Evaluation of Pressure Variations Generated During Flexographic Post-Print of Corrugated Board and Effects of Mechanical Properties of Printing Forms on Printed Banding

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Keywords: Flexography, Corrugated board, Pressure, Banding

Abstract: The effect of pressure variations, generated by the use of different printing forms, on printed banding in post-printing of corrugated board was studied. Pressure variations were measured by placing a pressure sensor between the printing form and the corrugated board during printing in a laboratory press. Differently designed printing forms, with different mechanical properties, and one single-wall B-flute corrugated board were used in the investigations. A strong correlation was found between the printed banding, coinciding with the washboarding structure, and the pressure variations in the printing nip. The pressure variations were affected by the compressibility modulus and bending stiffness of the printing forms. A higher compressibility modulus gave higher pressure variations, and a mid magnitude of bending stiffness gave lower pressure variations.

1. Introduction

The demand for quality printing is growing in the boxmaking sector. The print quality of post-printed corrugated board is affected, among other things, by the pressure applied on the ink in the printing nip, since the contact pressure affect ink transfer (Frøslev-Nielsen, 1962; De Grâce & Mangin, 1984 and Johnson, 2003). Netz (1996) investigated how the banding effect, the printed stripes, in post-printing is influenced by the board properties and the printing conditions. He concluded that the flute structure was the most important factor influencing the appearance of banding and that the banding is generated by the variation in local pressure in the printing nip.

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The measurement of pressure variations is important in several engineering fields (Paikowsky, Palmer & DiMillio 2000). To be able to measure the lateral pressure variations in post-printing would be of great benefit in studying the behavior of printing forms with different mechanical properties.
This paper presents a study of how the pressure variations generated by different printing forms affect banding on post-printed corrugated board.

2. Materials

2.1 Substrate for pressure variation measurements and printing

An uncoated single-wall B-flute corrugated board was chosen as substrate for the trials. The corrugated board consisted of three layers; a White Top Kraft outer Liner (WTKL), a SemiChemical (SC) fluting and an inner Kraft Liner (KL). The corrugated board was supplied by StoraEnso Packaging (Skene, Sweden). The following substrate properties are listed in Table 1; grammage (SCAN-P 6:75), thickness (SS 84 30 09), burst strength (SCAN-P 25-81), FCT (SCAN-P 32:71) and washboard number. The washboarding number is the average magnitude of the unevenness of the corrugated board associated with the fluting pattern (Netz, 1996).

Table 1. Substrate properties.

	Corrugated board	Outer Liner	Fluting	Inner Liner
Grammage [g/m^2]	528	141	143	186
Thickness [mm]	2.97			
Burst Strength [kPa]	1447			
FCT [N]	499			
Washboard number [μm]	2.56			

2.2 Printing forms

Four printing forms were used for the pressure variation measurements and printing trials. The structures of the printing forms are shown in Table 2. They consisted of a sheet plate with a light-sensitive photopolymer layer bonded to a polymer base, FAC 2.84 mm (BASF, Germany) with a hardness of 38^o shore A, and different mounting materials, viz: a plate cushion: CyComp 2.1 mm or CyComp 2.6 mm, (DuPont, Germany); and a mounting foil: Mylar 0.25 mm or Mylar 0.35 mm, (DuPont, Germany). The photopolymer plate was produced using straight light illumination by Flexokliché AB (Värnamo, Sweden). The layout consisted of a solid-tone area and a halftone area with a tone value of 30

%. The screen ruling of the halftone area was 33 lines/cm. Mounting tape CT274, polyester 0.10 mm (Scapa, UK) was used.

Table 2. Printing form structures.

Printing form combination	A	B	C	D
CyComp 2.1 mm	X	X		X
CyComp 2.6 mm			X	
Mounting tape 0.1 mm	X	X	X	X
Mylar foil 0.25 mm	X			
Mylar foil 0.35 mm		X	X	
Photopolymer FAC 2.84 mm	X	X	X	X

2.3 Ink

A commercial water-based cyan ink Scanbrite Raster 707-44024 (Sun Chemical, Stockholm) was used in the printing trials. The viscosity of the ink was 20 seconds, determined with a Zhan cup #2 (Cusdin, 1999).

3. Methods

3.1 Measurement of pressure variation

The pressure variations were measured using a pressure sensor. The sensor was placed between the printing form and the corrugated board at the moment of printing. In order to measure the pressure variations, the test set up shown in Figure 1 was used. The sensor thus passed trough the nip together with the board.

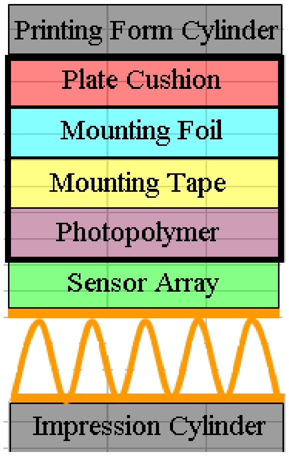

Figure 1. Schematic illustration of the printing form cylinder, the printing form, the pressure sensor, the corrugated board and the impression cylinder in the laboratory flexographic printing press.

The acquisition system used to record the pressure variations was the Tekscan tactile pressure sensor model 5051 (Tekscan, Inc., South Boston, USA). The sensing area dimensions were an area of 56 × 56 mm and a thickness of 0.1 mm. The sensor consists of 1936 sensing locations located in 44 columns and 44 rows. The effective spatial resolution of each sensing location is 1.62 mm^2. The acquisition system has been described by Paikowsky, Palmer and DiMillio (2000). The sampling frequency during the trials was 137 Hz. The size of the pressure map used to evaluate the pressure variation was 39 rows and 44 columns. The 39 rows used represent the width of the printing form cylinder. The sensor generates a pressure map as shown in Figure 2, and this is converted into pressure data using a calibration curve. In the test set-up rows of the sensor were perpendicular to the flutes. In this work, the pressure maps were evaluated using the peak pressure mode. The peak pressure mode displays the maximum pressure value that each sensing area reached during the recording, in one composite frame. It allows viewing, simultaneously, of the highest pressure experienced by each part of the sensor during the recording. In this work, the standard deviation was used to describe the pressure variations. An example of evaluation of the pressure variations can be seen in figure 2, for printing form A.

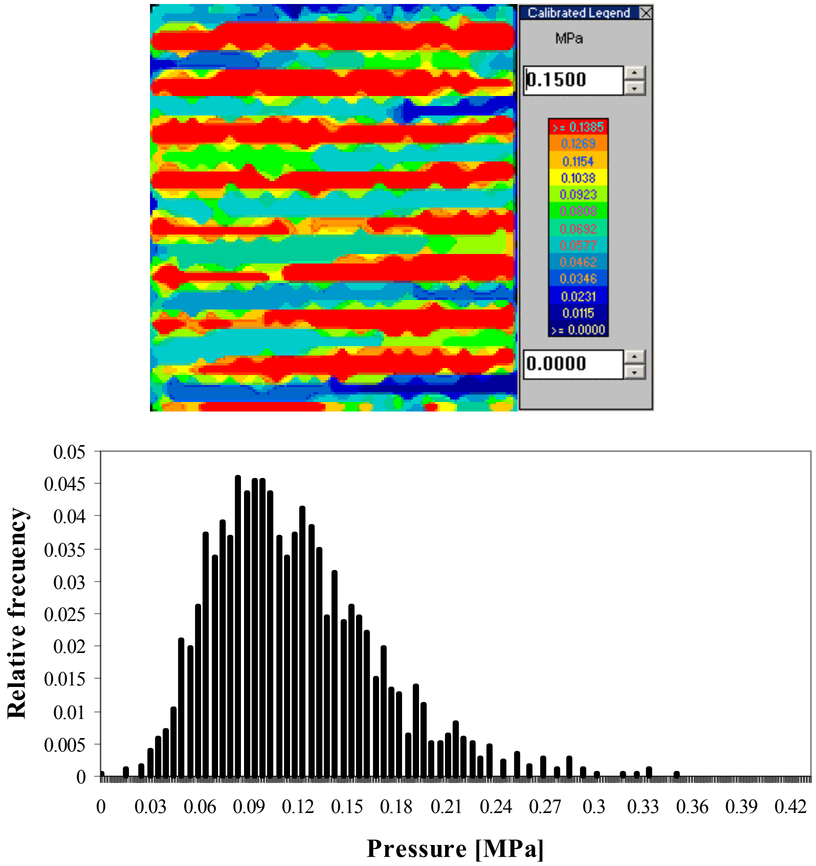

Figure 2. Example of the evaluation of the pressure variations for printing form A: (top) distribution generated in the printing nip, (bottom) pressure histogram.

3.2 Laboratory printing

The corrugated board was printed in a laboratory flexographic printer IGT F1 (IGT Testing Systems, Amsterdam, NL). The printing conditions were; printing speed 0.6 m/s, printing force 50 N, anilox force 50 N, anilox volume 6.5 ml/m^2, screen ruling anilox 140 lines/cm with two revolutions of the printing form cylinder against the anilox roller before substrate contact. For each printing form, 6 samples were printed. The dimensions of the area used for print quality evaluation were 40×200 mm^2. The layout contained a 30 mm wide solid-tone strip, and a 10 mm wide halftone strip with tone value of 30 %.

3.3 Printed banding, orientated print mottle

Printed banding, orientated print mottle, was evaluated on the solid-tone areas using the STFI Mottling v 2.4 software (Swedish Pulp and Paper Research Institute, Stockholm). The software is based on a 2D Fourier transform (Johansson, 1999). It is used for the structural analysis of reflectance images and determines the variations in reflectance and the mean reflectance of the measured areas. Data were collected using an AGFA Duoscan T2500 flatbed scanner, with a scanning resolution of 300 dpi. Eight areas, each 21.7 × 21.7 mm in size, were measured. In this work, the angle sector in the machine direction (MD) $\pm \pi/12$ with the 4-8 mm spatial wavelength band was used to evaluate the printed banding. The B-flute spatial wavelength in the MD direction is within the angle sector used. The results are reported as the coefficient of variation.

3.4 Compressibility modulus of printing forms

The deformation in compression of the printing forms was studied by separate measurements on the different components in a MTS (Material Testing Systems) servo-hydraulic platen press at STFI (Swedish Pulp and Paper Research Institute, Stockholm). The linear elasticity peak pressure value of the corrugated board during compression was 0.3 MPa, pressure applied during a pulse time of 1000 ms using a haversine pulse. The compression tests were therefore carried out to a maximum pressure of 0.3 MPa. In order to achieve this pressure, square samples with dimension of $57 \times 57\ \mathrm{mm}^2$ were loaded. The load in the thickness direction was built up using a hydraulic cylinder which enables a load up to 40 kN to be applied. Load and displacement were recorded with an A/D converter and the pressure and strain were followed throughout the experiment. The compressions experiments were performed at different pulse times: 9, 18 and 1000 ms, using a haversine pulse, 18 ms corresponds to the dwell time in the printing nip of the laboratory printer. The compressive stress and strain values were defined as positive. The printing form compressibility modulus, E_{eff}, was evaluated assuming constant pressure according to equation 1 (Dowling, 1998):

$$\frac{1}{E_{eff}} = \frac{V_{Photopolymer}}{E_{Photopolymer}} + \frac{V_{Platecushion}}{E_{Platecushion}} \tag{1}$$

where

$$V_{\text{Photopolymer}} = \frac{l_{\text{Photopolymer}}}{l_{\text{Photopolymer}} + l_{\text{Plate cushion}}} \tag{2}$$

$$V_{\text{Plate cushion}} = \frac{l_{\text{Plate cushion}}}{l_{\text{Plate cushion}} + l_{\text{Photopolymer}}} \tag{3}$$

and,

E_{eff}: is the calculated compressibility modulus of the printing forms at compressive pressure of 0.1 MPa,

$E_{\text{Photopolymer}}$: is the approximate compressibility modulus of the photopolymer calculated as the differential compressibility modulus at compressive pressure of 0.1 MPa,

$E_{\text{Plate cushion}}$: is the calculated Young's modulus for the plate cushion,

$l_{\text{Photopolymer}}$: is the thickness of the photopolymer and

$l_{\text{Plate cushion}}$: is the thickness of the plate cushion.

$E_{\text{Photopolymer}}$ and $E_{\text{Plate cushion}}$ were calculated using compressive stress and strain curves. The equation gives an approximate value of E_{eff} for small deformations. The mounting foil was not included in the calculation of E_{eff} because it was much stiffer and thinner than either the photopolymer or the plate cushion. The mounting tape was not included in the calculation of E_{eff} since it was thin compared to the photopolymer and plate cushion.

4. Result and discussion

The platen press trials showed that the most compliant component of the printing form was the plate cushion and that the halftone areas of the photopolymer is more compliant than the solid-tone areas, see Figure 3. It was therefore probable that the most of the deformation during printing occurred in the plate cushion.

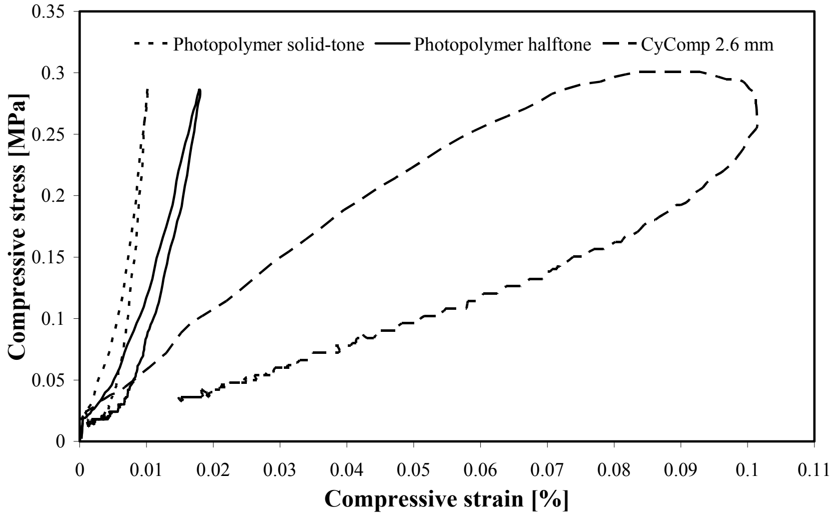

Figure 3. Compressibility stress and strain curves for photopolymer solid-tone, photopolymer halftone 30 % and CyComp 2.6 mm plate cushion. Trials performed in the platen press using a haversine pulse with a pulse time of 18 ms.

In accordance with equation 1, the E_{eff} of the printing form was lower with the thicker plate cushion, see Figure 4. The E_{eff} of the printing form was higher with shorter pulse times, i.e. the press speed will affect the behavior of the printing form.

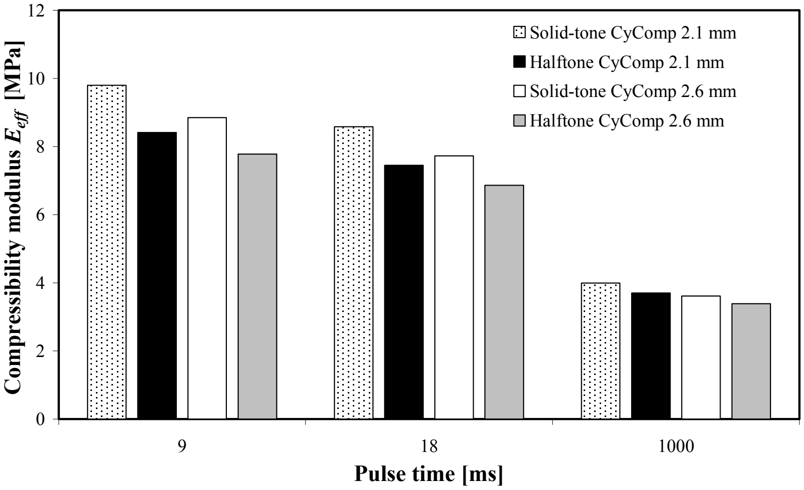

Figure 4. The compressibility modulus, $E_{eff,}$ calculated according to equation 1 for different printing form structures at different pulse times.

Figure 4 also shows that at a higher press speed the value of E_{eff} will be higher. The E_{eff} values were different in solid-tone and halftone area. Even if the difference is small, this may mean that the halftone areas are more compressed than the solid-tone areas. The fact that the photopolymer plate is more compliant in the halftone areas is presumably due to the smaller content of material in the surface. The halftone areas consist of a number of protruding reliefs rather than a smooth surface as in the solid-tone, and this means that some degree of lateral deformation is also possible. Figure 5 shows the effect of the different printing forms on the pressure distribution during printing.

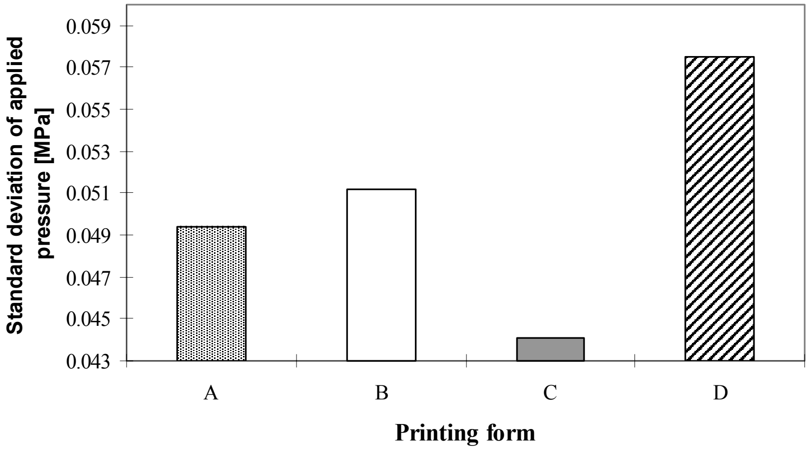

Figure 5. Standard deviation of applied pressure for the different printing forms.

The difference in the pressure variations between printing form C (thicker plate cushion) and printing form B (thinner plate cushion) may be explained by the difference in E_{eff}. Printing form B with the higher E_{eff} was less able to be deformed and less able to compensate for the washboarding. The plate cushion material has a cellular structure, where the walls convert kinetic energy developed in the printing. Energy is absorbed by cell wall bending during loading in the linear-elastic regime of the elastomeric foam, plate cushion (Gibson & Ashby, 1997). The printing form B with higher E_{eff} due to the thinner plate cushion had a smaller amount of cell walls in the plate cushion than printing form C with lower E_{eff}.

The standard deviation was greater with printing form D and was lower with printing form A and B. Printing form D contained no mounting foil which results in a printing form with the lowest bending stiffness. The mounting foil is likely to act as a distributor of applied pressure and the lack of mounting foil thus make the printing form more able to adjust to washboarding.

The influence of the mounting foil thickness i.e. the bending stiffness of the printing form on the pressure variation can further be discerned by comparing the values for the printing forms containing the same plate cushion but mounting foils with different thicknesses, A and B, figure 5. The pressure variation was less for printing form A (thinner mounting foil) than for printing form B (thicker mounting foil). The interpretation is that the thinner mounting foil gave a printing form with lower bending stiffness than the thicker mounting foil. The lower bending stiffness means that the printing form can more easily accommodate to the washboarding structure.

The measured pressure range in the nip was from 0 to 0.43 MPa. These pressure variations are to be due mainly to the variation in local pressure between the valleys and the tips of the corrugated board, see figure 2. Figure 6 shows that there is a highly correlation between banding and the standard deviation of the pressure during printing, that a smaller pressure variation, i.e. a more uniform contact situation between the corrugated board and printing form, is associated with less banding. The linear correlation, r^2, was 0.99.

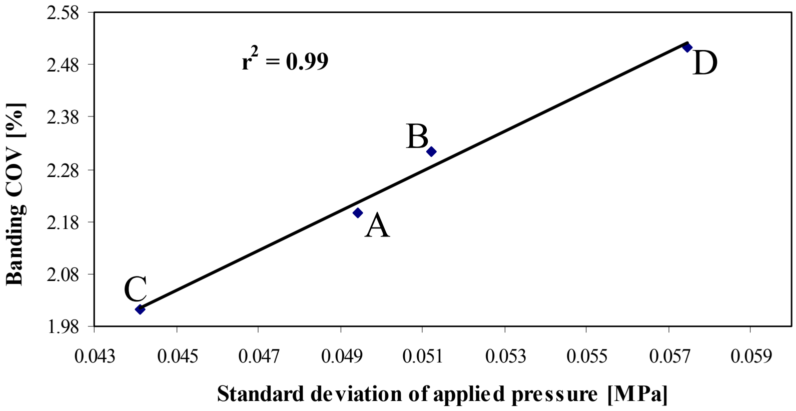

Figure 6. Banding as a function of the standard deviation of the pressure during printing. Linear correlation $r^2 = 0.99$.

This result strongly suggests that the pressure variation induced by the washboarding structure is responsible for the banding, and that the mechanical properties of the printing form are probably the key factor for its ability to compensate for the washboard structure.

5. Conclusions

It is possible to record the pressure variations generated by different types of printing forms in the nip between the printing form and the corrugated board using a pressure sensor. In the results it was showed that there was a strong correlation between the printed banding and the magnitude of the pressure variations in the nip. The magnitude of the pressure variations was affected by the compressibility modulus and bending stiffness of the printing forms. A higher compressibility modulus gave higher pressure variations, and a mid magnitude of bending stiffness gave lower pressure variations. In the future, this method based on a pressure sensor can be used for optimizing the contact behavior between printing forms and corrugated board.

Acknowledgements

Financial support from the T2F program is gratefully acknowledged. The support of Flexokliché Värnamo, Sweden, with printing form material is also greatly appreciated.

Literature Cited

Cusdin, G.
1999 "Ink on Press," In G. Cusdin (Ed.) Flexography: Principles & Practices Method of measurements 5th ed. Vol. 5. pp 67-113.

De Grâce, J. H. & Mangin, P. J.
1984 "A mechanical approach to ink transfer. Part I: Effect of substrate properties and press conditions," In W. H. Banks (Ed.), Advances in Printing Science and Technology. vol. 17, pp 312-332. London: Pentech Press.

Dowling, N. E.
1998 "Stress-Strain Relationships and Behavior". In M. Horton (Ed), Mechanical Behavior of Materials, Engineering Methods for Deformation, Fracture and Fatigue. 2nd ed. pp 166-199. New Jersey, Prentice-Hall, Inc.

Frøslev-Nielsen, A.
1962 "The influence of pressure, pressure distribution, packing and printing speed upon ink transfer and coverage in letterpress," In W. H. Banks (Ed.), Advances in Printing Science and Technology. vol. 2, pp 11-34. London: Pergamon Press.

Gibson, L. J. & Ashby, M. F.
1997 "The mechanics of foams: basic results," In C. R. Clarke, s. Suresh & I. M. Ward (Eds.), Cellular solids, Structure and Properties.2nd ed. pp 175-231. Cambridge, Cambridge University Press.

Johansson, P.-Å.
1999 "Optical Homogeneity of Prints," Doctoral dissertation, Royal Institute of Technology, 2000. Stockholm, Sweden.

Johnson, J.
2003 "The Influence of Moisture, Temperature, Pressure Pulse and Substrate on Print Quality in Flexographic Printing," Licentiate Thesis, Karlstad University, Karlstad, Karlstad University Studies 2003:13, Universitetstryckeriet Karlstad.

Netz, E.
1996 “Washboarding and Print Quality of Corrugated Board,”
Licentiate dissertation, Royal Institute of Technology, 1997. Stockholm, Sweden.

Paikowsky, S.G., Palmer, C. J. and DiMillio, A.F.
2000 Visual Observation and Measurements of Areal Pressure Distribution under Rigid Strip Footing. Performance Verification of Constructed Geotechnical Facilities, 2000: G-I / ASCE Specialty Conference, Amherst, USA, April 9-12 2000.