Coating Structure Requirements for Improved Rotogravure Printability and Reduced Ink Demand

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Abstract

Rotogravure printing is the preferred method when large print runs are required, such as for catalogues. Penetration of ink into the paper is not desirable as this increases the amount of ink needed to obtain a certain print density. Thus the differences in ink demand between different papers have a significant impact on the economics of the process. In order to control the ink penetration and improve the print quality, paper is often coated with clay, talc or GCC. The extent of ink penetration depends on the structure of this coating and the characteristics of the ink used.

In this work, some aspects of the coating porosity were analysed with respect to ink spread and penetration. It was found that both the average pore size of the coating and the number of pores per unit area on the surface of the coating had a significant influence on the ink spread and penetration. Larger pores were found to imbibe the ink to a greater extent and this led to small dots and generally a lower print density. Conversely, coatings with smaller pores had a higher print density. When looking at a series of different coatings which had similar average pore sizes, it was found that those having the highest pore number per unit area had the lowest colour density print. Coatings which had larger printed dots (more ink spread) were also perceived to give a more even print.

A focused ion beam (FIB) was used to obtain cross-sections in order to visualise the penetration of ink into the paper. The more conductive nature of the ink used here compared with the coating gave high contrast between them, allowing easy assessment of the penetration. Ink is seen to have penetrated further into a paper coating with a 'blocky' morphology than one with a 'platey' morphology. This is consistent with the smaller dot area, lower print gloss and lower print density achieved on the blocky paper coating.

Introduction

Rotogravure relies on transfer of ink from cells to paper surface, primarily by surface tension effects. For this to be successful the substrate surface must be uniform and smooth. A compressible paper also ensures that there is good contact in the printing nip and aids the ink transfer process. In practise electrostatic assist is used to improve the transfer of the ink from the cylinder to the paper. One of the key measures of rotogravure print quality is the % of missing or 'skipped' dots. A high number of missing dots decreases the quality of the printed image. Other requirements of a rotogravure printed paper are a high print gloss and print density and an even, mottle free finish.

The scale of the smoothness required is often debated, but one reference suggests that it should be of the order of the dot size or greater (~70-100 µm). Gate [i] used a Talystep profilometer and stereological SEM images to study the relationship between depressions in the coated paper surface and the instances of missing dots. Depressions of greater than 0.5 µm (under zero load) were found not be smoothed out by the pressure of the printing nip, and the most frequent surface depression depth associated with missing dots was found to be 2 µm below the mean surface plane. This size range is generally associated with basepaper fibres, paper formation and coverage of these fibres by the coating colour. The coating colour components, namely the particle size distribution and shape factor of the mineral components, together with the formulation and mode of application have a significant influence on the coverage of the basepaper, the topography of the final sheet and also the compressibility of the paper. Endres [ii] showed that missing dots occurred in 'valleys' or low areas situated in close proximity to load bearing areas such as points where fibres cross over.

Bulky pigments have often been used to generate a compressible sheet to lower the % missing dots [iii],[ivv].

Ink consumption is an important aspect of the economics of the rotogravure process and is related to the hold out of the ink. If ink is found to overly penetrate into the coating layer, the print density of the surface layer will decrease and consequently more ink will be required to reach the specified print density. Thus, slight differences in the ink distribution in the z-direction of the paper will have a significant effect on the cost of the final print job. Platey materials have been cited as being good for this aspect as they effectively close the sheet thus hold the ink on the surface [vi].

The technique of focussed ion beam (FIB) has previously been used for preparation of thin sections of paper by Uchimura *et al*. [vii],. These sections were subsequently analysed by the EDX attachment on a SEM. The authors showed that the paper sample did not suffer from the usual structural changes or artefacts associated with resin embedment. In a more recent paper, Uchimura et al. [viii] further developed the technique to differentiate between ink pigment and ink resin by first treating the printed paper with osmium tetroxide. This attaches to the double bonds in the ink vehicle and allows the detection of the ink vehicle alone by techniques such as EDX. The ink pigment (barium sulphate) was also detected directly by the EDX technique. They showed that in screen printing the ink pigment was held on the surface of the substrate, but that the ink vehicle penetrated into the centre of the paper.

In this work, a large number of coated papers which had been produced using a wide variety of different clays and calcium carbonates were used to explore the influence of coating porosity characteristics on rotogravure print gloss and density. For each of these papers the coating pore size, pore volume and number of pores per unit area was measured using mercury intrusion porosimetry. The rotogravure print quality in terms of the print gloss and density was then determined. Focussed ion beam was used to help visualise differences in Z direction ink penetration into selected coated paper surfaces.

Samples

A wide range of coated papers were measured as part of this study. Many of the samples had been characterised in detail as part of earlier studies [ix]. The coatings contained a number of mineral types, including platey, blocky, fine and coarse kaolins, precipitated calcium carbonates (PCCs) and ground calcium carbonates (GCCs). These pigments were pilot-coated individually and in blends, in similar formulations, and at a similar coat weight on 80 gm^{-2} woodfree basepaper. The coatings were applied at 1000 m/min using a roll applicator, blade metering device (Valmet Autoblade^{TM}). The coated papers were then passed through an 11 nip supercalender (Kleinwefers AG Germany) at a speed of 800 m/min, a temperature of 100°C and a linear pressure of 300 kNm^{-1}.

The general coating formulation was as follows: 14 gm^{-2} coating on both sides, 11 pph styrene butadiene latex (DL950^{TM}), 3 pph starch and 0.5 pph calcium stearate.

Samples presented in Figures 4, 10 and 11 were from another coating study. These samples were coated using a laboratory Helicoater^{TM} onto a commercial LWC rotogravure basepaper at 600 m/min. The coatings were blends of 80:20 kaolin:talc and contained 5 pph Acronal 410V latex.

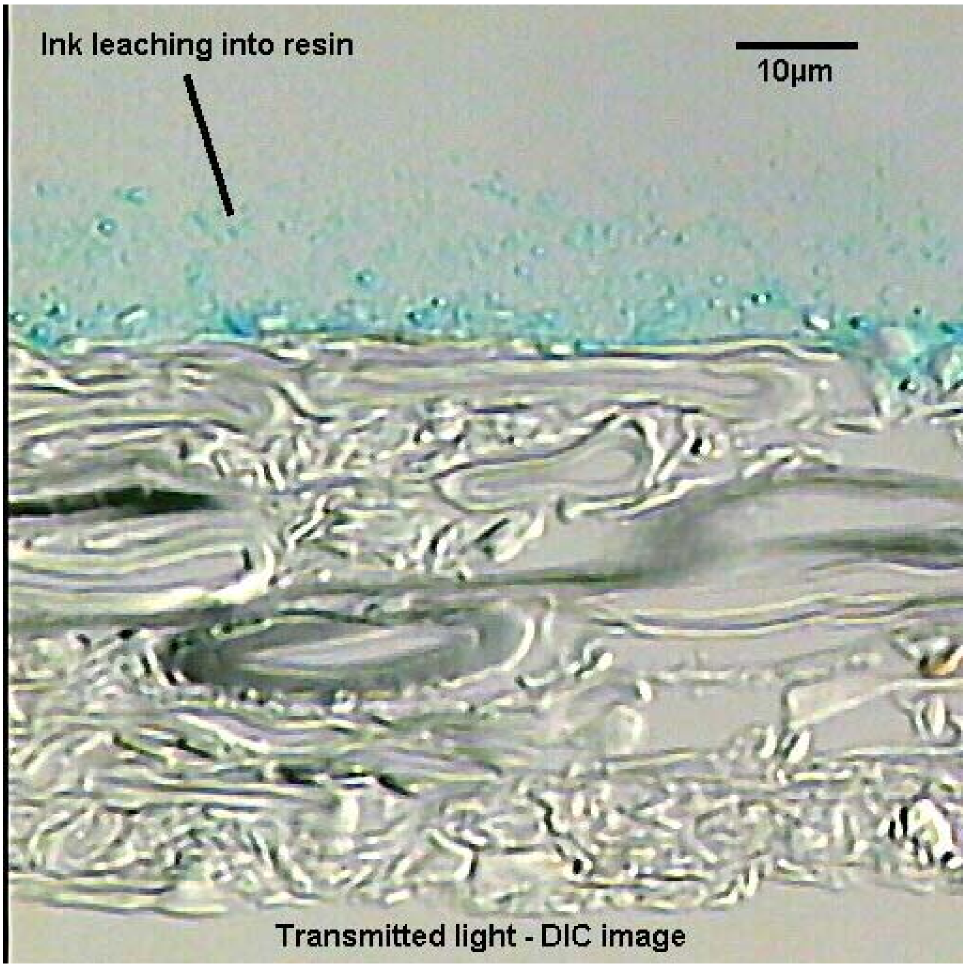
Methods

The paper samples were printed on a laboratory scale Winstone press, as described by Swan [x]. Print gloss was measured using a Hunter glossmeter as described in TAPPI standard T480, and the print density using a Gretag densitometer (D186 Zurich).

Mercury intrusion porosimetry (using a PASCAL 240 Porosimeter, CE Instruments) was used to determine the average pore size of the coating layers. Curve fitting programs were used to subtract data for the coating from those of the basepaper. This is described in more detail in reference [xi].

Electron microscopy has been used for many years to help visualise the pore structures of paper coating layers [xii], and usually involves embedding the substrate in a resin and making cross sections using an ultra microtome or by grinding the surface. However in this case conventional sectioning techniques, where the paper is embedded in a polyester resin before sectioning, were not possible as the ink appeared to be soluble in the resin (Figure 1).

Figure 1. SEM cross section showing rotogravure ink leaching into the embedding resin



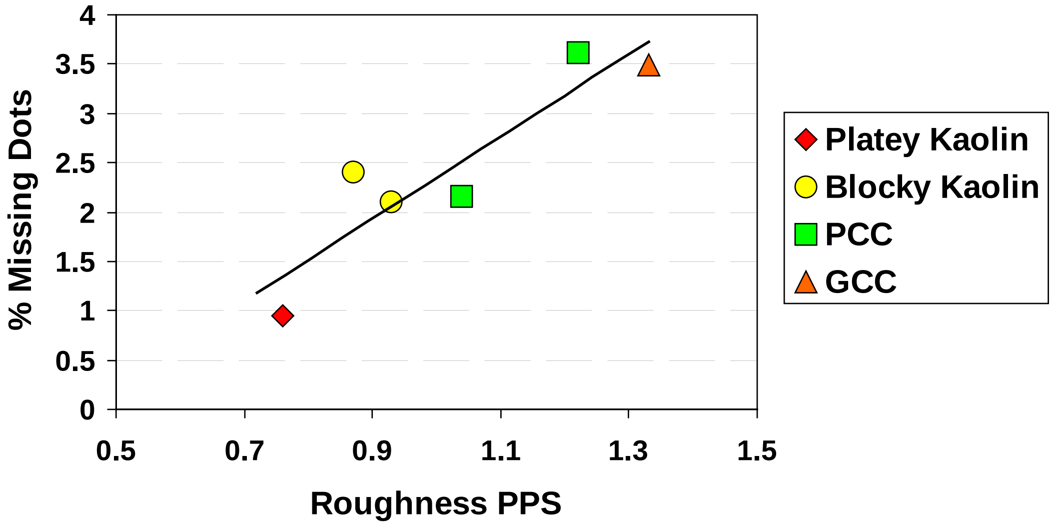
For this reason an FEI FIB201 gallium focused ion beam instrument was used for sectioning, high-resolution imaging and for TEM sample preparation. The instrument is capable of producing a gallium ion beam of between 7nm (at 1 pA beam current) and 300 nm (at 12 nA) in diameter at 30 keV energy. A platinum organometallic gas injector allows ion beam assisted deposition of platinum over selected areas of the sample. This facility was used prior to the sectioning shown here in order to protect the top surface of the sample during ion milling. For sample sectioning, a large ion current was used initially to remove a staircase-shaped trench. A finer beam of lower current was then used to ‘polish’ the larger vertical face of the trench by scanning the beam in a line and moving it progressively up to remove further material. The sample was then tilted to 45° and the polished face imaged using the same ion beam, generally at a much lower beam current to achieve high resolution. Two clay coated, printed samples were selected for examination of ink penetration using this technique; one clay having low aspect ratio ‘blocky’ particles and the other, high aspect ratio ‘platey’ particles.

Results and Discussion

Percent Missing dots

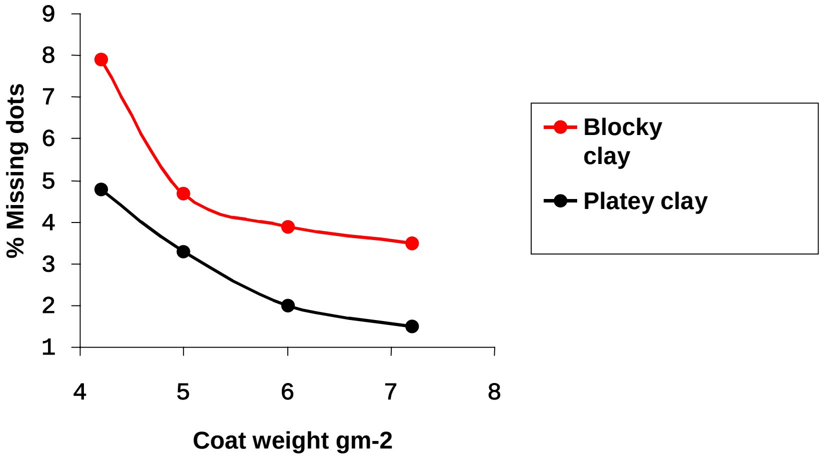
The most important paper property for influencing % missing dots is the topography of the paper whilst under the printing nip. In order to obtain good contact between the substrate and the cells in the printing cylinder, the substrate should be smooth and compressible. Good correlations between Parker Print-Surf (PPS) roughness and % missing dots have been reported by several authors (xiii) and this is shown in Figure 2.

Figure 2. For single mineral component coatings a good correlation existed between the % missing dots and PPS roughness. Smoother samples gave lower missing dots



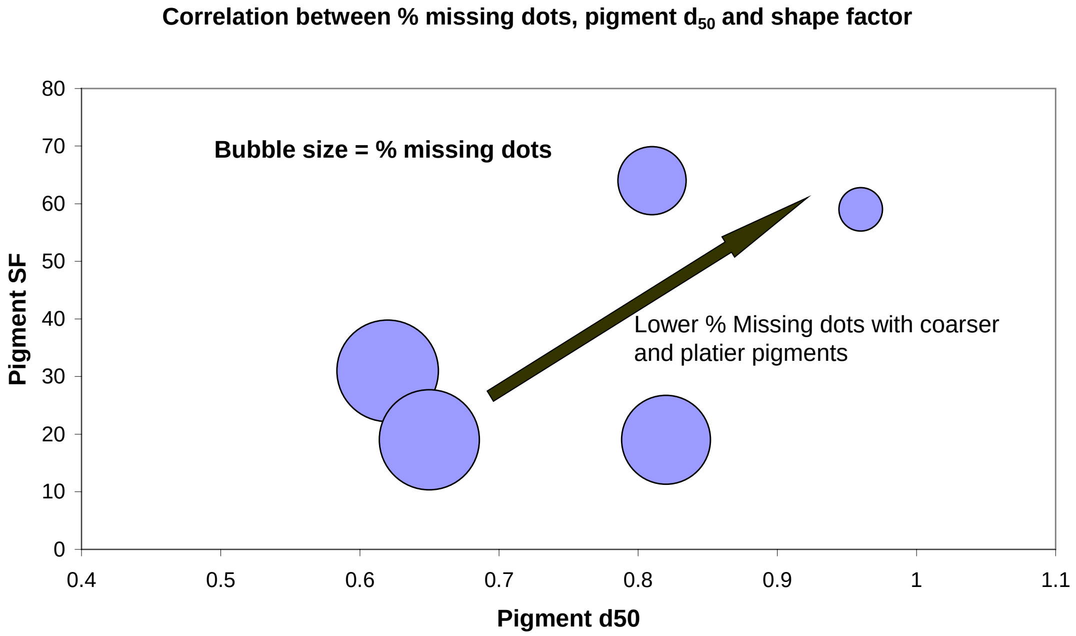
In general, coatings containing pigments with a higher aspect ratio tend to be more compressible and will often give lower levels of missing dots than a blocky shaped kaolin coating pigment (Figure 3). Increasing the coat weight also decreased the % missing dots, probably due to a smoother coating layer.

Figure 3. The influence of coat weight and kaolin SF on % missing dots.



In general it can be seen that lower % missing dots are given by coarser and platier kaolins as shown in Figure 4.

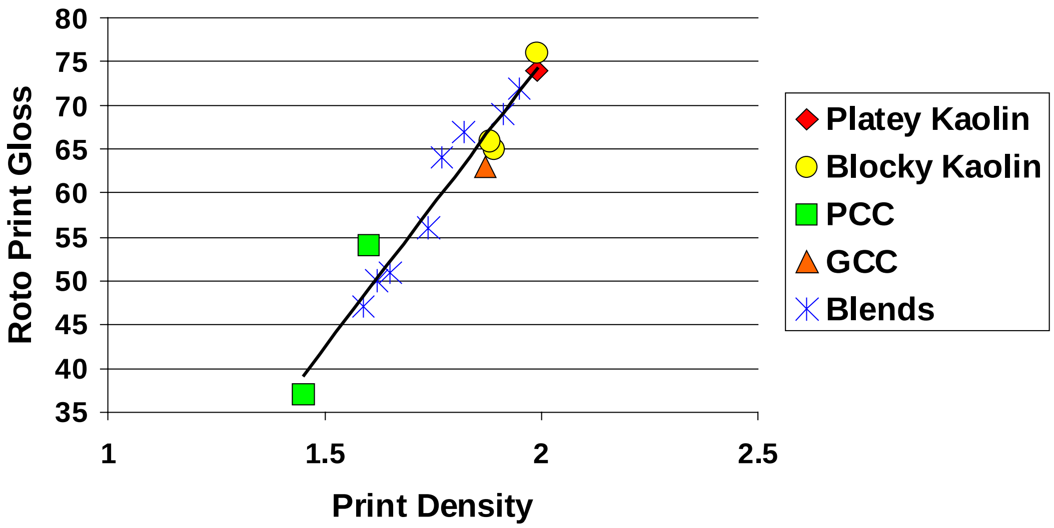
Figure 4. Coarse and platy kaolins give lower % missing dots



Print gloss and print density

In rotogravure printing, the print gloss is determined largely by the topography of the surface (sheet gloss) and also by the hold out of the ink on the surface. The rate of ink drying has less effect on the print gloss than with offset inks, however it has been reported that the dots themselves can be measured as standing 'proud' of the sample surface and can thus contribute to the gloss of the print [vi]. The authors suggest that there is a film split pattern on the surface of each dot, which can be worse if the coating sets the ink fast. For the gloss papers studied here, the key influence on the print gloss appeared to be the print density. If the ink is held out on the surface of the paper, both a high print density and gloss result (Figure 5).

Figure 5. Prints with a high print density also had a high print gloss



In Figure 6, the print density of the samples is plotted as a function of the average coating pore size. It can be easily seen that for a wide range of different pigment types, there is a general trend of decreasing print density with increasing pore size. However there are a number of points, circled, which have the same average pore size, but still have different print densities. In Figure 7, the subset of print densities circled in Figure 6 are plotted as a function of the sample's number of pores per unit area. It can clearly be observed that the pore density of the coating is also an important factor, with a higher number of pores per unit area giving a lower print density. One way of reducing the surface pore density is to use a high shape factor mineral such as a platey clay or talc. Blending calcium carbonate with a proportion of clay can help to reduce the penetration of ink into the coating and also increase the print density.

Figure 6. Coatings with large pores generally had a lower print density. However there are a group of coatings with similar pore sizes and very different print density values (circled)

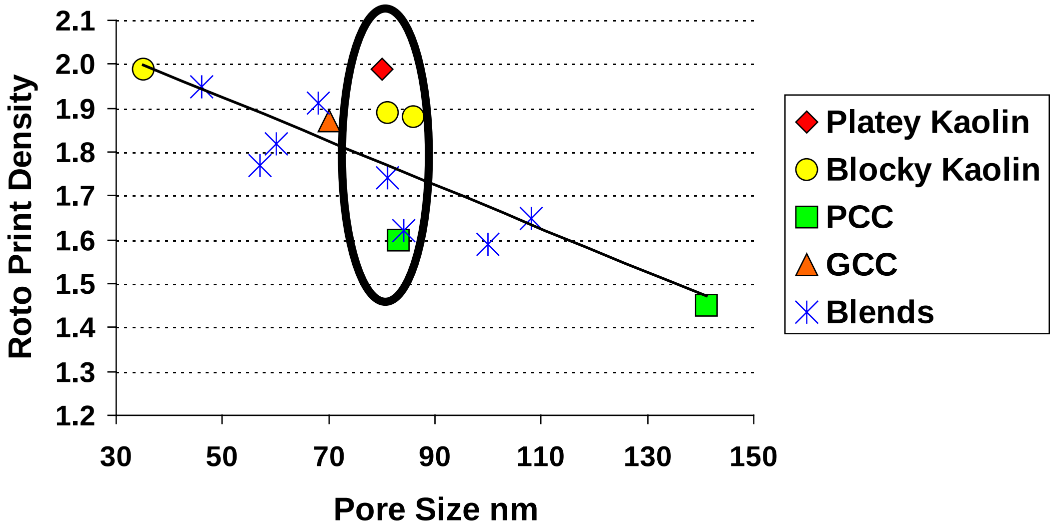


Figure 7. The number of pores per unit area is also important. These papers all have a pore size of approx 80 nm.

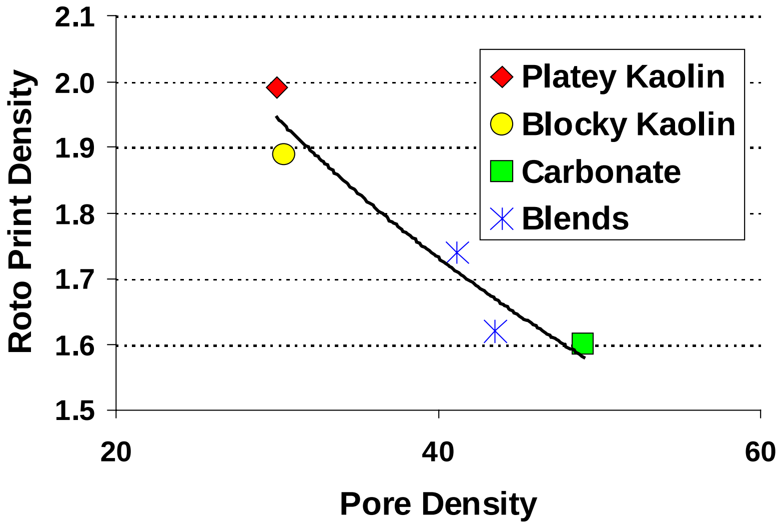
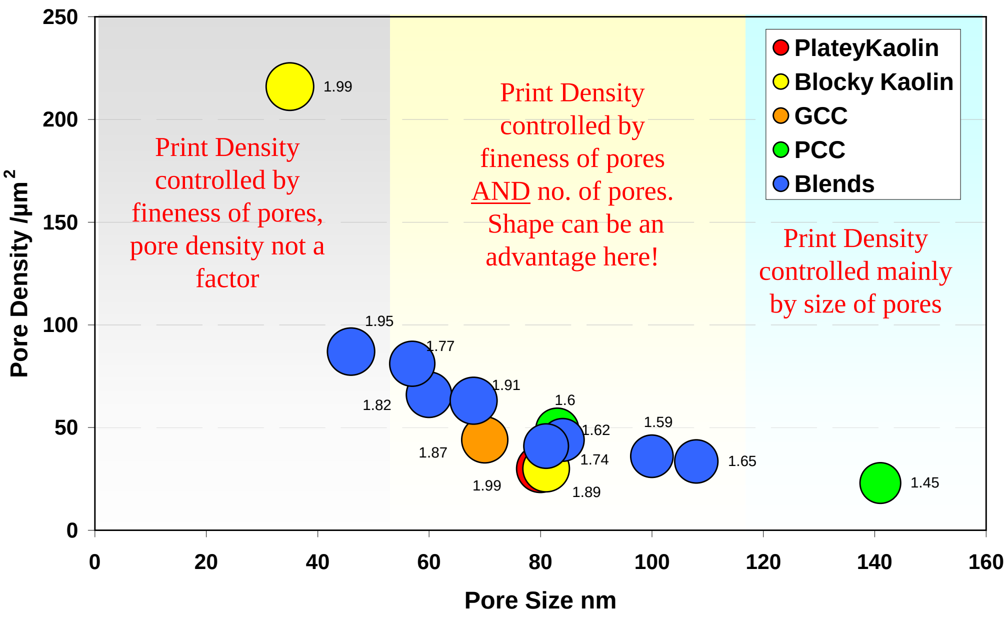


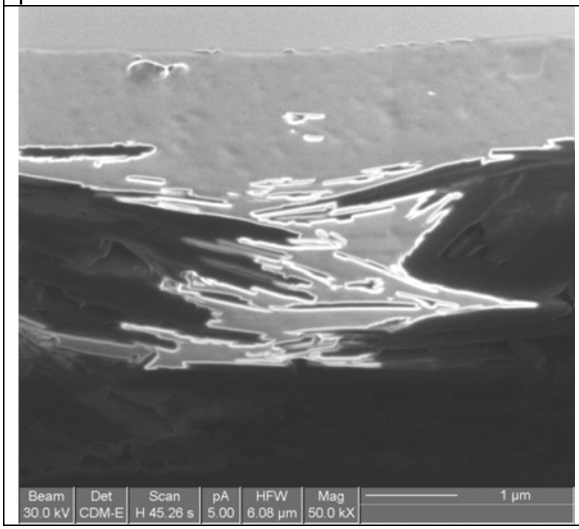
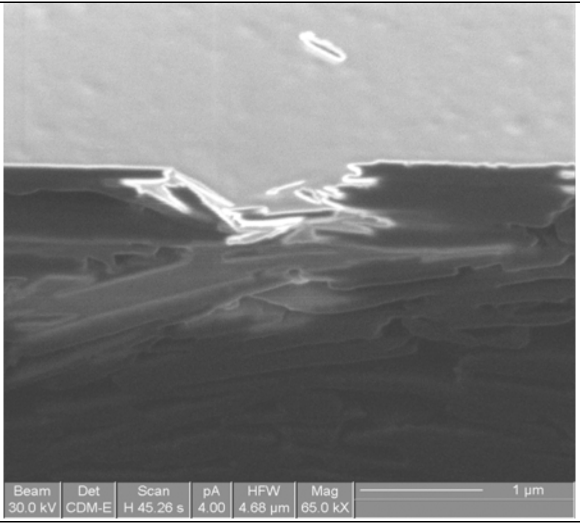
Figure 8 shows the combined influence of pore size and pore density. The print density is also given as the bubble size, and the different colours depict the different types of pigments. It can be seen that there is a general trend of samples which have small pores having a larger number of pores per unit area.

The data fall into 3 distinct regions. Where the pores are very small and numerous (far left of Figure 7), it can be seen that the print density is high despite the fact that the samples have a very high number of pores per unit area. In this instance it is probable that the pores are too small for significant penetration of the ink, and this causes it to stay on the surface of the paper. In the middle section of Figure 7, there are a number of samples which have pores that are sufficiently large to imbibe the ink. In this pore size range, the number of pores per unit area becomes important, and the print density decreases as the pore size and pore density increases. For very large pores, it is the pore size which is likely to dominate.

Figure 8. Influence of pore size and pore density on print density – Print density figures are the numbers next to the bubbles



Images from the two coatings printed with rotogravure ink are shown in Figure 9. The ink layer is most conductive and shows up as a white layer, with the less conductive kaolin plates beneath appearing black. Paper (a) on the left is coated with a blocky kaolin, compared to a platey kaolin coating (b) on the right. There is more penetration of ink into the blocky clay coating.

Figure 9a . Sample a. FIB section through clay coated paper printed by rotogravure. Low aspect ratio clay allows substantial ink penetration.	Figure 9b. Sample b. FIB section through clay coated paper printed by rotogravure. High aspect ratio clay showing slight ink penetration.
	

Print density, dot area and print evenness

There is also a clear relationship between the print density of a halftone printed area and the dot size (Figure 10). Bigger dots are found to occur with coatings made with coarse and platey pigments (Figure 11). These results agree with those found previously, for example by Gane and Hooper [vi], who showed that there is a strong relationship between dot area and print gloss and density, and that dot area is determined by the spreading characteristics of the ink. A fast absorption rate of the ink resulted in smaller dots and a lower print gloss and density. Dilution of the ink to a low solids level increases the imbibition rate into porous and open coatings, but into platey clay coatings to a much lesser extent.

Figure 10. Larger dots result in a higher print density

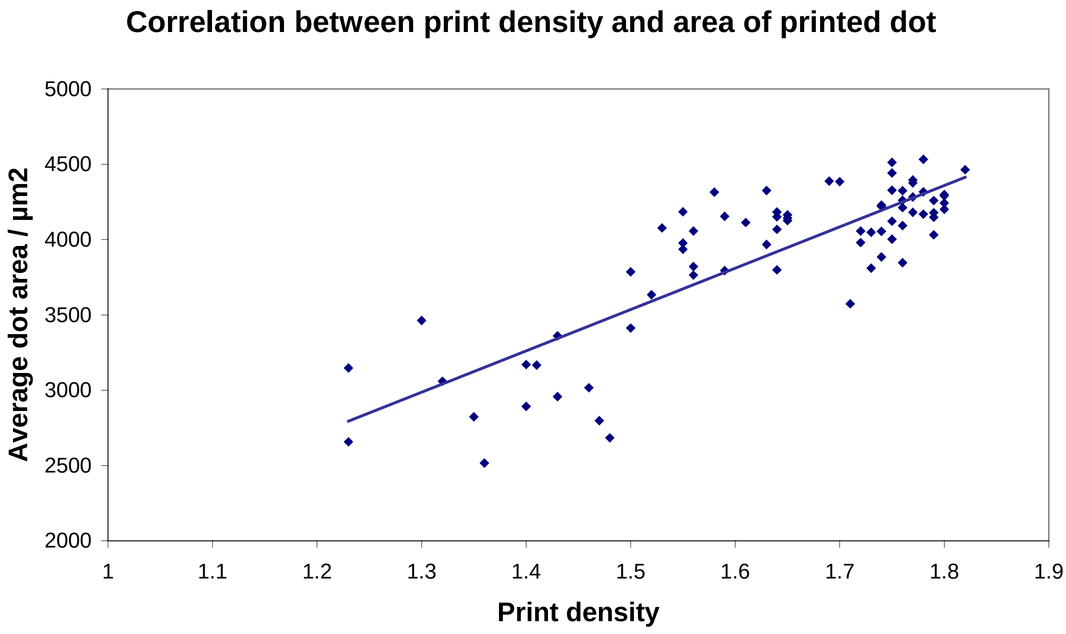
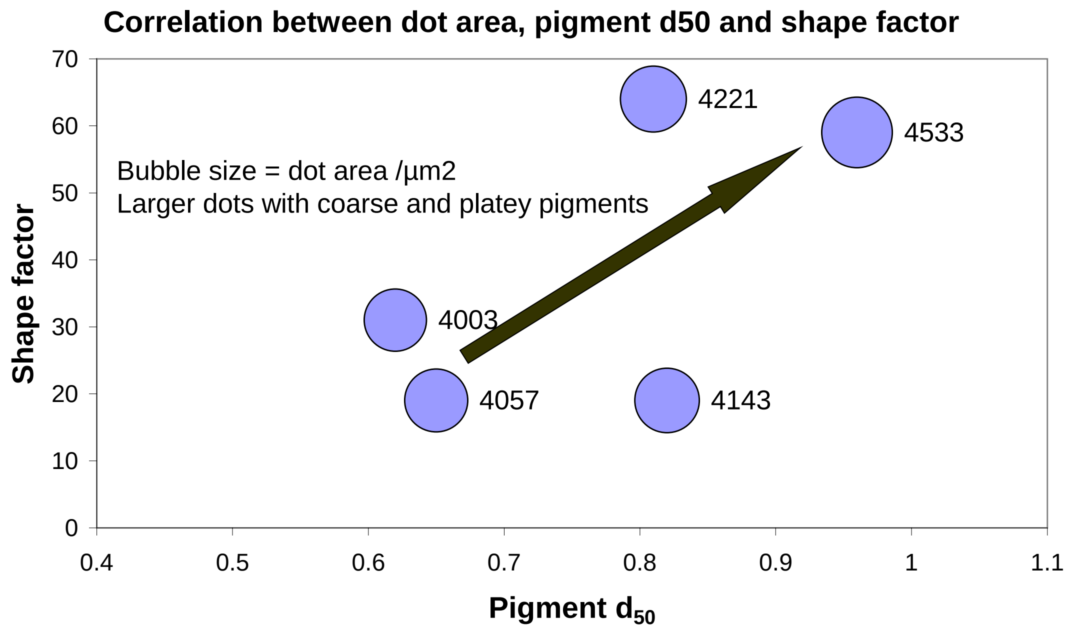


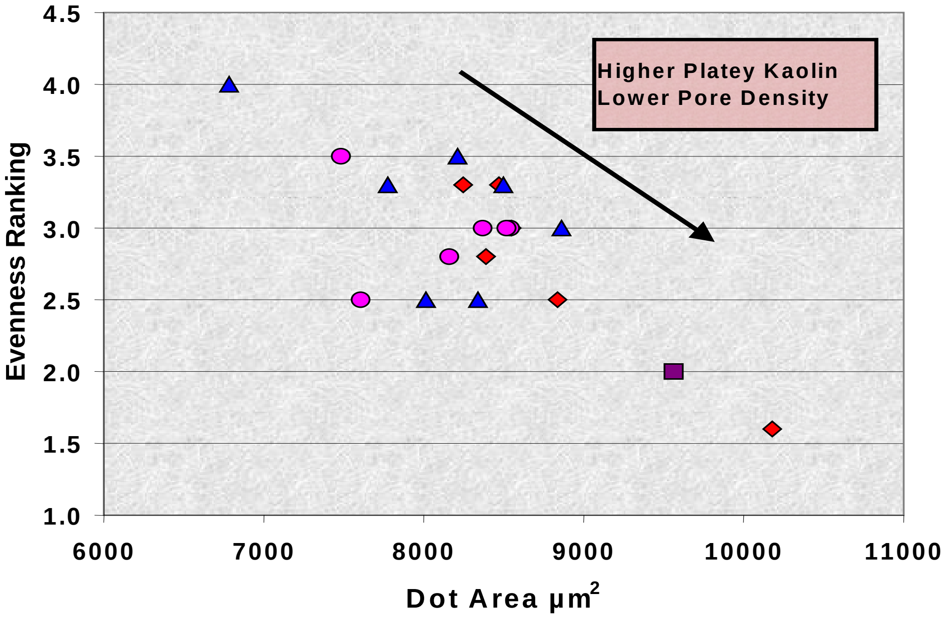
Figure 11. Coarse and platey pigments give larger dots



Dot spread partly occurs due to the surface tension effects causing lateral spread of the dot and for any rough topography there will always be some spread of the ink. The degree of spread will be a balance between the wetting and surface tension and the porosity of the paper, which will impact the ink imbibition. Absorption is significantly faster into coatings with a low tortuosity, such as those produced by blocky, low aspect ratio particles.

Larger dots have also been cited as producing a more even print and this is also shown in Figure 12.

Figure 12. Relationship between visual evenness ranking and rotogravure printed dot area



Conclusions

This work has highlighted the important pigment parameters in producing rotogravure papers.

Percent missing dots was once again are shown to be closely related to the topography of the sheet with a smooth and compressible paper giving the best results. Print gloss and print density are related to the hold out of the ink on the sheet surface, and this is also a crucial factor in determining the ink demand of the paper and the economics of the printing process. Nonporous surfaces with small pores and few pores per unit area on the surface of the substrate were shown to be the best for ink hold out in accordance with previous findings. If the ink remains on the surface of the paper, the dots also tend to be larger, and the print may appear to have a greater evenness.

The technique of FIB has been shown to be a good tool for visualisation of ink penetration into the coated paper surface. These images can be used in conjunction with other results to determine the ink demand of different papers.

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