Investigation into the Causes for "Mottle"

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Abstract: This paper is based on a case study in which a flexographic folding carton printer has suffered intermittently from the print fault "mottle." The printer has had little success with the normal problem solving techniques based on empirical experimentation. The print fault is difficult to cure due to its apparent random nature. Commercial pressure has made the printer focus on this print production problem. Solutions based on empirical testing failed to identify the causes of the problem. Factorial designed experiments allow for the simultaneous study of the effects that several factors may have on a process. By identifying the key interacting factors provoking the "mottle" phenomenon and establishing if the effect was random, it was thought that production efficiency (yield) could be improved.

A two-level factorial experiment was designed to include all of the key components used in normal production. The results and conclusions from the experiment are reported and highlight the preferred properties for each of the key components used in the experiment, which are able to deliver improved printing performance and consistency.

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Introduction

The flexographic process is the principle printing method used by the packaging market. Commercial pressure has had a significant impact on the unit price paid for folding cartons in recent years. Traditionally the sheetfed lithographic process has been used for the production of folding cartons.

Commercial pressure in recent years has influenced folding carton manufacturers to show increased interest in the new emerging flexographic technology, which has shifted the research emphasis to finding alternative "higher added value markets." By adopting the latest production techniques and optimising the flexographic printing process it is now possible to compete commercially and technically for folding carton work, which is normally printed using the lithographic printing process. Some of the cost savings accrue from the fact that lower quality substrate can be used to produce flexographic cartons.

The factorial experimentation process was selected to solve the difficult and persistent problem of mottle at a flexographic folding carton printer site. The factorial technique allowed several factors to be varied simultaneously, which saved time and the cost of carrying out the analysis of the problem on a production machine. A two-level factorial design was selected to quickly analyse the interactions, which were thought to be the major cause of the problem, unable to be detected by alternative problem solving methods. Whilst the two-level design was not able to explore the full extent of the factorial space, the experiment was designed to provide useful information from relatively few runs per factor change. Due to time and cost constraints it was decided to run a fraction of the full factorial design. The choice of the "best fraction" was taken on subjective opinion and specialist knowledge of the process and resulted in the experiment being made up of twelve separate tests. The purpose of the experiment was to indicate major trends that would provide information for the optimisation of the production process.

Manufacturers and suppliers often recommend processing conditions, which are best suited to their individual products. However, 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. The printer was under commercial pressure to reduce the visual effect in halftone pictures caused by the print fault "mottle." The problem was difficult to categorise and define due to its apparent random nature. 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 "mottle" print fault. Mathematical tests of hypotheses procedures were used to determine if the observed data differed significantly from the results expected and thus determine if the hypothesis should be accepted or rejected.

Sample Data Gathering

The print "mottle" experienced by the printer was apparently random in nature. It appeared in unpredictable areas of halftone image and in a variety of colours being printed. The initial investigation was to establish if one or more of the pre-press production processes was generating or provoking the print fault. Figure 1 illustrates a typical example of the extent of the problem experienced when printing a smooth vignette. The printed result appears to be blotchy to the observer.

Figure 1. Illustration of "mottle."

Illustrated in Figure 2 are sections of the negative, plate and print which were examined using a light microscope. Whilst it is appreciated that the negative was imaged on an X,Y, plotter and thus same value dots are made from different numbers of pixels, no "mottle" effect could be observed in either the negative or the plate. However, the print sample image taken from a similar sample area did display the print fault "mottle." The 37μ diameter dot represents approximately 4% dot area at 150 line per inch and was chosen for analysis on the basis that the dot is considered to be the finest robust dot, less susceptible to print pressure variation.

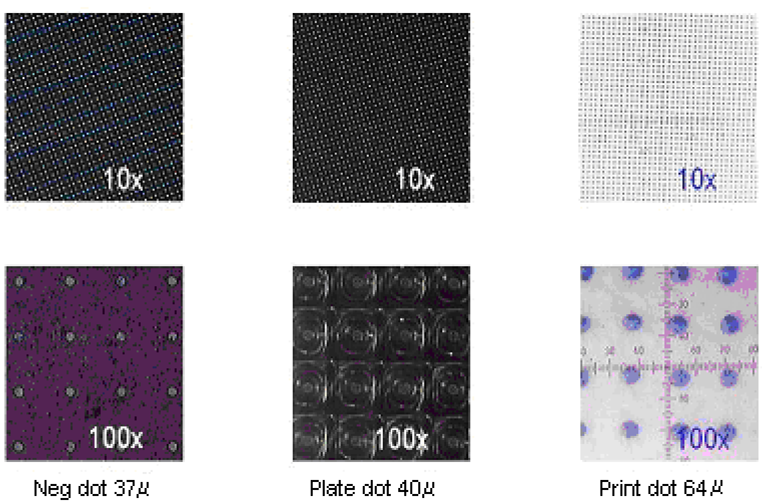

Figure 2. Image of the negative, plate and print from the light microscope.

Due to the random nature of the print fault a small pilot print test was conducted to establish which factors to model into the experiment. The results from the pre-test were used to set a suitable range for the upper and lower levels for each factor used in the experiment.

A combination of sampling theory, probability theory and statistical inference, was used to determine whether the observed differences in the data related to the factors included in the experiment, were due to chance variation or, if they really were a significant factor provoking the "mottle" print fault. Data was subjected to two proving tests to ensure that it was reliable.

Proving Test (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 in the raw data gathered of between 1–2%. This was included in the result field in the Minitab software.

Proving Test (2) due to the small number of Tests (12) 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 were selected randomly for the required number of measurements to satisfy the error criteria of Test (1) to ensure that the true underlying value was recorded.

Measurement Methods

"Mottle" is the optical effect of making halftone dots in a picture appear to be different sizes. The print fault is thought to be associated with the flexographic printing process when printing onto lower quality porous substrate which has an uneven or poor surface finish.

Prior to this experiment being conducted, the printer had tried several empirical experiments to establish the main causes for the "mottle" without success. The normal flexographic printing technique was adopted for this experiment. The press was a standard UV flexographic printing press. The press ink was applied to the plate via an Anilox roller through a closed doctored ink chamber. The UV ink factors were set at 3 centipoise[2] and 6 centipoise[2], pumped to the ink chamber with a peristaltic pump capable of running 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 data was generated by careful analysis of the printed sheet after "mottle" first became apparent on the print. Four printing characteristics were analysed from the data produced by the twelve tests as follows:

- "Mottle Print": quantified subjectively
- Solid Density: quantified using a reflection densitometer
- Print Contrast: quantified using a reflection densitometer
- Dot Gain: quantified using a reflection densitometer

Due to space restrictions a representative selection of the results are discussed in detail in the paper.

Table 1. The basic factorial designed experiment

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
StdOrder	RunOrder	CenterPt	Blocks	Srn Value	Srn LPI	Plate type	Ink Visco	Ink Hue	Anilox Cell	Substrates	Tape Type	Print Speed	Result
4	1	1	1	1	-1	1	1	-1	1	1	-1	-1	
1	2	1	1	1	-1	1	-1	-1	-1	-1	1	1	
10	3	1	1	1	-1	-1	-1	1	1	-1	-1	1	
5	4	1	1	1	1	-1	1	1	-1	-1	-1	-1	
9	5	1	1	-1	-1	-1	1	1	1	1	1	1	
12	6	1	1	-1	-1	-1	-1	-1	-1	1	-1	-1	
6	7	1	1	1	1	1	-1	1	1	1	1	-1	
8	8	1	1	-1	-1	1	1	1	-1	-1	1	-1	
3	9	1	1	-1	1	1	-1	1	-1	1	-1	1	
7	10	1	1	-1	1	1	1	-1	1	-1	-1	1	
11	11	1	1	-1	1	-1	-1	-1	1	-1	1	-1	
2	12	1	1	1	1	-1	1	-1	-1	1	1	1	

The factorial experiment shown in Table 1 has 9 variable factors, which are labeled under the column heading C5-C13. The design is a two level experiment represented by the -1/1 symbols.

The Photographic Test Image

The 300mm × 350mm test image, shown in Figure 3, was created on an Apple Macintosh iMac using FreeHand software. The design was influenced by the need to provoke the "mottle" print fault. The 60° Anilox roller dictated that 150 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° 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.

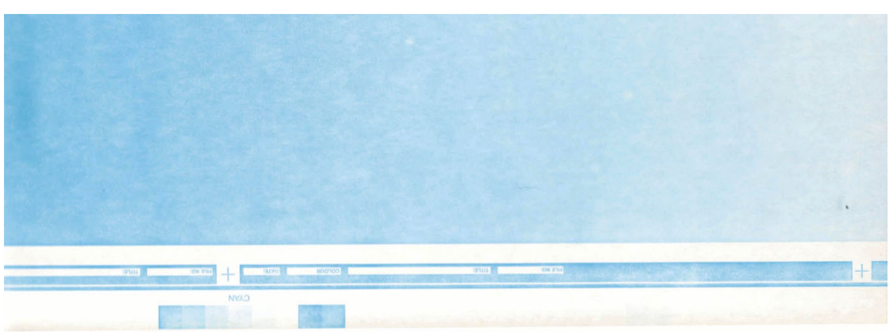

Figure 3. The experiment test image.

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. The large step wedges outside the bearer bars were included on each side of the image to give a visual check of the correct printing pressure and Anilox to plate pressure 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.

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.

Equipment for platemaking:
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 perchlorethylene/butanol 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 hydrocarbon 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."

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 7centipoise[2] and 3centipoise[2] using oligomers. The ink hue was varied by selecting two different blue pigments.

Anilox rollers selected for the experiment:
Anilox Specification
The high Anilox screen count was set at 1400 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 2 & 3.

Substrate used for the printing test:
Two different substrate qualities of "Vena Freeze" were supplied by M&M for this experiment. Both substrates were from the same master reel. The high factor was from the centre of the master reel and the low factor was from the edge of the master reel.

Mounting tape selected for the experiment
Two different tape qualities of 3M Mounting Tape were selected from the same manufacturer 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.

Printing Speed selected for the experiment:
The mottle problem was thought to be related to printing speed. The low level printing speed was set at 75m/m and the high level printing speed was set at 150m/m.

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

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 13.1 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 twelve 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 initial investigation confirmed that the "mottle" fault was induced by a combination of factors associated with the printing press.

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 "mottle" print fault as follows:

- Screen value
- Screen lines per inch
- Plate type
- Ink viscosity
- Ink hue
- Anilox screen ruling
- Substrate type
- Mounting tape compressibility
- Printing speed

Each of the factors monitored in the experiment was assigned high and low values. The twelve tests used for the experiment were designed to investigate if interaction between various production factors influence the "mottle" print fault. 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 plate type selection to improve flexo print consistency. The results were analysed to identify the best combination of materials, which would work well together.

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 the capability of showing the data graphically which makes it easier to communicate the results to printers and platemakers.

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 "mottle". The plate being the image carrier was suspected by the printer as being the prime cause of the "mottle" print fault. Due to production time constraints the experiment was restricted to twelve tests.

The twelve tests were run simultaneously over a nine-hour period randomly to eliminate such variables as press-hall temperature, humidity, press temperatures, operator change and operator experiment fatigue from influencing the data. The press was not fitted with pressure gauges so the printing pressure was adjusted using the skill of the operator. During the test an attempt was made to keep the printing pressure constant. The random running order of each test was designed to filter out the possibility of variable having a significant influence on the results.

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. For the purpose of this experiment "mottle" has been classified as random and uneven "dot gain". A rather unconventional novel approach to solving this difficult and persistent problem has been successfully adopted. The initial stages of the analysis of the raw data were focused on finding a link between the level of "mottle" seen on a test results print samples and the dot gain characteristic. The most effective method was found to be to subjectively grade the printed results from each test in rank order. The method used was to ask three observers to visually assess the sheets for "mottle" and to allocate a score, lowest being least effected by mottle the highest score the most effected by mottle. The sheets once ranked in order were characterised for solid density, print contrast and dot gain. Once the "mottle" was ranked the raw data generated by these results was closely examined to identify a correlation between the print samples and the raw data. With the Alpha level set at 0.10 the data was analysed for P-values below 0.700 indicating which factors were significant. It is this fitted data that has been used to solve the print fault "mottle" at this particular printer's site.

Identification of the most significant factors causing "mottle" was 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.

Assessment of the Level of "Mottle"

Two types of mounting tape and plate were selected for each test. The principle difference between the plates used for the experiment was the Shore hardness. The principle difference in the tape was compressibility or resilience properties.

The first test applied to the raw data was to see if the data gathered from the twelve tests was normally distributed. Initially the histogram plot of the frequency was produced shown in Figure 4. Due to small amount of tests included in the experiment the classic bell shape is not depicted by the polygon. The results shown in Figure 4 were generated from the "standard t" test for normal distribution of data for 50% dot gain. The bell shape although displaying a skew is sufficiently formed to show that the data gathered is normally distributed. The graph displays frequency of dot gain measurements being recorded for the 50% mid-tone dot area of the test print.

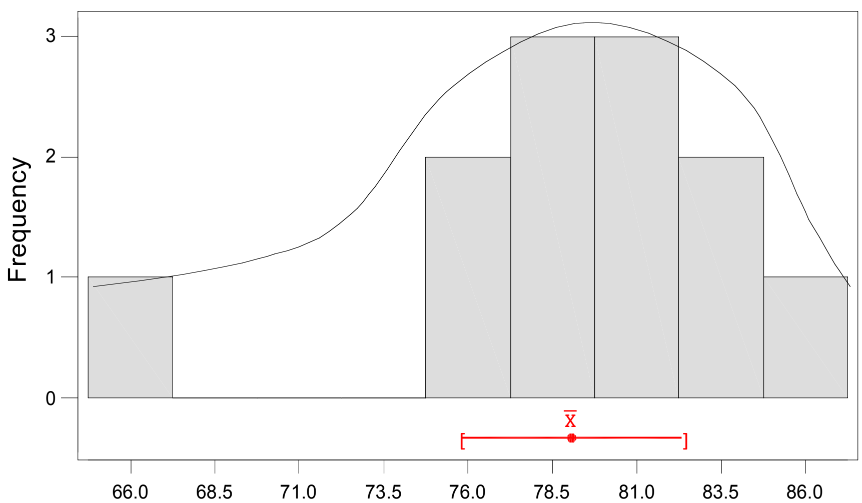

Figure 4. Histogram of frequency plot for 50% dot gain.

The main effects for the nine factors included in the experiment are illustrated in the normal probability plot shown in Figure 5. The significant factor influencing the "mottle" when the data was analysed can easily be determined by referring to Figure 5.

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 clearly shown in the plot in Figure 5, the only factor highlighted is that the type of mounting tape used has a significant effect on the level of "mottle" displayed. The isolated dot at the top far right of the graph has been identified as the plate factor.

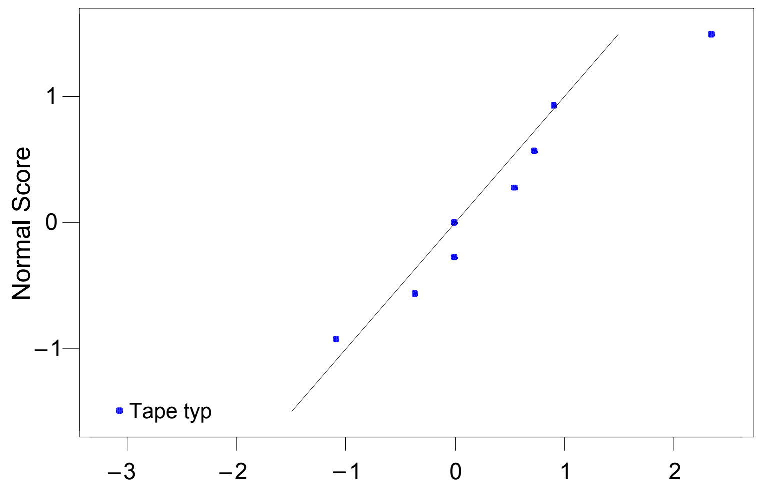

Figure 5. Normal probability plot for “mottle.”

Analysis was carried out to establish if the “mottle” problem was prevalent throughout the tone range. All of the test results confirmed that the “mottle” phenomenon was most noticeable in the quartertone to mid-tone area of the test sheets. The data produced from these areas of the print samples were found to be the most significant.

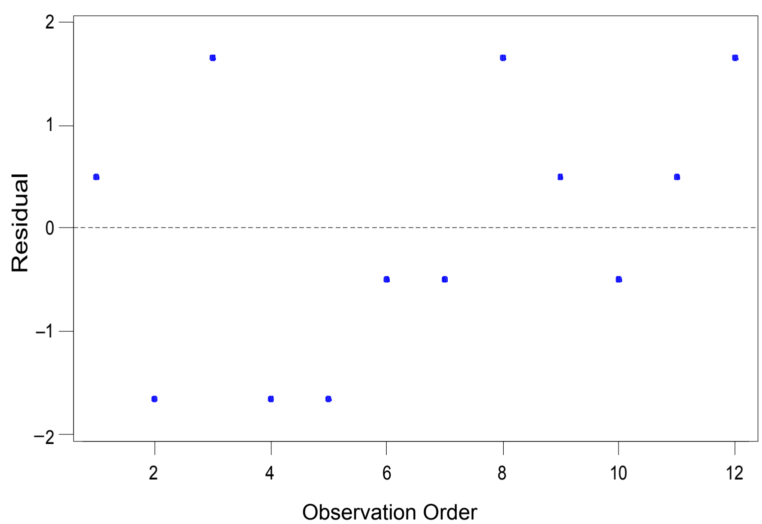

Figure 6. Data points for the twelve tests.

To be able to determine if the “mottle” was time or temperature dependent the order of the tests was randomised. The results shown in Figure 6 indicate that no significant pattern in the data and the test run order could be identified.

The main effects plot for the subjectivly ranked test sheets clearly indicates that the plate type and the tape type had the most siginificant effect on producing the mottle print fault. The main effects plot shown in Figure 7 helped establish a clear statistical link between "mottle" and dot gain print characteristics.

The initial subjective ranking was marked from the low value being the best print sample (lowest level of "mottle" displayed) to the highest value being the worst print result (highest level of "mottle" displayed) on the test sheets.

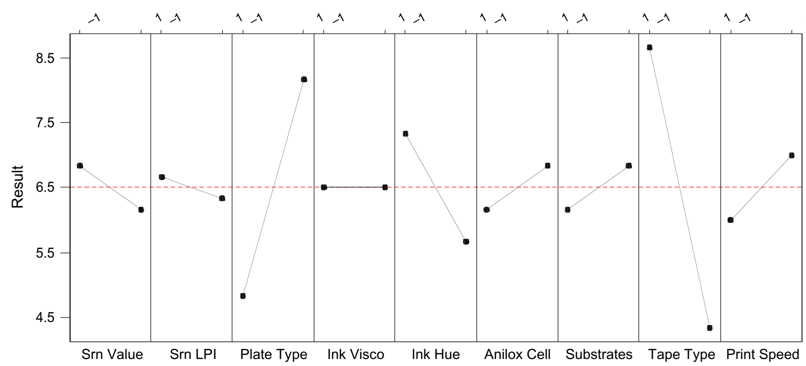

Figure 7. Main effects plot for the subjectively assessed test sheets for "mottle."

The cube plot shown in Figure 8 indicates three-way interaction. The plot indicates that statistically the combination of factors modelled in the experiment least likely to produce the print "mottle" are the darker hue (cyan) the softer plate and harder plate mounting tape.

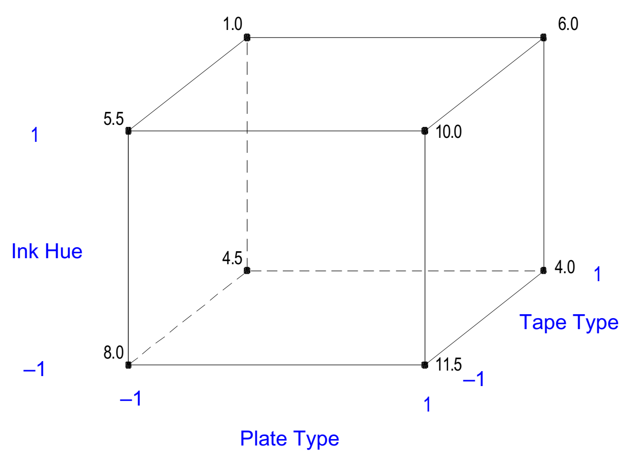

Figure 8. Cube plot for subjectively ranked test sheets.

It can be seen from the interaction plot shown in Figure 9 that many of the factors monitored during the test, are predicted in certain circumstances to reverse their trend. The two key factors indicated as significantly provoking the print "mottle" do not appear to have any interdependence. The chart clearly indicates that the lower durometer plate when combined with the higher resilience tape is predicted to significantly reduce the dot gain which has been proved to be linked with the "mottle" print fault.

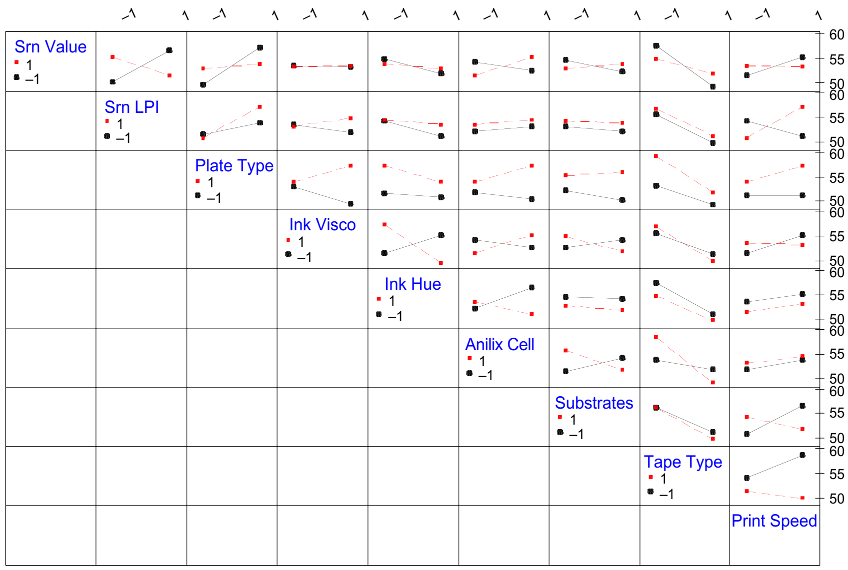

Figure 9. Interaction plot for factors affecting "mottle."

Print Contrast

The print contrast data shown in Table 2 has been used to explain the results as it is a good indicator of balance between solid printing and halftone printing. The contrast calculation is made by simply dividing the result of the density reading for the three-quarter tone by the density reading for the solid print. The result is expressed as a percentage difference.

Table 2. Results for print contrast.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
StdOrder	RunOrder	CenterPt	Blocks	Srn Value	Srn LPI	Plate type	Ink Visco	Ink Hue	Anilox Cell	Substrates	Tape Type	Print Speed	Result 1
4	1	1	1	1	-1	1	1	-1	1	1	-1	-1	41
1	2	1	1	1	-1	1	-1	-1	-1	-1	1	1	28
10	3	1	1	1	-1	-1	-1	1	1	-1	-1	1	35
5	4	1	1	1	1	-1	1	1	-1	-1	-1	-1	23
9	5	1	1	-1	-1	-1	1	1	1	1	1	1	20
12	6	1	1	-1	-1	-1	-1	-1	-1	1	-1	-1	33
6	7	1	1	1	1	1	-1	1	1	1	1	-1	28
8	8	1	1	-1	-1	1	1	1	-1	-1	1	-1	32
3	9	1	1	-1	1	1	-1	1	-1	1	-1	1	38
7	10	1	1	-1	1	1	1	-1	1	-1	-1	1	42
11	11	1	1	-1	1	-1	-1	-1	1	-1	1	-1	27
2	12	1	1	1	1	-1	1	-1	-1	1	1	1	29

The results shown in the histogram for print contrast data in Figure 10 are skewed due to the very small number of tests conducted for this experiment. The polygon shown in the graph, whilst not perfectly bell shaped does indicate that the data is normally distributed.

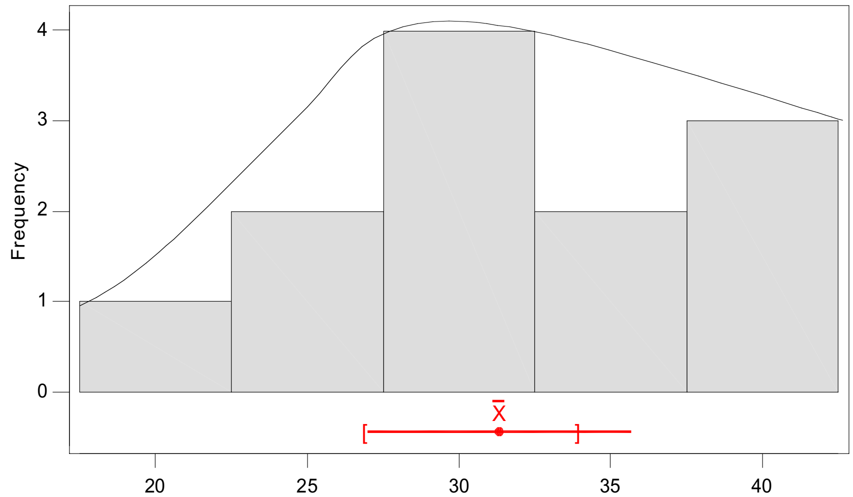

Figure 10. Histogram of frequency for print contrast.

The results from the print contrast data indicated in Figure 11, show that the tape type is the factor that is the most significant factor closely followed by the plate Shore hardness. This combination was consistent throughout the analysis of the results. The factors are ranked in order of significance.

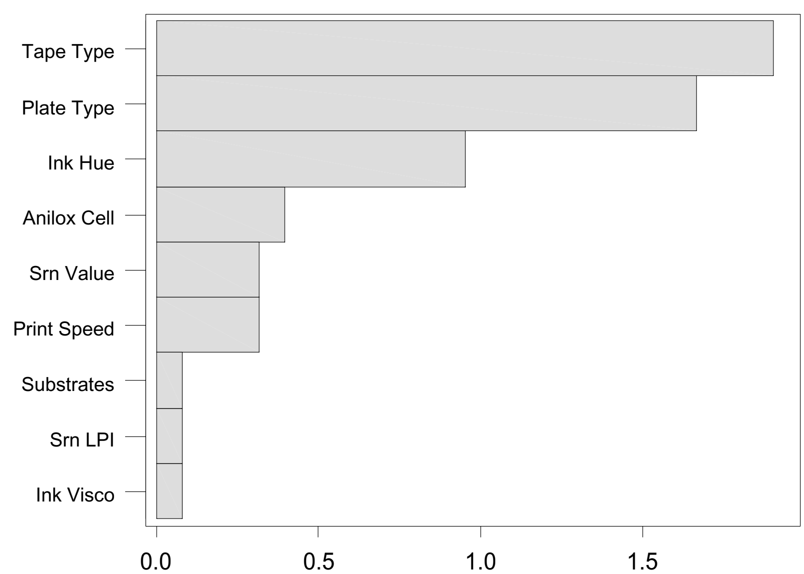

Figure 11. Pareto chart showing the order of significance of the factors.

The main effects plot for print contrast shown in Figure 12 confirms that the three factors most affecting the print fault are tape type, plate type and to a lesser extent the hue of the ink. The best print contrast was produced from the softer tape, which was consistent with the subjective assessment and ranking of the sheets. Statistically the harder plate type are predicted to produce the best print results which is opposite to what was subjectively observed. The reason is that the print dot gain is lower when printing from the higher Shore hardness plate and the print contrast calculation is significantly influenced by this fact.

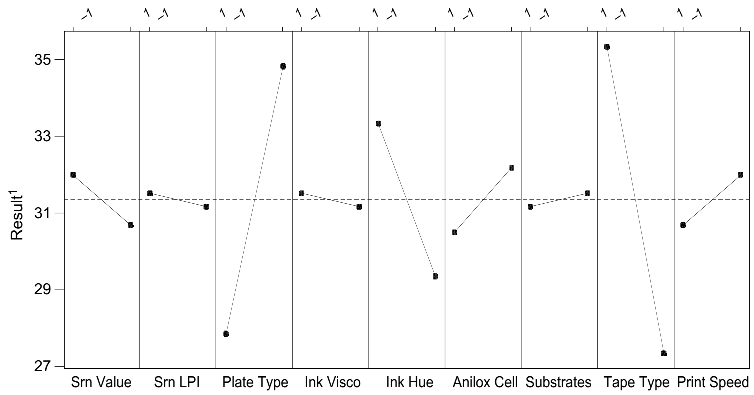

Figure 12. main effects plot for print contrast.

Assessment of the Level of "Mottle"

Table 3. Results of data for the 5% dot gain.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
StdOrder	RunOrder	CenterPt	Blocks	Srn Value	Srn LPI	Plate type	Ink Visco	Ink Hue	Anilox Cell	Substrates	Tape Type	Print Speed	Result 1
4	1	1	1	1	-1	1	1	-1	1	1	-1	-1	30
1	2	1	1	1	-1	1	-1	-1	-1	-1	1	1	20
10	3	1	1	1	-1	-1	-1	1	1	-1	-1	1	24
5	4	1	1	1	1	-1	1	1	-1	-1	-1	-1	19
9	5	1	1	-1	-1	-1	1	1	1	1	1	1	19
12	6	1	1	-1	-1	-1	-1	-1	-1	1	-1	-1	24
6	7	1	1	1	1	1	-1	1	1	1	1	-1	21
8	8	1	1	-1	-1	1	1	1	-1	-1	1	-1	22
3	9	1	1	-1	1	1	-1	1	-1	1	-1	1	28
7	10	1	1	-1	1	1	1	-1	1	-1	-1	1	30
11	11	1	1	-1	1	-1	-1	-1	1	-1	1	-1	20
2	12	1	1	1	1	-1	1	-1	-1	1	1	1	22

The Pareto chart which ranks all of the factors in order of significance is shown in Figure 13. Due to space restriction in this report it was decided to include results from the two extreames of the halftone print scale being 5% and 100% (solid). The data produced for the 5% dot gain results are in the same trend as all of the other results analysed. The red dotted line on the chart shown in Figure 13 indicates that the tape factor alone is the single most influencing factor at 5% having more impact on the final result than the other factors.

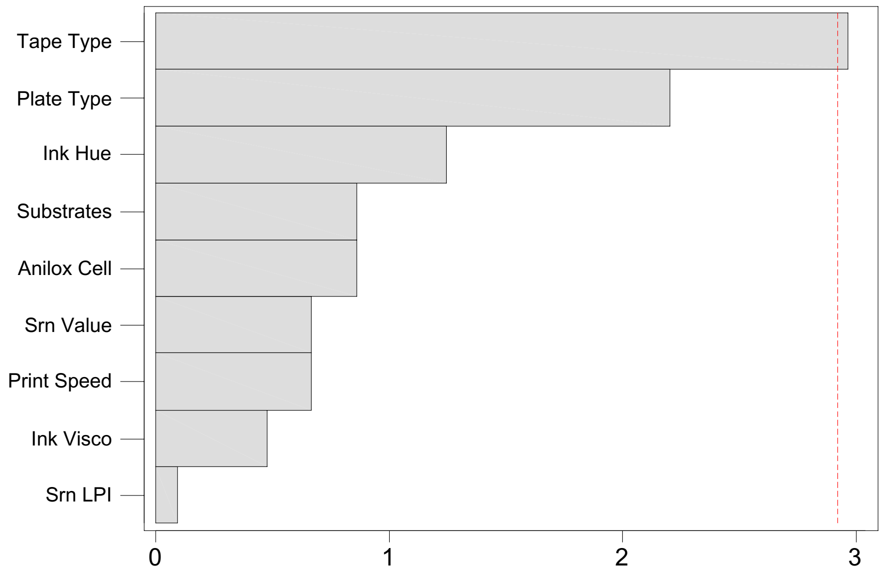

Figure 13. Pareto chart of results for 5% dot gain.

The main effects plot shown in Figure 14 confirms the trend that tape type followed by plate type are the two significant factors at the hightlight end of the vignett used to test for the print fault ìmottleî

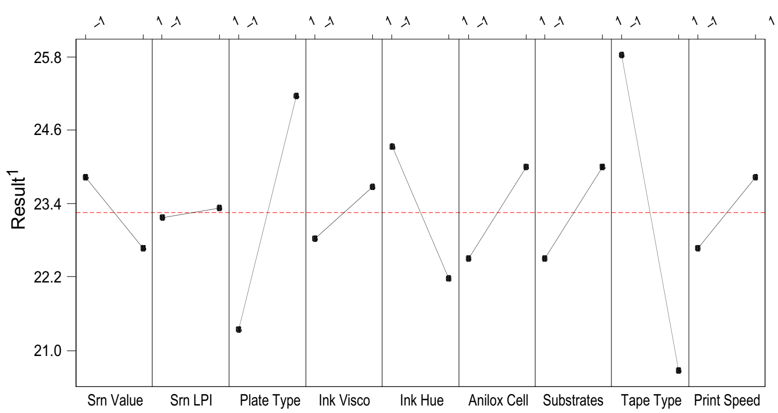

Figure 14. Main effects plot for 5% dot gain.

The cube plot graph shown in Figure 15 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 lowest dot gain indicated by (19) on the cube plot was produced by a combination of high ink hue, low Shore hardness plate and high resilience tape. This result confirms the previously reported trend for results of print contrast, where lower Shore hardness plate produces higher ink transfer, which produces improved print contrast results. What is a surprise in this result is that the lower Shore hardness plate would not normally be expected to produce the lowest dot gain result.

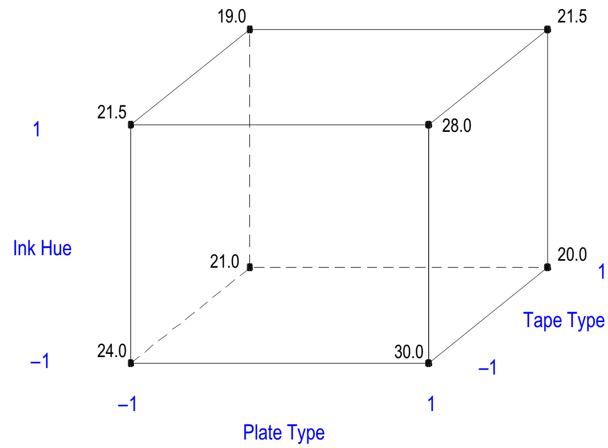

Figure 15. Cube plot for the interaction of the three most influencing factors.

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 shown in Figure 15.

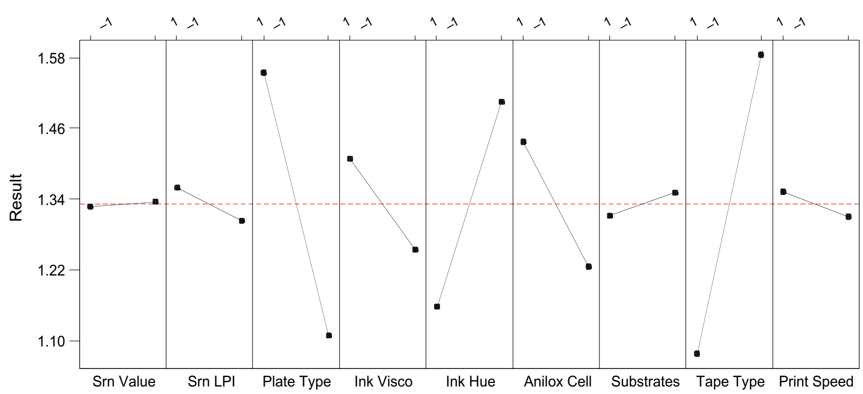

Figure 16. Results for Print density.

The scale on the graph shown in Figure 15 is the density readings taken using a reflection densitometer. The high values gave the best print results. The results shown in Figure 16 indicate that the trend for tape and plate is reversed. The hue factor is influencing the result, as the darker hue gives the highest value densitometer reading. The classic combination of hard tape and soft plate is shown to improve the ink transfer. This result was predictable as the lower Shore hardness plate in known to generally produce a higher ink transfer and thus record a higher ink density measurement on the plate.

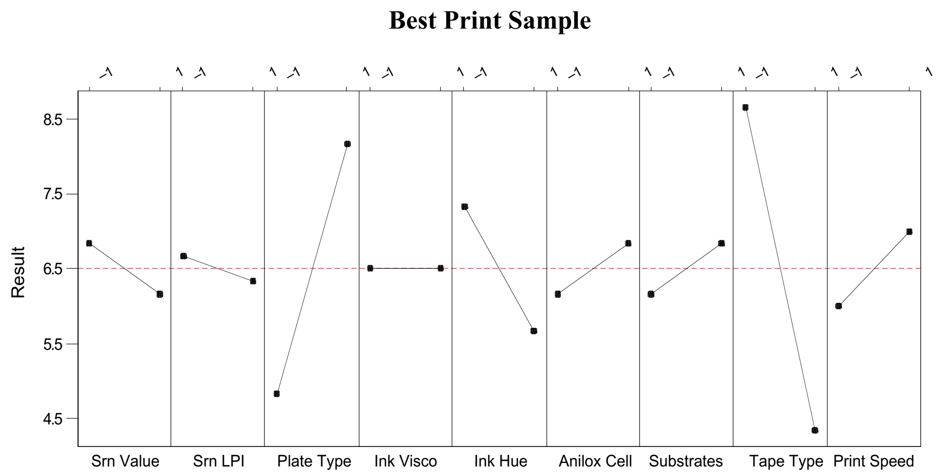

Figure 17. Main effects plot for the best print sample.

The scale on the left hand side of the main effects plot shown in Figure 17 relates to the subjective score given to the print in rank order i.e. low scores are the best prints. It can be clearly seen from the main effects plot in Figure 17 that the combination of the higher resilience plate mounting tape and the lower Shore hardness plate made a significant contribution to improving the visual appearance of the print i.e. reduction in mottle.

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.

Conclusion

The initial physical investigation of the test sheets using a powerful light microscope revealed that the dots on the test plates were uniform but the ink transfer was not, thus the appearance of the print fault “mottle.”

The initial filtering of the raw data gathered during the experiment provided valuable additional information about the link between the raw data and the print samples affected by “mottle.” The graphs generated from the filtered data reported here was able to graphically show which factors could be manipulated to reduce the effect of ìmottleî for this particular printer.

The main reason for the printer failing to identify the problem was the apparent random nature of the fault. The printer had been trying to solve the problem of “mottle” by using a combination of experience and empirical result, without achieving any success. The first hypothesis, which posed that “mottle” was a random effect, was rejected. This conclusion was reached on the basis that the manipulation of the plate type and tape type factors could be statistically identified as being significant. By carefully planning a controlled experiment based on Factorial Designed principles it proved possible to pin point the factors which had most influence on provoking the print fault “mottle.” The second hypothesis was that the level of print contrast did not influence the appearance of “mottle” during the experiment, was rejected. The tape and the plate type were both statistically significant factors affecting print contrast as shown in the main effect plot in Figure 12. The print sample with the least contrast displayed the least optical “mottle” level. The third hypothesis was that the print density was related to plate Shore hardness was accepted. The main factors significantly influencing the print density during this experiment were a combination of mounting tape type followed closely by the Shore hardness of plate. Psychometric results, which ranked the printed samples were statistically analysed and revealed that the type of plate and the tape 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 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 test was carried out implementing the best combination of factors, suggested by the results of the experiment, to confirm that the condition of Test 5 gave more than 6000 linear meters of clean print which displayed significantly lower levels of “mottle”. The print sample produced from this test was less blotchy to the observer. The test was stopped at 6000 metres due to the cost and time factors. The confirmation test proved that the experiment has demonstrated it has been possible to optimise the press performance using the data provided. The softer plate was able to transfer the image to the uneven surface of the substrate with less printing pressure, which resulted in a more even printing of the vignette than was possible using the harder Shore plate and thus a reduction of “mottle” was achieved.

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