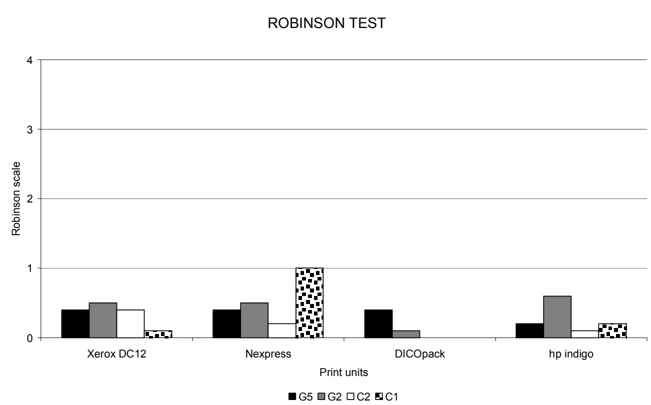


Diagram B. Digital printed substrates were judged to have less than just perceptible deviation from reference sample. The substrates not shown were not deviant from the results mentioned above.

The gas chromatography analysis indicated high amounts of emitted volatile substances from substrates printed at hp indigo 1000. A probable explanation was the solvents (petroleum hydrocarbon) in the liquid ink. Diagram C shows a gas chromatograph diagram of an analyzed graphical paperboard, G5, printed in different print units. The amount of hexanal in relation to unprinted samples was not very high, in any combination of press or substrate. A hexanal amount of 500ng/ml will, for certain, give off-flavor or taint (Ljungberg, 2004). But the maximum amount of hexanal measured, were minor in comparison to 500ng/ml.

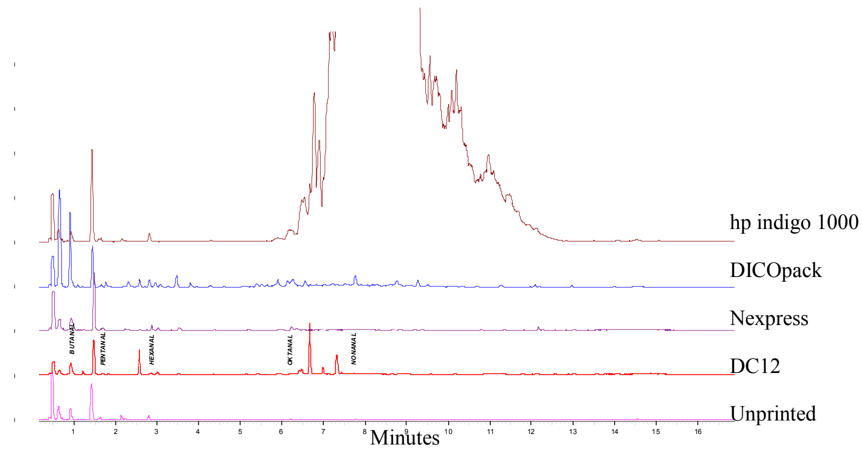


Diagram C. The diagram shows a GC analysis at one paperboard (G5), printed in different print units. The hp indigo press indicates high amounts of volatile substances. The other substrates were not particularly deviant from G5 according to the GC analysis.

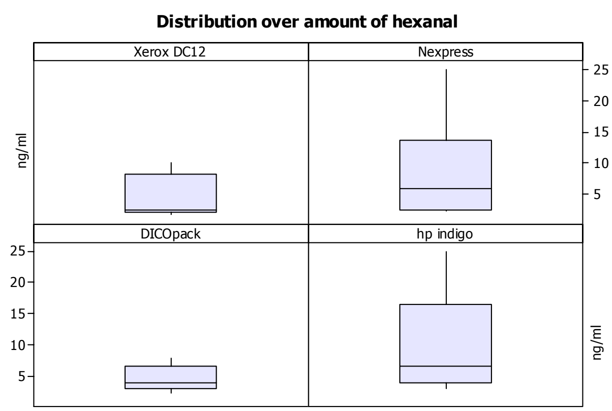


Diagram D. The diagram shows the distribution of the amount of hexanal emitted from different substrates. The hexanal amount is largest in Nexpress and hp indigo.

Whiteness stability

The whiteness stability of the tested substrates was not affected by the digital print units. But, the whiteness before Suntest differed between substrates that had passed through the press and not passed through. The substrates that had passed through the press indicated a slightly lower whiteness. The decreasing whiteness was, however, caused by very small cyan toner particles. The problem was most obvious in the DICOpress. Xerox DC12, hp Indigo, and Nexpress did not have these problems. Below, diagram E and F show examples of the difference in whiteness (Paper and G1) which were the extremes in the DICOpress.

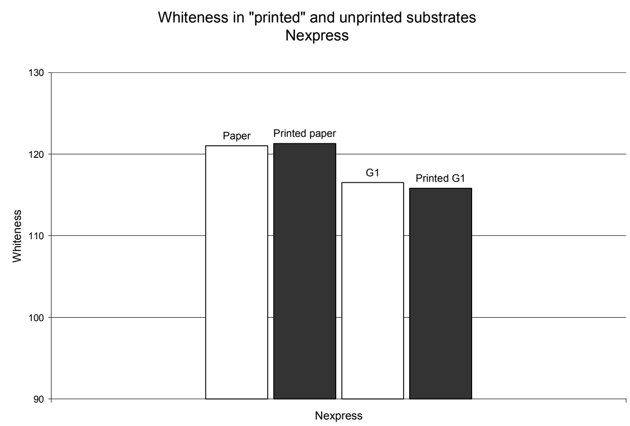


Diagram E. The diagram shows the difference in whiteness in two substrates before and after printing in Nexpress.

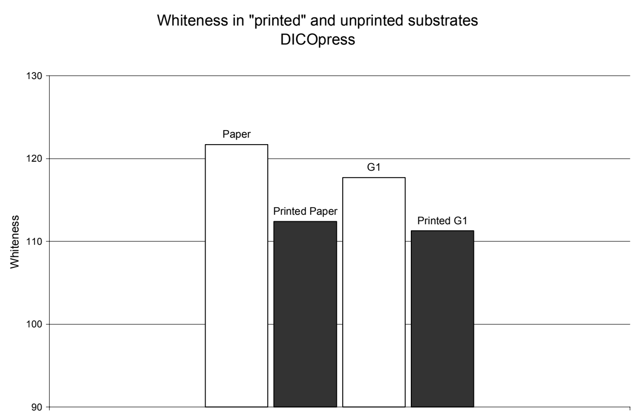


Diagram F. The diagram shows the difference in whiteness in two substrates before and after printing in DICOpress.

Creasing
Cracking in folds occurred very seldom, but when they occurred they were generally not very annoying. It was, however, not possible to see if a certain printing technique caused more or fewer cracks.

The result of the observations showed that the mean value never exceeded grade three (slightly annoying cracks). The substrates were, however, conditioned and stored a long time after printing and this may have affected the result positively. In this study cracks were more frequent in the paper grade and in paperboards with lower thickness then 0.2mm. A plausible explanation was the use of a too thick crease ruler for substrates of thickness under 0.2mm. An earlier study in dry toner electrophotography, also indicates that lower grammage produces poorer fold quality than heavier stock weight paper (Eklund et. al, 2002). Diagram G shows how the observers judged substrates with defects and cracks. Combinations not shown in the diagram were not damaged.

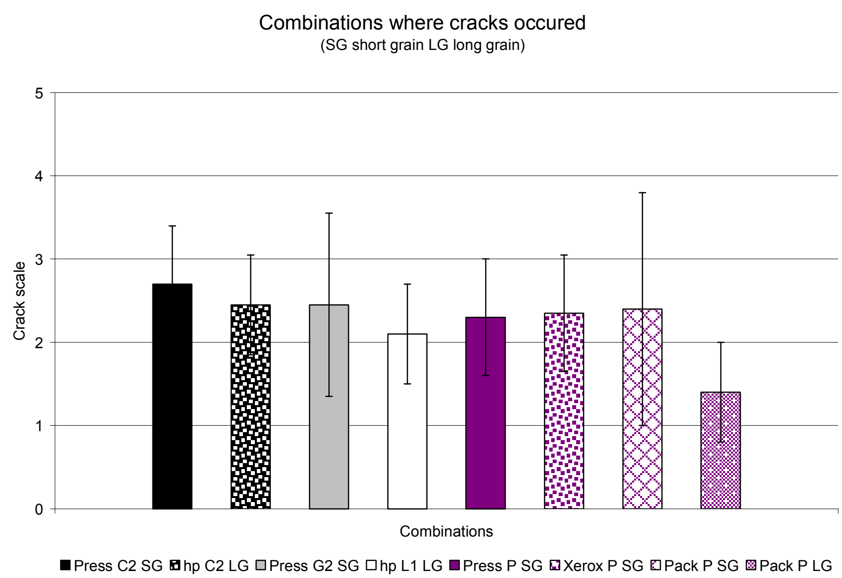


Diagram G. The diagram shows substrates that received cracks. The mean value of the observations shows that cracks were judged to be less than slightly annoying.

Toner adhesion

The toner adhesion was very good in substrates printed in DICOpress, DICOpack and Xerox DocuColor 12, but the hp Indigo press indicated a poorer result. The best toner adhesion for substrates printed in hp Indigo press was achieved for the grades G5, G2 and G3. But, in substrates with low surface strength both the toner/ink and the surface were peeled off. In diagram H, substrates with good and poorer toner adhesion are shown, but not substrates with the lower surface strength, mentioned above.

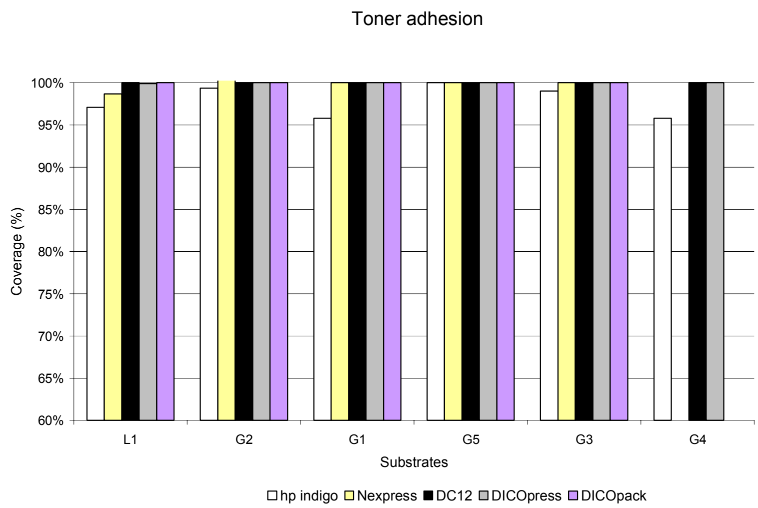


Diagram H. The diagram shows that the toner adhesion is lower in print units based on liquid toner technology. The standard deviations for substrates printed in hp indigo are; 3.3 % G1, 2.0 % L1 and 0.9 % G4, but the other substrates have a standard deviation lower than 0.5%

It was not possible to estimate if lower or higher surface energy caused a poor toner adhesion (Diagram I). However, if G1 was ignored, a lower surface energy indicated a better adhesion. This coincides with Sipi's result (2001), that adhesion strength was better in coated substrates with lower surface energy. Sipi's result was, however, based on coated paper printed in dry toner technology. But according to Lamperth (2001) a correct surface energy in relation to electro ink was important.

Furthermore, earlier studies indicate that roughness affected toner adhesion in dry toner electro photography (Sipi, 2001) (Lathi, 2003). According to Lathi, a smooth surface must have a high surface energy in order to achieve good toner adhesion. If this was a reality even for substrates printed in liquid toner technology, the low toner adhesion in G1 may be explained by a too low surface energy and surface roughness (diagram J).

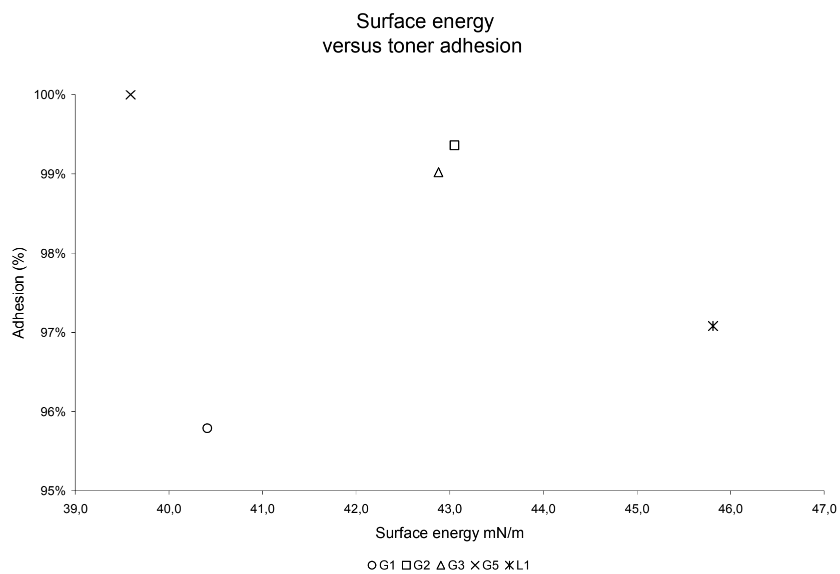


Diagram I. If the substrate G1 was ignored the trend indicated; lower surface energy - higher toner adhesion.

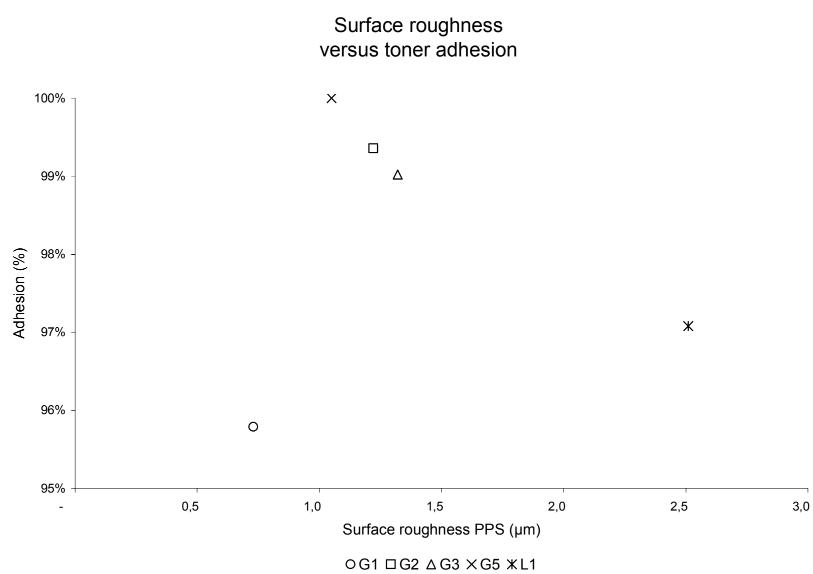


Diagram J. The diagram shows that surface roughness between 1.0 and 1.5 gave better toner adhesion than 0.7 and 2.5.

Conclusion

The functionality of digital packaging printing was more than satisfactory according to this study. Consequently, digital printing can in most cases, be advantageously applied to packaging printing. Food and chocolate can be wrapped in digitally printed paperboard without taint or off-flavor affecting the products. Boxes can most likely be created without and damages and cracks, if the samples are conditioned.

Furthermore, digital printing can be applied on exclusive packages with high demands on whiteness stability without affecting the appearance. Concerning toner adhesion in this study, packages printed in dry toner electro photography will most likely stay intact during transportation or handling.

There are, however some issues that have to be considered in order to achieve a perfect functionality in digital packaging printing. Toner particles on non-printable areas must be eliminated and the toner adhesion in liquid toner technology must be improved. A low toner adhesion can be caused by several factors, but the surface energy and the surface roughness are probable explanations according to this study and earlier studies (Lamperth, 2001)(Sipi, 2001)(Lathi, 2003).

As for taint and odor no problems were discovered, but it is important to consider the high amount of emitted volatile compounds from substrates printed in hp Indigo press. Problems with cracks were not common, but when they occurred the cause was most likely the thickness of the crease ruler. However, further tests are, necessary in order to explain and understand the most significant problem - low toner adhesion in substrates printed in an hp indigo press.

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