

Consistency of Flexographic Platemaking

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Abstract

The ink transfer and tone gain in flexographic printing are functions of the interaction of the features on the plates with process parameters such as speed and impression pressure. As well as tone gain in the plate making process, the plates can also have different physical characteristics, such as elasticity, that effect their behaviour during the printing process. In order to get an understanding of the extent of the potential effects of these parameters in normal production, a study was undertaken of plates produced by 3 different companies. Each company produced an image containing 100%, 75%, 50% and 25% tonal patches. The companies produced 5 plates under nominally the same conditions but at different times. The physical dot areas were measured on each plate using white light interferometry and physical properties of the plates, i.e. roughness, Young's Modulus and surface energy, were measured.

Significant differences were found both in tone gain and dot depth both between plates made by the same manufacturer, as well as between plate makers. There was a wide spread of physical properties between the plates made by the different companies. This can be attributed to the use of different photopolymers. On the basis of this recommendations are made for improving print quality and consistency.

Introduction

The dot areas on a film negative primarily determine the area of the halftone dots on a conventionally processed flexographic printing plate. However, changes in the processing of a plate including the exposure and washout will affect the final area of the dots and their profiles. This can lead to dots being

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larger or smaller than intended and therefore affect the amount of ink transferred to the substrate.

The control over the plate-making procedure may not only affect the area and profile of the halftone dots, but also the material properties and surface energy. These could all impact on the performance of the plate during printing. Prior to investigating the influence of the plate in the printing of halftone dots, an experimental investigation to benchmark the variability in plate characteristics that typically exists as a result of the plate processing was undertaken.

Plate characterisation

Three companies supplied plates for the investigation. These consisted of a reproduction house, which is a company that specialises in plate processing. The other two companies were print companies that had their own processing facilities. Each company produced a set of five plates, processed using their own procedures. The processing conditions to be used were not specified because the different companies utilised unprocessed plate stock from different photopolymer manufactures, and these manufactures recommend different exposure and washout conditions to suit their products. It is also dependent on the processing equipment used. However, each of the five plates within the set was to be processed under the same conditions, but produced at different times. This would allow the companies' control of the plate processing procedure to be assessed.

Each plate was to contain a test image containing four halftone patches of 25%, 50%, 75% and 100% coverages each measuring 100 mm x 150 mm. The layout of the image was left up to the individual companies. All the companies utilised a conventional exposure process using a negative to process the plates.

The plates within each set were assessed in terms of their surface topography, including the dot areas, dot depths and the roughness of the 100% patch. The material properties and the surface energy were also examined.

Plate topography

The surface topography and dot area of the 25%, 50% and 75% halftone patches were measured using a white light interferometer. To evaluate the consistency of the surface finish, 16 measurements were taken within the 100% patch on each plate. Analysis software was used to provide the average roughness (Ra) of each measurement.

Material Properties

Samples of the plates were measured using a Hounsfield materials testing bench to examine the behaviour of the photopolymer under loads similar to those experienced during printing. Originally it was envisaged to perform both compressive and tensile tests to examine the homogeneity of the material, and obtain both the Young's modulus and Poisson's Ratio. However, problems were experienced in the clean removal of the polyester backing from the plates. For the compression tests, the thickness of the polyester layer was small compared to that of the photopolymer layer, so that its affect on the compression results was assumed to be negligible. However, the properties of the polyester would have a dramatic affect on the results obtained from tensile tests. For this reason, only compression tests were performed.

Surface Free Energy

The surface free energy could be a key factor in determining the amount of ink transferred from the anilox to the plate, and ultimately from the plate to the substrate. The surface free energy was measured from the contact angles produced from depositing liquid droplets onto the surface of the plate. A Fibro DAT1100 dynamic absorption tester was used to assess the surface energy of two samples from each plate.

Prior to testing it was necessary to clean the samples with a solvent to remove any contamination from the surface of the plates, methanol is typically used in industry for this purpose. The initial tests showed the methanol lowered the surface energy of the plates. However, the surface energy did return to its original value after several hours. Therefore the plates were left for 24 hours after cleaning before being used for a test.

Test liquids

Owens et al [1] developed a method of measuring the surface energy of solids by resolving the contributions of dispersion and dipole hydrogen bonding forces at the liquid-surface interface for two test liquids. The surface tension of one of the liquids was required to be predominately dispersive and the other polar. Due to hydrogen bonding the atoms of polar liquids are more strongly attracted to each other rather than to an external surface. This results in a tendency for a droplet of the liquid to bead-up on the surface. The atoms in a dispersive liquid have weaker bonds and a strong attraction to external surfaces. These liquids therefore tend to spread when applied to a surface.

For this investigation distilled water was selected for the polar liquid, as the properties were already known, and was unlikely to have an adverse affect on the photopolymer. Many of the dispersive liquids commonly used in surface free energy measurements including toluene, attack the surface of the photopolymer. While other liquids such as diiodomethane possessed a serious inhalation danger requiring specialist safety equipment such as a ventilation hood. Oleic acid, a natural fatty acid was found not to adversely affect the plate during the measurement time, and could be used safely without the requirements of any specialised equipment. The surface tension properties of both test liquids are shown in Table 1. The typical behaviours of the two test liquids in terms of their contact angle are shown in Figure 1. This shows little change in contact angle occurred for water during the time period due to its polar nature. However, for oleic acid, the contact angle decreased rapidly as the droplet spread across the surface.

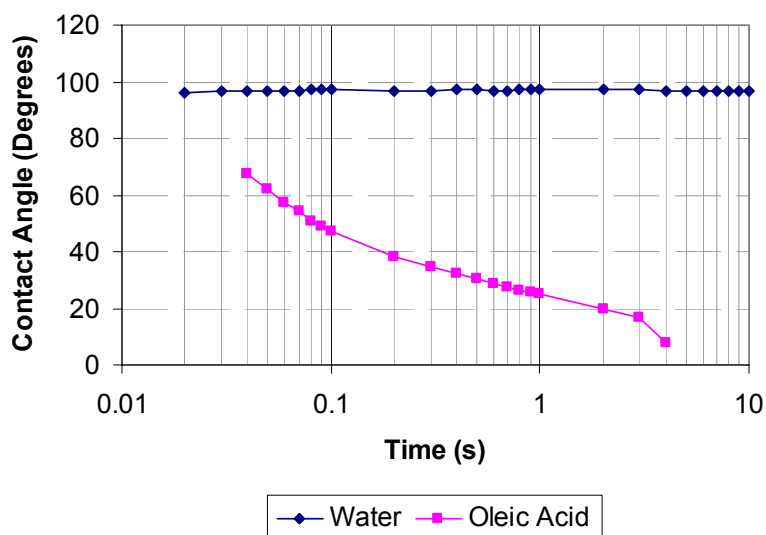


Figure 1 – Example of how contact angles changed over time

Table 1– Surface tension properties of test liquids

Liquid	Surface Tension, γ (Dynes/cm)	Dispersive Component, $\dot{\gamma}$ (Dynes/cm)	Polar Component, $\ddot{\gamma}$ (Dynes/cm)
Distilled water	72.8	21.8	51
Oleic acid	32.5	32.5	0

Contact angle measurement

Nine droplets were deposited onto each sample under the conditions shown in Table 2. Due to the nature of the experiment some contamination of the sample surface often occurs resulting in some spurious results. The three contact angle results furthest from the mean on each sample were therefore ignored. The samples were cleaned with methanol following each experiment. Tests with distilled water were repeated to check the repeatability of the instrument. The more viscous nature of the oleic acid led to a pump delay being used. This extends the time between when the instrument finishes pumping the droplet to the shock pulse being applied, to allow the viscous fluid to form a droplet. An initial experiment determined that a 3 second pump delay was the minimum additional time required to form a 4 μl droplet.

Table 2– Contact angle measurement conditions

Parameter	Setting
Droplet size	4 μl
Shock pulse	10 (instrument setting)
Measurement time	12 sec
Ambient temperature	20 °C

Surface free energy calculation

The following method was used to calculate the surface free energy [2]. The contact angles for both liquids were taken at 0.1 seconds, which was the point at which the water droplet had stabilised on the sample. The contact angles from the repeated tests using water were averaged. Two simultaneous equations relating to each of the liquids used were used to determine the dispersive and polar components of the surface energy of the plates: -

$$\gamma_{\text{oleic}}(1 + \cos\theta_{\text{oleic}}) = 4 \left[\left(\frac{\dot{\gamma}_{\text{oleic}}(\lambda_{\text{d}})}{\dot{\gamma}_{\text{oleic}} + \lambda_{\text{d}}} \right) + \left(\frac{\ddot{\gamma}_{\text{oleic}}(\lambda_{\text{p}})}{\ddot{\gamma}_{\text{oleic}} + \lambda_{\text{p}}} \right) \right]$$

Equation 1

$$\gamma_{\text{water}}(1 + \cos\theta_{\text{water}}) = 4 \left[\left(\frac{\dot{\gamma}_{\text{water}}(\lambda_{\text{d}})}{\dot{\gamma}_{\text{water}} + \lambda_{\text{d}}} \right) + \left(\frac{\ddot{\gamma}_{\text{water}}(\lambda_{\text{p}})}{\ddot{\gamma}_{\text{water}} + \lambda_{\text{p}}} \right) \right]$$

Equation 2

Where:

- γ was the surface tension of the liquid
- θ was the contact angle of the liquid at 0.1 seconds
- $\dot{\gamma}$ was the dispersive component of the surface tension for the liquid
- $\ddot{\gamma}$ was the polar component of the surface tension for the liquid
- λ_d was the dispersive component of the surface energy of the surface
- λ_p was the polar component of the surface energy of the surface

Solving these equations simultaneously resulted in the determination of the polar and dispersive components of the surface energy of the plates. The surface free energy was then calculated as,

$$\text{Surface Free Energy, SFE} = \lambda_d + \lambda_p$$

Equation 3

Results

In the following section the results from the topography, material properties and surface free energy investigations are presented and discussed. Where appropriate the measurement errors of $\pm 3t$ calculated using Equation 3.6 are also presented. The results for the dot areas have also been calculated as percentage area using Equation 3.2.

Dot area

The average measured dot areas for the 25% coverages for the plates of Company A, Company B and Company C are shown in Figure 2. The dot areas and errors, for all coverage analysed, are also tabulated in Table 3.

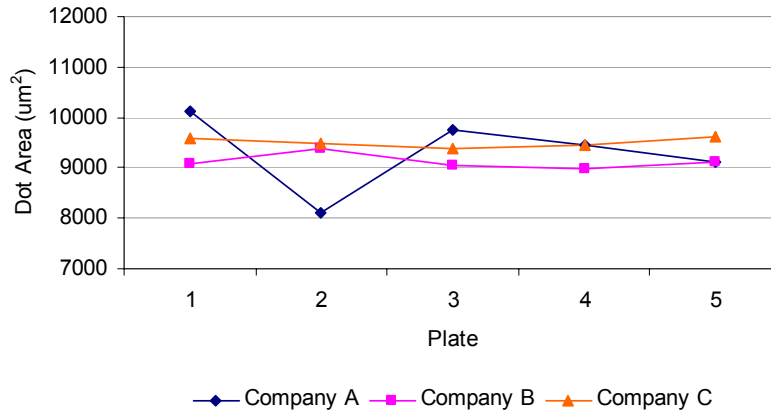


Figure 2 – Average measured dot areas for 25% coverages

The greatest variation in the dot size between the plates occurred for Company A, where the dot area ranged between 8122.46 μm^2 and 10134.15 μm^2 . The measurement errors for Company A were also relatively high on each of the plates ranging between 198.63 μm^2 and 313.63 μm^2 due to the non-uniformity in dot area. Unfortunately, the film negative used to produce the plates was unavailable for measurement therefore it is not possible to determine whether this dot-to-dot variation within each plate resulted from the negative. For Company B, the variation between the plates was smaller, ranging between 8968.98 μm^2 and 9380.41 μm^2 . Company C had the lowest variation in plate dot area for the 25% coverage, with a range of 229.68 μm^2 .

Table 3 - Measured dot areas

Nominal Coverage (%)	Plate	Company A			Company B			Company C		
		Dot Area (μm^2)	Error (%)	Measured coverage (%)	Dot Area (μm^2)	Error (%)	Measured coverage (%)	Dot Area (μm^2)	Error (%)	Measured coverage (%)
25	1	10134.15	1.96	36.52	9078.56	1.29	29.31	9575.68	1.79	29.54
	2	8122.46	3.62	29.27	9380.41	1.39	30.28	9497.52	1.62	29.30
	3	9759.63	3.21	35.17	9057.57	1.56	29.41	9395.92	1.51	28.98
	4	9460.57	2.77	34.09	8968.98	1.25	28.96	9440.98	1.19	29.12
	5	9121.20	2.30	32.87	9105.50	1.31	29.40	9625.60	1.46	29.69
50	1	18918.16	0.86	68.18	17128.69	1.56	55.30	18593.78	6.57	57.35
	2	18394.02	1.23	66.29	17587.99	1.65	56.78	18158.37	0.85	56.01
	3	18872.49	1.02	68.01	17424.57	0.81	56.25	18510.77	0.85	57.10
	4	19210.38	1.14	69.23	17108.33	0.75	55.23	18070.08	0.94	55.74
	5	18310.37	1.52	65.99	17363.34	1.66	56.06	18409.20	0.83	56.79
75	1	24423.77	0.63	88.02	25230.97	1.42	81.46	28970.52	0.68	87.83
	2	24784.24	1.44	89.32	25508.89	1.09	82.35	28489.60	0.56	86.35
	3	24701.44	1.09	89.09	25665.82	1.04	82.86	28678.79	0.77	86.93
	4	24506.98	1.39	88.32	25521.73	1.06	82.39	28032.41	0.51	84.93
	5	25085.54	0.55	90.40	25363.02	1.29	81.88	28664.62	0.92	86.89

The results for the 50% coverages are shown graphically in Figure 3. The figure shows the largest dot sizes for Company A, with the smallest dots for Company B. The variation between plates for Company A was less than that observed for the 25% coverages. However, for Company B, greater variation between measurements was observed (Table 3). Plate 1 for the 50% coverage for Company C produced a large measurement error of $\pm 1220.80 \mu\text{m}^2$. The dots measured within a small region of the patch were significantly larger than those in the remainder of the area. Since all of the plates within the set were produced from the same negative, quality issues with the negative are unlikely to have been the cause. It is likely this large error on plate 1, was due to a small portion of the patch being over exposed due to a poor contact between the negative and the plate. This would allow light to leak around the perimeter of the dots on the negative exposing larger areas of the photopolymer. The measurement error on the other plates was otherwise small. If the dot area from plate 1 is ignored, the largest differences occurred between plates 3 and 4 where a difference in dot area of $440.69 \mu\text{m}^2$ were observed.

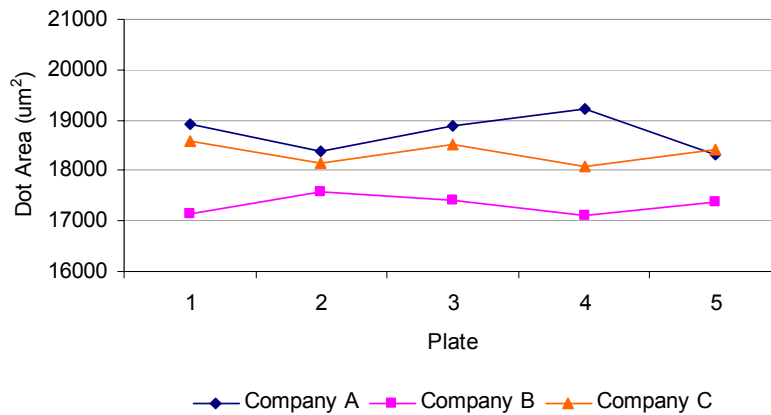


Figure 3 – Average measured dot areas for 50% coverages

Figure 4 shows the variation in dot size between the five plates for the 75% coverage. Company C was shown to have the largest dot sizes of the three companies participating in the investigation, with Company A having the smallest dot areas. Company B showed the least variation between plates, however the percentage error (Table 3) was not as low as for Company C.

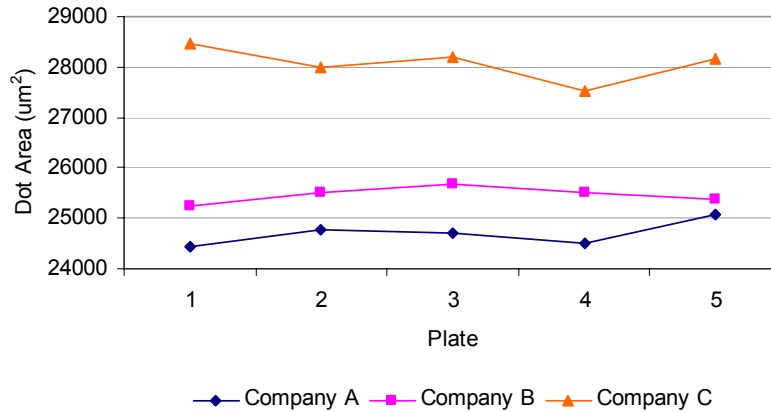


Figure 4 – Average measured dot areas for 75% coverages

The tone gain for the plates produced by Company A, Company B and Company C is plotted in Figure 5, Figure 6 and Figure 7 respectively. The plates of all three companies produced a tone gain, where the actual dot areas were greater than the specified dot areas. This is not uncommon in the production of conventional flexographic plate exposure due to some light leaking around the perimeter of the dots on the film negative, and therefore exposing a slightly larger area of plate. The tone gain on the plate would be compounded by the deformation of the dots in the printing nip, which would increase their area further, and the spreading of the ink on the substrate producing a higher tone gain on the print [3][4][5][6]. Compensation can be applied to the dots on the film negative to correct for the tone gain produced on the prints and therefore correct for the increase in dot area incurred during all of the stages of print production. Due to the conditions under which the investigation was performed, with each company manufacturing the plates according to their own specifications, it is not known if any compensation was applied.

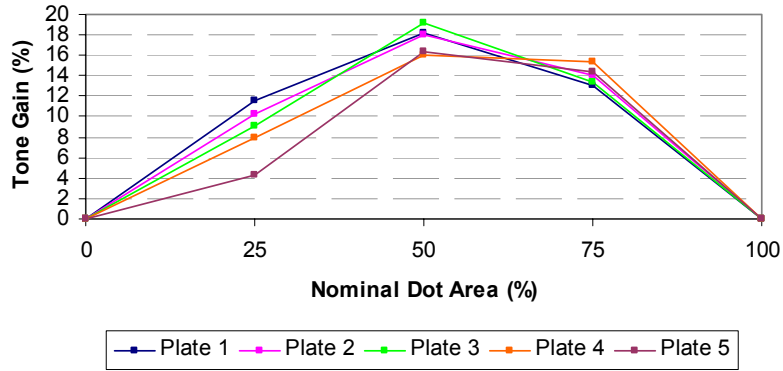


Figure 5 – Measured tone gain for Company A

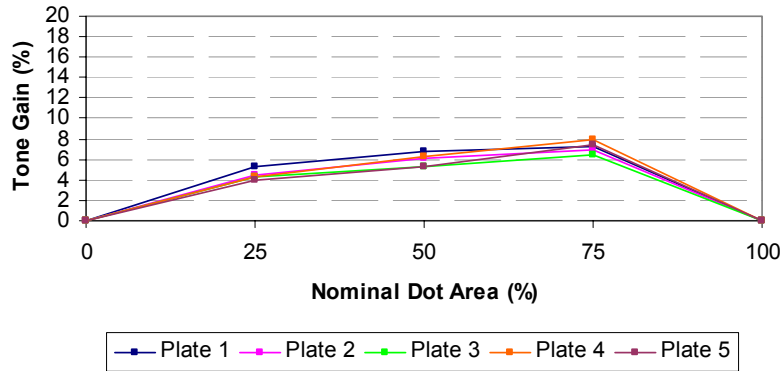


Figure 6 – Measured tone gain for Company B

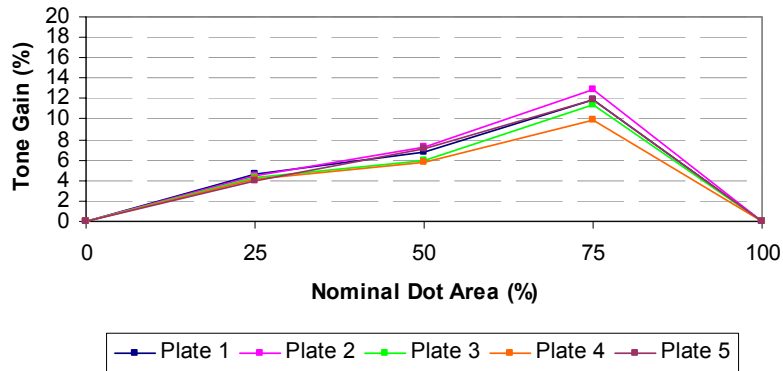


Figure 7 – Measured tone gain for Company C

For the plates of Company A (Figure 5), the tone gain was significant reaching a maximum of over 19% at the 50% patch, resulting in a percentage dot area of over 69%. If uncorrected this could produce a substantial amount of tone gain on the print. The tone gain for the plates of Company B (Figure 6) and Company C (Figure 7) were more modest reaching a maximum at the 75% coverage patches. For plate 1 of Company C the tone gain for the 75% patch was 12.83% therefore leading to an overall dot area of 87.83%. Combined with the increased tone gain due to deformation and ink spreading this could result in a 100% coverage being printed, leading to a loss of detail within an image.

Dot Depth

Plots of the dot depths for the different halftone coverages are shown in Figure 8, Figure 9 and Figure 10 for Company A, Company B and Company C respectively. The measurement error from all of the plates was typically less than $\pm 1\%$ of the overall height. The plates from all of the companies showed a reduction in the depth of the dots as the halftone coverage increased from 25% to 50% and 75%, although they exhibited different characteristics. The overall differences between plates for Company A were approximately 6 μm . The plates of Company B had the largest dot depths at approximately 80 μm for the 25% halftone. Plates 1, 3 and 4 were consistent with each other on all three patches, while plate 2 had a larger depth at 25% coverage. However, the dot depths on plate 5 were approximately 5 μm lower than the other plates. Company C's plates had the shallowest dot depths, approximately 37 μm at 25% coverage. The depth for plate 1 at 50% was significantly lower than the other plates within the set. This was due to lower depths being measured within the same small region of the patch discussed for the dot areas. This supports the hypothesis of the plate being overexposed within this small region during the main exposure. Overall the consistency between the plates of Company C was similar to those of Company A. This may be showing that both Company A and Company B exerted less control over the initial back exposure of their plates.

The different dot depths shown between companies' highlights the different processing procedures used. The lower dot depths of Company C suggests a relatively long back exposure time, while the larger depths of Company B implies a shorter back exposure and long front exposure times were used.

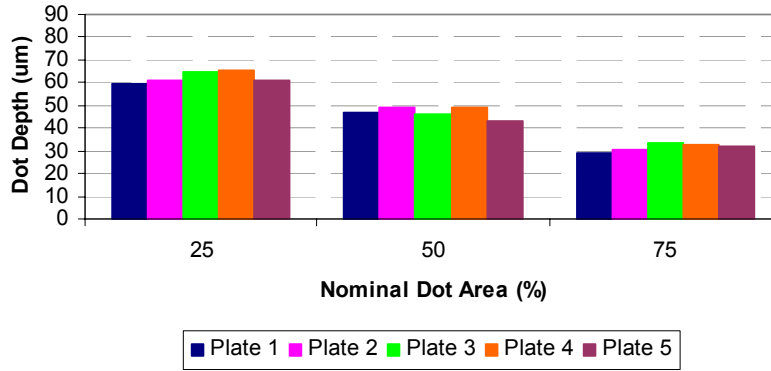


Figure 8 – Measured dot depths for Company A

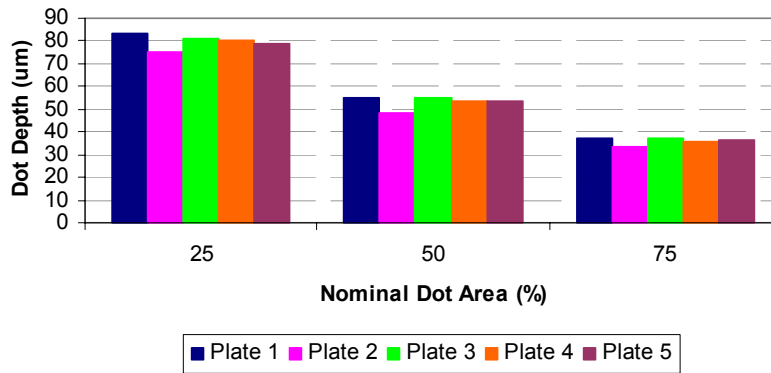


Figure 9 – Measured dot depths for Company B

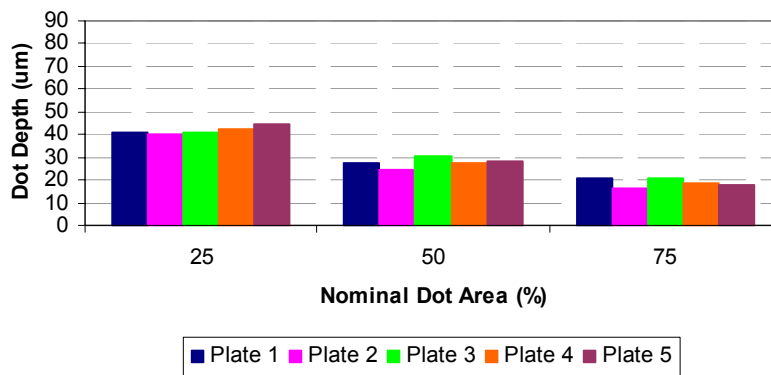


Figure 10 – Measured dot depths for Company C

Surface roughness

The average surface roughness and measurement errors for the plates of Company A, Company B and Company C are shown in Figure 11. Very large inconsistencies were found between the plates for Company A, with the average surface roughness (R_a) ranging from approximately 400 nm to 900 nm. It is likely that such differences in roughness between plates would result in some differences print quality due to differences in the amount of ink transferred. The measurement error was also relatively high, which shows large inconsistencies also occurring within each plate. The error was highest for plate 4 where the roughness ranged from 442 nm to 1250 nm. This could lead to printed colour differences being produced between different regions within the same plate.

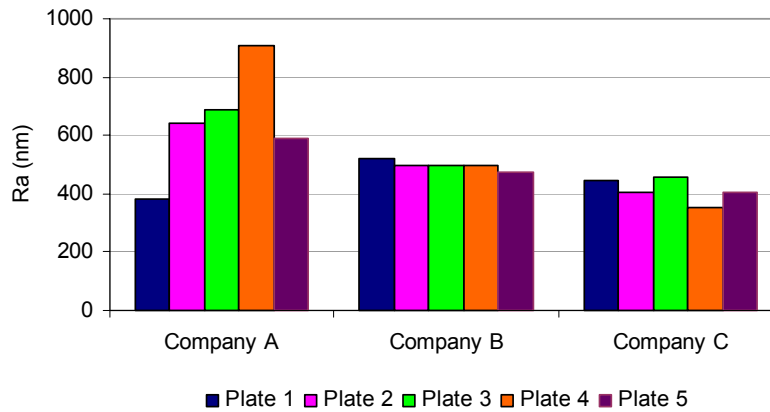


Figure 11 – Variation in surface finish

The plates of Company B were highly consistent in terms of their surface finish. The average roughness ranged from 471 nm to 520 nm between the plates. Low measurement errors were observed between individual measurement for each plate, which highlights the uniformity of the roughness within each patch. Overall the plates from Company C, were smoother than those from the other two companies, but less consistent than those of Company B. The surface roughness ranged from 350 nm to 445 nm between the plates. Each of the companies utilised unexposed plate stock from different manufacturers. The difference in the surface finish between companies was therefore likely to be mostly due to the properties of the different photopolymers used. However the differences between the plates of each set are likely to be due to differences in the processing conditions.

Material properties

The average Young's modulus of the set of plates of each company is plotted against vertical displacement in Figure 12. Due to the different photopolymers and processing conditions the plates from the different companies had different characteristics. The plate materials all remained within their elastic region during the testing. The strain hardening affect was more rapid for Company B's plates providing a harder plate, while those from Company C's plates were softer. The differences observed in the Young's modulus between plates thought to be significant particularly at higher displacements. This was investigated using the numerical models.

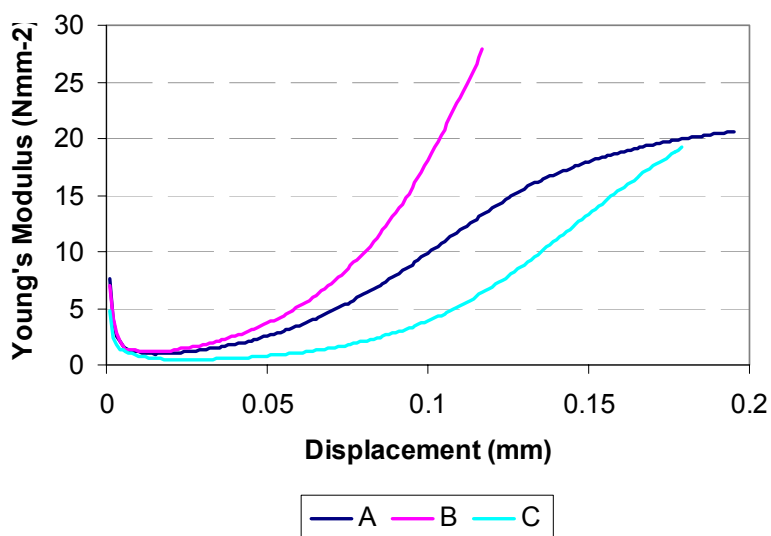


Figure 12 – Average Young's modulus for all three companies plates

The Young's modulus for the five plates for Company A showed the greatest inconsistency, with the differences between the plates increasing non-linearly with the displacement. Therefore the significance of not achieving consistent material properties could increase with increasing the impression pressure on a printing press. The material properties of the plates from Company C were the most consistent over the displacement range considered.

Surface free energy

The difference in surface free energy between plates relative to the mean, for all of the companies is plotted in Figure 13. While the differences in surface free energy have been examined, the significance of these differences in terms of ink transfer was not established. However, the majority of the differences between

plates fall within the estimated repeatability of the instruments' contact angle measurement of $\pm 2^\circ$, which equated to a surface energy tolerance of ± 1.3 . The majority of the differences appear therefore to be insignificant.

The surface free energy did show larger differences occurring between the different companies, which was attributed to the different photopolymers used, rather than the processing conditions. The plates from Company A had a lower surface free energy than Company B and Company C, which could lead to compatibility issues with inks with a high surface tension. This also suggests the surface free energy of the plates are not highly sensitive to small differences in the processing conditions used, but are more sensitive to larger processing changes such as the use of different photopolymer materials.

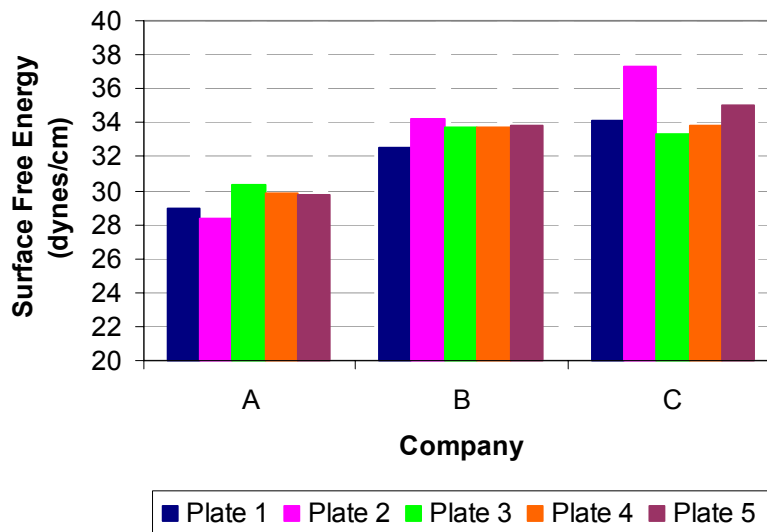


Figure 13 - Average surface free energy

Discussion

An experimental investigation has been performed to examine the consistency of the plate-making process. The aim was to provide a benchmark to the variability between plates due to fluctuations that can occur within a company's plate-making operation. White light interferometry was used to assess the consistency of dot areas; dot depths and surface finish within a set of five plates. Compression testing was used to examine the plates' material properties and dynamic contact angle analysis to evaluate their surface free energy.

The set of plates from Company A were the least consistent of the three companies participating. The measurements showed significant variation both within each patch and between the plates in terms of the dot area, surface finish and material properties. While these plates were not used as part of a printing investigation, the differences observed in dot areas between some the plates were such, that differences in the ink transfer from each plate and therefore the printed colour are highly likely to occur. While little previous research has been previously carried out to quantify how the surface finish of the plate affects the ink transfer, the magnitude observed within the plates of this set are likely to result in some variation in printed colour. The differences in the material properties are another area that could affect the performance of the plates. This could affect the deformation of the dots in the printing nip influencing the areas of the printed dots. The overall spread in the Young's modulus between plates was more than double the combined spreads of the other two companies.

The dot areas were more consistent on the plates produced by both Company B and Company C. Within each set the differences between plates were relatively small although they could be detected. Their consistency in the surface finish was also superior to that of Company A, although the different companies produced different roughness values. This was attributed to the different photopolymers used by the three companies, rather than as a result of the processing. The material properties plates were also more consistent. Overall the least amount of variation in dot area, surface finish and material properties were between plates of Company B, while a little more variation was observed in most of the tests in the plates of Company C.

A similar spread in the results for dot depth was observed within each set of plates for all of the companies. This was despite a very small measurement error for each of coverages. They also did not tie up with the fluctuations in the dot areas. This was probably due to the dot depth being influenced by both the back and front exposures of the plates and the washout, while the dot areas were influenced mainly by the front exposure.

The results from the surface free energy tests were inconclusive. The differences observed between the plates were similar to the measurement error of the instrument. This could be due to the choice of liquids used or the poor sensitivity of the instrument with regard to measuring photopolymer plates. Differences were however detected between the different photopolymers, which could lead to compatibility issues between inks. Larger differences were also detected between the material properties of the different photopolymers, which could lead to differences in the performance of the plates during printing.

Overall this investigation has shown variations can occur in dot areas and dot depths between plates, which highlights the need to quantify the dot geometries of the plates used for printing rather than using one set for printing and another for quantification. This further supports the use of white light interferometry for topographical plate measurements. Some of the likely variations in ink transfer resulting from the differences observed on the plates could possibly be compensated for through manipulation of the ink properties and press controls. However, this would be at the expense of production time and resources. The variation between plates has shown the need for maintaining a good control over plate-making operations and therefore the requirement for the plates to be quantified using a repeatable instrument prior to use.

Conclusions

As a result of this investigation, the following conclusions have been drawn:

- Consistency within the plate making process can have a significant effect on the quality of the reproduction of an image on a flexographic printing plate.
- Different tonal characteristics were observed between the different plate making companies. Local regions of larger than average dots for a particular tonal patch highlight effect of inadequate contact between the negative film and the plate during the exposure process.
- Surface roughness was shown to vary significantly for Company A, which will result in inconsistent ink transfer to the substrate during printing.
- Large differences exist between the material properties for the three different companies. These differences are a function of the photopolymer used in the manufacture of each plate type, rather than the result of variations in the exposure process.
- Results from the analysis of surface energy of the plates was inconclusive as the differences observed in surface energy were within the measurement error of the instrument.

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