Investigation into the Causes for Dot Bridging

David Galton* MSc

Keywords: Characterisation, Flexo, Interaction, Photopolymer, Standardisation, and UV

Abstract: Commercial pressure has forced improvements in the reduction of press down time, due to cleaning of flexographic printing plates during the print run. One restraining factor for the flexographic printing process has been the lack of predictability and consistency.

It was perceived that in order to make a significant improvement to flexographic printing efficiency, a reduction in the number of press stops due to plate cleaning would be desirable. The aim of the experiment was not to define the optimum printing condition. The experiment was designed to improve the understanding of the characteristics and properties of the interaction of several of the key components used during the printing process. By identifying the optimum characteristics of key interacting factors affecting printing consistency, it was thought that production efficiency would be improved.

Investigations into the complex interactions of many variable factors that take place during the printing process were carried out. Various statistical methods were employed for the design of the experiment and for the interpretation of experimental data generated.

A two level factorial experiment was designed to include all of the key components used in normal production. Due to the experiment being conducted in a print-works, time restrictions were applied which meant that a fraction method of experimenting was preferred. Some components such as the print units used and the printing pressure were kept constant. Other factors such as ink, Anlilox roller, plate and press speed, were varied. The conclusions from the experiment are reported and highlight the preferred properties for each of the key components used in the experiment, which deliver improved printing performance and consistency.

Introduction

The flexographic process is the principle printing method used by the packaging market. Commercial pressure has had the effect of increasing the technical demands/capabilities of the production process. The current preference for many print buyers is to insist that their packaging is printed using Computer to Plate technology and the latest flexographic printing techniques. For many applications

*Asahi Photoproducts (UK) Ltd, 1 Prospect Way, Wash Road, Hutton, Brentwood, Essex, CM13 4XA, England.

CtP plate is not the most efficient technology to use. In recent years increased competition from this emerging new technology has shifted the research emphasis to finding solutions, methods and techniques, which will improve production efficiency. Control of analogue platemaking techniques has been found to be the most significant factor to improving production consistency in order to compete with the image quality demonstrated by CtP technology.

Typically the current flexographic print quality demanded by many print buyers is expected to match the print quality of other more established printing processes such as Gravure and Offset Litho. Traditionally the calibration for each stage of the flexographic printing process has been carried out using separate tests based on empirical results treating each process as a separate step. Using a calibration technique that obviously does not take the interaction of each stage of the process into consideration, needs small margins of safety built into each process. Often this technique prevents the printing process from being optimised. It is common practice for many printers to rely on the technical expertise of their suppliers. Manufacturers and suppliers often recommend processing conditions, which are best suited to their individual products but this does not take the interaction with other products used in the production chain into consideration. The products selected for the evaluation reported here, were chosen on the basis that they were the standard materials used by the printer. The printer was under commercial pressure to improve efficiency and compete technically with high quality images produced by the CtP plate technology. The demand for enhanced print quality from the analogue plate was thought to increase the incidence of dot bridging in half-tone areas of pictures. The research was focused on trying to understand the variables associated with the elimination of the printing fault. The experiment was designed to include all of the interacting factors, which were thought to provoke the dot bridging print fault. Mathematical tests of hypotheses procedures were used to determine whether observed data differ significantly from the results expected and thus determine if the set hypotheses should be accepted or rejected. The results of the analysis are designed to be used to characterise the factors, which will result in less press stops for plate cleaning.

Sample data gathering

A combination of sampling theory, probability theory and statistical inference, was used to determine whether the observed differences in the data relating to the factors included in the experiment, were due to chance variation or if they really were a significant factor provoking the dot bridging print fault.

A small pilot test was conducted to establish the range that would be used for the upper and lower levels for each factor used in the experiment. The small test established the levels that would provide the useful data for materials under investigation. Data was subjected to two proving tests, to ensure that it was reliable.

Proving Test N<u>º</u>1 was used to indicate how many readings were required to be taken from each sample. A standard margin of error equation was adopted to ensure an appropriate sample size was obtained for each of the properties being investigated. An error level was set of between 1%-2% in the raw data gathered, this was included in the result field in the Minitab software.

Proving Test N$^{\underline{0}}$2 due to the small number of Tests (8) involved in the experiment it was not always possible for the Minitab software to display a clear histogram of normal distribution. Prior to the data being entered into the Minitab software a standard equation was used and referenced against a published confidence of normal distribution table. During the data gathering, each of the measurement points was selected randomly for the required number of measurements to satisfy the error criteria of Test N^{0}1 to ensure that the true underlying value was recorded.

Measurement methods

Dot bridging is the effect of halftone dots being joined up with ink on the printed sample as shown in Figure 1. The print fault is typically associated with the flexographic printing process and is usually only visible in the quarter tone areas of half tone pictures.

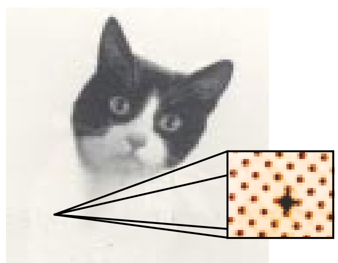

Figure 1 Illustration of dot bridging

Prior to this experiment being conducted the printer had tried several empirical experiments to establish the main causes for the dot bridging without success. The normal flexographic printing technique was adopted for this experiment. The press was a standard Primographic UV flexographic printing press. The term Primography denotes a hybrid printing press. The term Primography is applied to presses which print using the flexographic printing system (ink is applied to the plate via an Anilox roller) but have the capability to run paste or thixotropic inks. The press used for this experiment was a standard production machine, due to this fact it was not possible to accurately measure some of the test variables such as Anilox to plate pressure and impression pressure. To be able to make a subjective assessment of these variables, visual elements were incorporated into the design of the printed image. The doctor blade angle was pre-set for the duration of the experiment. The dot bridging problem did not manifest itself until a considerable amount of material had been printed, which inevitably extended the time taken for each test of the experiment, thus a fractional factorial design was adopted. The data was generated by careful analysis of the printed sheet after the dot bridging was first apparent on the print. Four printing characteristics were analysed from the data produced by the eight tests as follows:

Dot Bridging:	quantified by the number of metres printed
Print Contrast:	quantified using a reflection densitometer
Dot Gain	quantified using a reflection densitometer
Best Print	quantified subjectively

To maximise the amount of data gathered during the limited time allocated for the experiment the plate cylinder was segregated into two separate halves (gear side and operator side). By adjusting the design of the experiment from an eight-test experiment to a non-orthogonal sixteen-test design, substantially more useful data was generated. The plate type parameter was the only factor that was manipulated. As can be seen from the results shown in Table 2 the experiment was manipulated to give two replicates. High Shore hardness plates were placed on the gear side of the press and low Shore hardness plates were placed on the operator side of the press.

Due to space restrictions only the Dot Bridging results and Print Contrast results are discussed in detail in the report.

Table 1 The basic factorial designed experiment

C1 Test Order	C2 Test N0	C3 Ink/ Viso	C4 Anilox	C5 D/Blade	C6 Plate/T	C7 Plate/ RD	C8 Tape	C9 Speed
4	1	+	+	-	+	-	-	-
7	2	-	+	+	-	-	+	-
6	3	+	-	+	-	+	-	-
2	4	+	-	-	-	-	+	+
8	5	+	+	+	+	+	+	+
1	6	-	-	-	+	+	+	-
5	7	-	-	+	+	-	-	+
3	8	-	+	-	-	+	-	+

The factorial experiment shown in Table 1 has 7 variable factors, which are labeled under the column heading C3-C9. The design is a two level experiment represented by the +/- symbols.

The photographic test image

The 100mm x 150mm test image shown in Figure 2 was created on an Apple Macintosh iMac using freehand software. The design was influenced by the need to provoke the dot bridging problem. The 60^0Anilox roller dictated that 133 lines per inch for the test image would generate the best quality print characteristic data. Screen ruling for the tone wedges using circular dot screen technology was set at a 45^0 angle. The negative was output onto Agfa 0.004" red laser sensitive matt Rapid Access film. The AGFA Impress Rapid Access hard dot film was processed in Agfa ACD Rapid Access chemistry. Kodak RA Fixer was used to ensure that all of the clear areas of the film did not exceed the D min 0.06. The film density was D max 4.25 and D min 0.04. A typical trade standard (rapid access) photographic negative was made with a complicated image constructed to test the process to the limit.

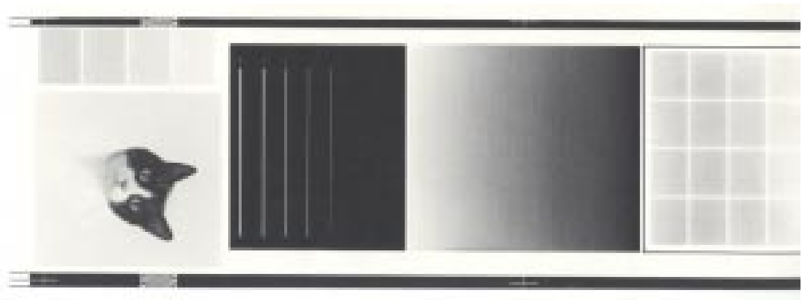

Figure 2 The experiment test image

5mm bearer bars were included in the design to ensure that the whole image had even printing pressure applied to the surface of the plate. Two large impression targets were included to give a visual check of the correct printing pressure on the plate during the printing test.

Equipment and materials involved in the trial

Image setting equipment used for the production of the test negative.
The image shown in Figure 2 was output onto film at 2400 dots per inch via an Agfa SelectSet Avanttra 25S laser image setter. The image was formed by a red diode laser 650 nanometers wavelength. Resolution was set at 2400 dots per inch.

Equipment for platemaking.
The platemaking process was split into five stages namely exposure, washout, drying, stabilisation, post exposure/de-tack. Each stage is completed in its own independent unit. Relevant information of each of these units is given as follows:

1) AFP 912 Fast Frame.
Fast Frame single sided exposure technology was used for the experiment. The unit was fitted with Philips 140 Watts UV A Lamps. The back exposure was controlled by a light integrator via an exposure computer. A timer controlled the main exposure. The plate exposure was quantified by measuring in milli-Joules of UV-A energy (365nm) using the following equation:

$$\text{mJ quantity} = \text{UV quantity (mW/cm}^2) \times \text{exposure time (seconds)}.$$

2) AFP 912W.
The washout unit was fitted with a programmable logic controller (PLC) computer, which controlled all machine functions to ensure repeatability. Solvent replenishment was automatic for the duration of the experiment. The computer controlled washout speed and brush pressure settings.

3) AFP 912D.
The drying unit had controlled temperature and forced air regime.

4) AFP 912S.
The plates rested in the stabilisation unit for approximately eight hours in ambient airflow, in an attempt to achieve original plate tolerance.

5) AFP 912F.
The finishing unit was fitted with two banks of lamps set at 90°. One bank used the same lamps as fitted to the main exposure unit (UV A). The other bank of lamps was of a shorter wavelength at 250nm (UV C) and was used to de-tack the plate. Independent timers control both sets of lamps.

Solvent
The standard recipe terpentine solvent was used. Photopolymer plates have a thin protective membrane on the surface, which is dissolved by the alcohol used in the recipe. Once the protective membrane is removed the pre-polymer on the plate is dissolved by the solvent.

Conventional photopolymer printing plates were selected for the experiment.
(1) Two grades of conventional analogue printing plate were selected from the same manufacturer on the basis of Shore hardness. The low-level factor was Shore hardness 55 “A” the high level Shore hardness was 65 “A”.
(2) The plates were made with different relief depths. The low-level relief depth was .5mm and the high-level relief depth was 1mm.

Mounting tape selected for the experiment
Two different tape qualities of 3M Mounting Tape were selected from the same manufacture for this test. The high value tape was 1115 and the low value tape was1015. The tapes were selected on the basis of their compressibility.

UV Ink selected for the experiment
Intercolour
Ink Specification
One batch of standard Free Radical UV ink was modified for the test. The only difference between the two batches of ink was the level of viscosity. The viscosity was adjusted to 27secs and 40secs using oligomers.

Anilox rollers selected for the experiment
Anilox Specification
The high Anilox screen count was set at 800 lpi and low Anilox screen count was set at 700 lpi. The correct level Anilox factor was achieved for each test in the experiment by alternating between two different printing units. The units used were 3 & 5.

Doctor Blade selected for the experiment
Two types of steel doctor blade were selected for the experiment. A standard mild steel square edged blade for the low factor and a Lamella blade for the high level factor.

Printing Speed selected for the experiment
The dot bridging problem was thought to be related to printing speed. The low level printing speed was set at 35m/m and the high level printing speed was set at 100m/m.

Printing press used for the experiment
The printing press selected for this experiment was an APECO label press.

Substrate used for the printing test
The substrate was standard throughout the experiment.

Instruments used for the characterisation of the printed images

The film was measured using a Macbeth Gretag D200-11 transmission Densitometer. A Gretag D 19c reflection Densitometer was used to measure the ink density of the printed images. Using the Murrey-Davies equation, dot percentage was calculated and displayed by both instruments.

Software used for the experimental design and data analysis

A MINITAB software program was employed for the design of experiments and for analysis of the data collected. The MINITAB version 12 software program is a powerful statistical package that provides a wide range of data analysis and graphic capabilities. The exploratory data analysis functions were used in the compilation of this paper.

Analysis methods

The experimental data was analysed using analysis of variance techniques. Units of standard deviation (any value in a distribution can be converted into z-values by subtracting the mean of the distribution and dividing the difference by standard deviation) were also used. The results were analysed using an alpha of 0.10 (meaning that there was a 10% risk of the null hypothesis being rejected when it was true). The various combinations of materials responded differently during the eight tests and it is these differences that have been used to characterise the printed results. The tests were designed to observe the changes in the (output) response to test factor level changes (input) and to draw conclusions from the responses. The first stage in the design of the experiment was to identify all of the interacting factors that were considered to have an impact on the dot bridging print fault as follows:

- Ink viscosity
- Anilox screen ruling
- Type of Doctor blade
- Plate type
- Plate relief depth
- Mounting tape compressibility
- Printing speed

Each of the factors monitored in the experiment was assigned high and low values. The eight tests used for the experiment were designed to investigate if interaction between various production factors influence the dot bridging problem. Experience suggests that shoulder angles, dot gain, Shore-hardness are the most significant properties of the plate that are affecting flexographic print consistency. It was therefore reasonable to design these elements into the experiment to see if the analysis of the data could identify a link with the print fault known as dot bridging. Statistical analysis was used to explain the relationship between the various interactions that took place between the materials used in the experiment. Each run of the experiment consisted of a combination of factors at the high and low settings set as far apart as possible. The various tests of the experiment were designed to indicate possible improvements that could be implemented into platemaking techniques to improve flexo print consistency. The results were analysed to identify the best combination of materials, which would work well together to minimise the press stops for plate cleaning.

The research is industrially sponsored and methods of easily transferring information to the industry in a practical way were of paramount importance. Computer based statistical experimental design techniques were adopted because they have proved to be reliable and can be made to carry out the design almost automatically.

Results and discussion

The experiment was designed to prove that it is the interaction of the various components used on the printing press that set up the conditions which cause the classic print fault known as dot bridging. The plate being the image carrier, the printer suspected the plate as being the prime cause of the dot bridging print fault. Due to production time constraints the experiment was restricted to eight tests. It was decided to conduct the factorial design experiment on the gear side of the press. The operator side was free to be used as a control. A new plate was used for each of the eight tests of the experiment, which means a total of sixteen plates were used for the experiment. All of the plates were made from the same two batches of materials in identical platemaking conditions.

The eight tests were run over a nine hour period randomly in order to eliminate such variables as press-hall temperature, humidity and press temperatures from influencing the data.

The analysis of the data used to characterise the print results were all based on measurements taken from the printed sheets using a reflection densitometer. Identification of the most significant effects causing dot bridging were the main focus of the experiment. Other useful conclusions were drawn from the experiment by filtering the data and measuring other elements on the test image. Graphs of the various combinations are provided to illustrate the findings. The factors influencing print quality properties have been the focus of the characterisation work carried out and reported here.

This section of the paper includes a representative selection of some of the graphs that were produced from the statistical analysis of the raw data gathered during the experiment. Such results, i.e. experimental data, were subjected to both statistical analysis and logical reasoning in order to reach conclusions that would be of benefit to the understanding of factors affecting both print consistency and print quality.

Run length

The principle objective of the experiment was to define the optimum combination, which would reduce the amount of press stops for plate cleaning due to dot bridging. Two types of plate were selected from the same manufacturer for each test. The principle difference between the plates made for the experiment was the Shore hardness.

To maximise the amount of data that could be gathered in allotted production time a decision was made to run two plate combinations on each test. The plate combinations were positioned on the same cylinder as dictated by the design of the experiment. The high Shore hardness plate was always positioned on the gear side and the low Shore hardness plate on the operator side of the press. The first test applied to the data gathered was to see if the data was normally distributed. Initially the histogram plot of the frequency was produced shown in Figure 3. Due to small amount of tests included in the experiment the classic bell shape is not depicted by the polygon. The bell shape is sufficient to show that the data gathered is normally distributed.

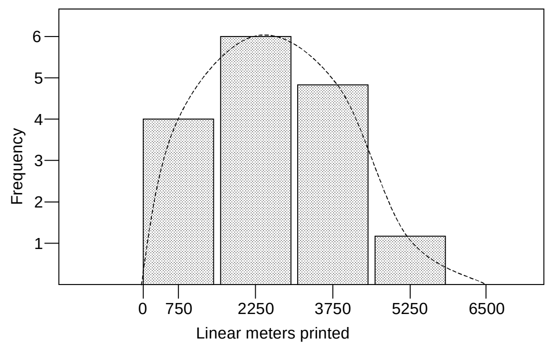

Figure 3 Histogram of frequency plot

The main effects for the seven factors included in the experiment are illustrated in the normal probability plot shown in Figure 4. The significant factor influencing the dot bridging when the run length data was analysed can easily be determined by referring to Figure 4. The plot clearly shows all of the factors not making any significant effect on the print fault are all plotted together on the straight line. As can clearly be seen in the plot the only factor highlighted is the type of doctor blade used.

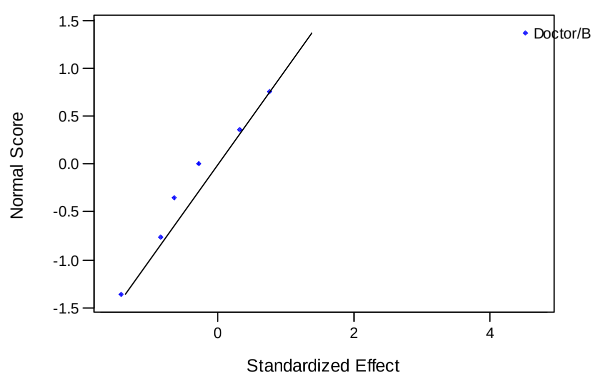

Figure 4 Normal probability plot for the dot bridging

The plot shown in Figure 5 indicates that the type of doctor blade will significantly affect the cleaning interval. The two types of blade that were used in the experiment were a normal round edge steel blade and a Lamella blade. The plots indicates that the cleaning interval in some conditions using the round edge steel blade is estimated to be as low as 1200 linear meters of substrate. Changing to the Lamella blade is estimated to improve the cleaning interval to longer than 3000 meters. Due to the cost of the substrate, all tests were terminated at 3000 meters. Inspection of the plates used in the conditions for Test 7 suggest that the cleaning interval would be substantially longer than 3000 meters as the plates were running much cleaner than for other test conditions. As seen from the results shown in Table 2 the only condition that allowed both types of plate to run successfully was Test 2.

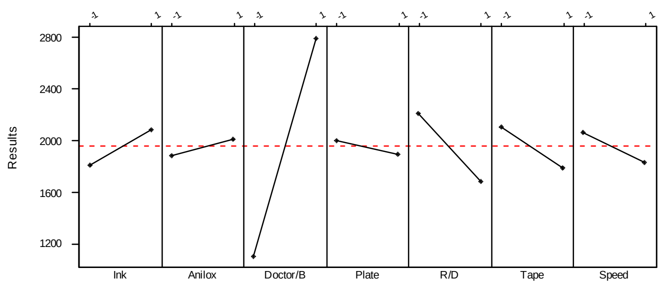

Figure 5 Main effects plot for dot bridging

The cube plot calculated the run length data is shown in Figures 6. Cube plots allows the interaction between components to be shown. Filtering the raw data allows the most significant interactions to be shown. Based on the data means calculated from results of the eight tests of the experiment, the three significant interacting factors are shown in Figure 6. The plot indicates that when the Lamella doctor blade is used with higher Shore hardness shallow relief plate it is predicted that the combination will print at least 3860 linear metres of substrate before presenting the symptoms of dot bridging.

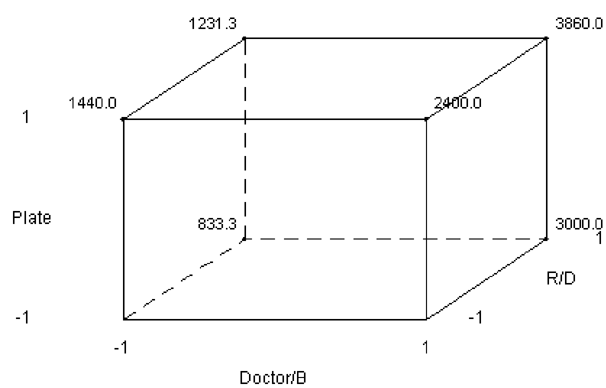

Figure 6 Cube plot to illustrate three-way interaction

It can be seen from the interaction plot shown in Figure 7.that many of the factors monitored during the test are predicted in certain circumstances to reverse their trend.

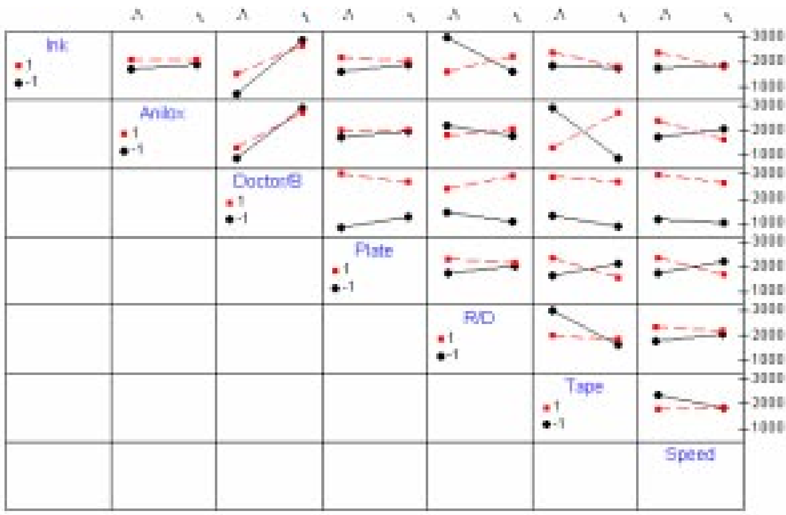

Figure 7 Interaction plot for factors affecting dot bridging

For example the low screen Anilox roller when combined with a Lamella doctor blade is predicted to allow at least 3000 linear meters of substrate to be printed without the need to clean the plate. However, this trend is predicted to be reversed by the selection of low durometer cushion mounting tape.

Table 2 Liner meters run for each test.

Test Order	Test N0	Ink/Viso	Anilox	D/Blade	Plate/ T	Plate/ RD	Tape	Speed	Result
4	1	+	+	-	+	+	-	-	3000
7	2	-	+	+	+	+	+	-	6000
6	3	+	-	+	+	+	-	-	2890
2	4	+	-	-	+	-	+	+	1440
8	5	+	+	+	+	-	+	+	1800
1	6	-	-	-	+	+	+	-	650
5	7	-	-	+	+	+	-	+	2690
3	8	-	+	-	+	+	-	+	1450
4	1	+	+	-	-	+	-	-	600
7	2	-	+	+	-	+	+	-	3500
6	3	+	-	+	-	+	-	-	3000
2	4	+	-	-	-	+	+	+	1025
8	5	+	+	+	-	+	+	+	3000
1	6	-	-	-	-	+	+	-	450
5	7	-	-	+	-	-	-	+	3000
3	8	-	+	-	-	+	-	+	250

The results for the linear meters run for each test before the dot bridging fault was seen, are recorded in Table 2. Due to the cost of the substrate the test was stopped after 3000 liner meters. The plates used for Test 2 were observed as being comparatively clean when the test was stopped indicating that the interaction of factors used for this test were reasonably in balance.

Print contrast

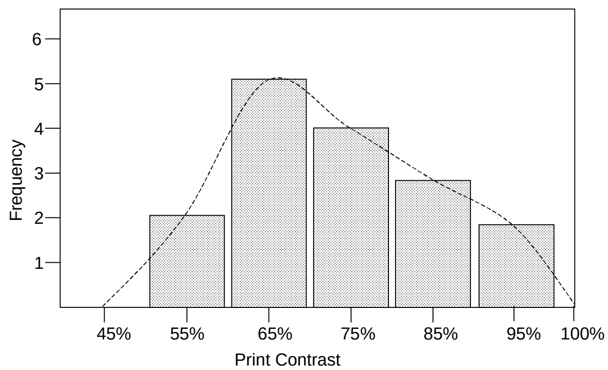

Figure 8 Histogram of frequency

The class parameters shown in Figure 8 are a graphic representation of the frequency of the results recorded. The classes were calculated from results shown in Table 3. The contrast figure quoted in the results column was calculated by dividing the logarithm of the solid density into the logarithm density measured on the 20% tone patch. Taking into account the small sample size the polygon displays a slightly skewed distribution. The shape does however, bear an acceptable resemblance to a normal bell shaped distribution curve.

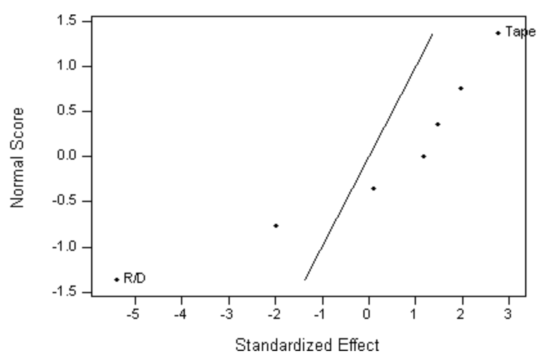

Figure 9 Normal probability plot for print contrast

The plot of normal probability was used to identify which factors had an influence on the print contrast. Active effects are effects that are significant or important. These are highlighted on the Chart shown in Figure 9 because they do not fit the line well. The most significant factor influencing print contrast in this plot, because it is furthest from the fitted line, is the relief depth followed by the tape type. The other factors are fitted close to the line, which signifies that they were inactive effects.

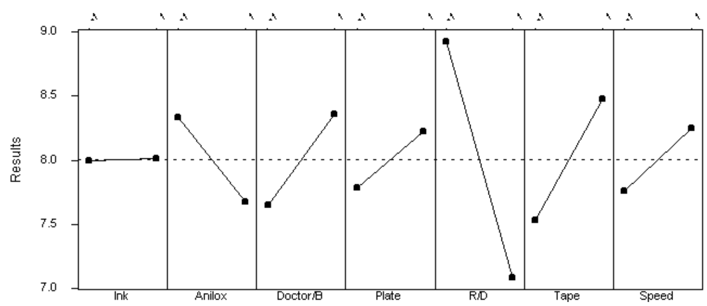

Figure 10 Main effects plot for print contrast

The main effects plot shown in Figure 10 indicates that relief depth is clearly the factor that is contributing to the change in print contrast. The scale on the left is calibrated to reflect the relative pecentage contrast of a 20% printed dot when compared with the solid density measured on the substrate. The conventional contrast equation was used to make the calculation. The steep slope of the descending line in the graph for relief depth (from –1 towards 1) indicates that the 20% dots are getting smaller and thus brighter, improving the print contrast.

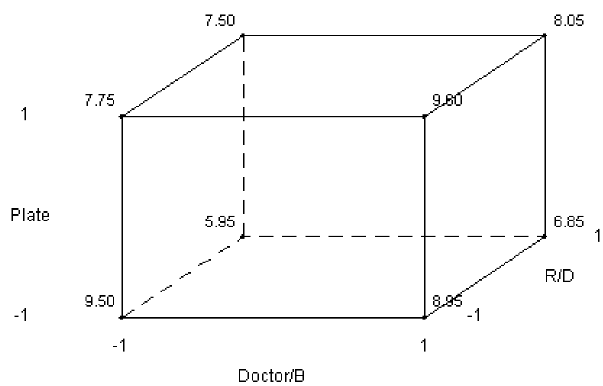

Figure 11 Cube plot for print contrast

The cube plot graph shown in Figure 11 illustrates the three-way interaction of factors chosen. The plot is generated using the means of the data gathered from the results shown in Table 3. The shallow relief depth indicated by (1) on the graph, produces a contrast figure of 6.85%. When combined with the Lamella doctor blade and the lower Shore hardness plate a figure of 5.95% is produced. The lower Shore hardness plate produces higher ink transfer, which improves the contrast result. Unfortunately, the lower Shore hardness plate produces higher dot gain when printing halftones, which does not allow this combination to be used for production purposes.

Table 3 Print contrast results

Test Order	Test N0	Ink/Viso	Anilox	D/Blade	Plate/ T	Plate/ RD	Tape	Speed	Result
4	1	+	+	-	+	+	-	-	5.2%
7	2	-	+	+	+	+	+	-	10%
6	3	+	-	+	+	+	-	-	7.3%
2	4	+	-	-	+	-	+	+	7.3%
8	5	+	+	+	+	-	+	+	8.9%
1	6	-	-	-	+	+	+	-	6.8%
5	7	-	-	+	+	+	-	+	9.5%
3	8	-	+	-	+	+	-	+	8.1%
4	1	+	+	-	-	+	-	-	7.4%
7	2	-	+	+	-	+	+	-	8.4%
6	3	+	-	+	-	+	-	-	6.9%
2	4	+	-	-	-	+	+	+	9.9%
8	5	+	+	+	-	+	+	+	8.8%
1	6	-	-	-	-	+	+	-	7.7%
5	7	-	-	+	-	-	-	+	9.2%
3	8	-	+	-	-	+	-	+	6.7%

Print density

A secondary evaluation of the raw data collected from the experiment was analysed. When the print density is evaluated and the main effects are plotted as

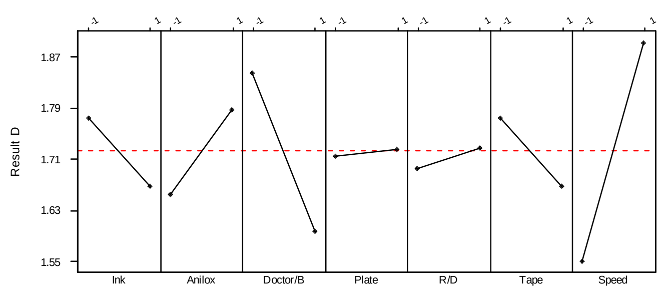

Figure 12 The main effects plot for print density

shown in Figure 12. The chart clearly illustrates that interaction of factors can work against each other. A classic example is the ink and Anilox effect. As the ink gets more thixotropic the density reduces. Increasing the screen count can counteract this. The Lamella doctor blade is clearly predicted to reduce density and can be assumed to be more efficient at metering the ink from the Anilox roller. Conversely increasing the printing speed is predicted to increase the print density from a D Max of 1.55 to a D Max of 1.87. Some of this effect is assumed to be the hydraulic forces in the printing nip, forcing more ink onto the surface of the plate. One surprise is that the two types of plate used in the experiment produced a neutral result. The lower Shore hardness plate would generally produce a higher ink transfer and thus record a higher ink density measurement on the plate.

Best print sample

The high contrast black and white printed picture included in the test image was subjectively graded from 1to 16. The prints were ranked from best being $N^{0}1$ to worst being $N^{0}16$

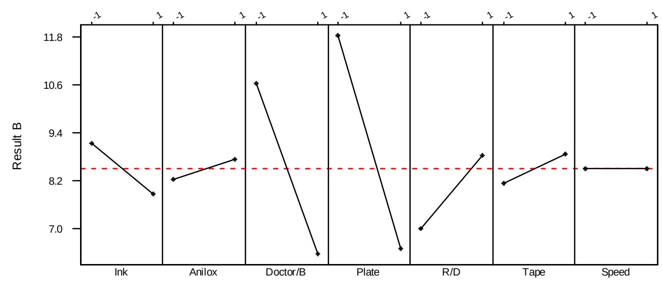

Figure 13 Main effects plot for the best print sample

It can be clearly seen from the main effects plot in Figure 13 that the combination of the Lamella doctor blade and the higher Shore hardness plate made a significant contribution to improving the visual appearance of the print. The plot shown in Figure 13 also shows that shallow relief depth is predicted to enhance halftone print quality.

Following the conclusion of the analysis a confirmation test was completed to confirm the finding of the report. The conditions for Test 2 were repeated and a print run in excess of 6000 linear metres were run without the occurrence of the print fault “dot bridging”.

It should be noted that during the confirmation test it was noticed that the printing pressure was found to be a significant factor influencing the print fault under investigation. The press is not fitted with pressure gauges so the printing pressure was adjusted using the skill of the operator. During the test the pressure was maintained as a constant. The random running order of each test was designed to filter out the effects of possible influencing factors such as temperature change, humidity change and printing pressure settings

Conclusion

The most important conclusion that can be drawn from the results presented in this paper is that it is possible to identify complex interactions that are compromising both the print quality and production efficiency. In this particular case study, the printer had been trying to solve the problem of “dot bridging” by using a combination of experience and empirical result, without achieving any success. The main reason for the failure to identify the problem was the apparent random nature of the fault. The first hypothesis, which posed that the problem of “dot bridging” was a random effect was rejected. This conclusion was reached on the basis that the manipulation of the Doctor blade factor could be statistically identified as being significant. As shown in the result Table 2 the printing cylinder was mounted with two types of plate of different Shore hardness. The hard plate out performed the soft plate, but both the conditions for Test 2 proved to alleviate the press stops for the "dot-bridging" problem. By carefully planning a controlled experiment based on Factorial Designed principles it proved possible to pin point the factors causing the print fault "dot bridging". The second hypothesis was that there was no difference in the print contrast during the experiment was rejected. The tape and the plate relief depth were both statistically significant factors as shown in the main effect plot in Figure 10. The third hypothesis that the print density was related to the plate Shore hardness was rejected. The main factors significantly influencing the print density during this experiment were the types of doctor blade and the press speed. Psychometric results, which ranked the printed samples were statistically analysed and revealed that the type of plate and the doctor blade type were found to be significant influencing factors on what was perceived to be the best looking print sample.

The use of statistical analysis made it possible to dramatically reduce both the numbers of tests, production time and materials without compromising the accuracy of the experimental results. The filtering of the raw data gathered during the experiment provided valuable additional information about the interactions which could be used to enhance print quality and improve production efficiency.

The data that has been provided by this experiment has supplied qualified information about the nature of the interactions that affect the press efficiency. The printing press is not fitted with pressure dials, therefore any conclusions from this data should be thought of as reliable indications of behaviour that deserve further study.

A further smaller tests was carried out implementing the best combination of factors, suggested by the results of the experiment, to confirm that the condition of Test 2 gave more than 6000 linear meters of clean print. The test was stopped at 6000 metres due to the cost and time factors. The experiment has demonstrated that it has been possible to optimise the press performance using the data provided. Once this was achieved the press was then characterised to optimise the print quality produced.

The author would like to acknowledge the support and guidance provided at the University of Leeds Colour Chemistry Dept, with a special note of thanks to Dr. Long Lin for his tireless support, friendship and encouragement.