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A preliminary investigation into the effect of select paper characteristics on dot gain in web offset lithography

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MASTER'S THESIS

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A PRELIMINARY INVESTIGATION INTO THE EFFECT OF SELECT PAPER CHARACTERISTICS ON DOT GAIN IN WEB OFFSET LITHOGRAPHY

by

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ABSTRACT

This thesis describes a screening experiment designed to determine which of seven paper characteristics influence dot gain in web offset lithography. Dot gain is the enlargement of halftone dots during printing from plate to paper with a resultant increase in dot area. The variability of dot gain during a press run and from run to run is detrimental to the quality of black and white and color reproductions.

The seven paper characteristics: gloss, smoothness, absorption, physical density, caliper, opacity, and formation are measurable characteristics used to describe the printability of a paper. Using one unit of a four-unit web offset perfecting press, four papers were printed and dot gain's two components, slur and fill-in, calculated. Correlation, regression analysis and graphic illustration were used to analyse data.

The thesis concludes that smoothness is the main contributor to slur and absorption has the greatest influence on fill-in. Other paper characteristics shown to influence slur and fill-in are caliper and physical density.

Also included are discussions of future experiments required to test the relationship between paper and dot gain and why certain paper properties may influence slur and fill-in.

INTRODUCTION

The purpose of this thesis is to describe a preliminary investigation into the effects of seven paper characteristics on dot gain in web offset lithography. This report is intended to provide background on the topic of dot gain, explain concepts fundamental to future investigations, and describe the methods used and conclusions reached in the experimental portion of the study. A section entitled "Discussion and Recommendations" explores possible future directions in the investigation of dot gain sources.

A secondary aim of this thesis is to gain an understanding of the variability of dot gain in a press run and to determine which types of paper exhibit the least amount of process variability. Paper is only one of many press variables which affect dot gain, but for reasons of manageability, only paper was studied.

Dot gain is the enlargement of halftone dots during printing from plate to paper with a resultant increase in relative dot area. Rhodes(1), in 1955, attributed dot gain to two sources: Slur, a smearing in one direction of the halftone dot and fill-in, a radial growth of the dot. Based on observations made during this investigation, Rhodes'

concept is sound, with different factors contributing to each phenomenon independently.

Dot gain in itself is not detrimental to the quality of halftone reproductions. It can be compensated for by reducing the dot size proportionally on halftone negatives or positives. Dot gain is of concern to pressmen as it changes unexpectedly during a press run and from run to run. In single color printing, changes in dot gain influence both the contrast and overall darkness of the reproduction. In process color printing, unexpected differences in dot gain between the three color printers causes shifts in gray balance. In extreme cases, reproductions must be discarded because of poor quality due to dot gain.

This project was born of the interest on the part of research institutes, universities and private industry to isolate the major sources of variability of web offset printing. In order to control such inconsistencies as unpredictable slur and fill-in, these sources must be identified and measurable. This thesis identified which of the following paper characteristics may be associated with slur and fill-in:

Formation	Physical Density
Absorption	Opacity
Caliper	Gloss
Smoothness	

Statistical correlation, regression analysis, photomicrographs and control charts are used to indicate relationships between

dot gain and these paper characteristics.

Using this information as a lead, future workers in the realm of dot gain may explore in detail the relationship between these paper properties and dot gain. Ensuing sections will provide a background on dot gain, a method of measuring slur and fill-in, an explanation of how light scattering affects halftone density and compensation for this phenomenon. The experimental methodology describes the use of a four-unit web offset press to print four different rolls of paper which were then measured to calculate slur and fill-in. The analysis of data section details statistical methods and the use of computers for analysing collected data. The final chapters, "Conclusions" and "Recommendations and Discussion" offer future directions in dot gain research.

BACKGROUND ON DOT GAIN AND THE ABILITY TO MEASURE SLUR AND FILL-IN

A review of pertinent literature has revealed that few studies of the sources of dot gain have been undertaken. In those that have been published, a large portion of the blame for dot gain is directed at ink-film thickness and paper smoothness. Smoothness is only one of seven characteristics chosen for this study. The other six, not mentioned in the literature, were chosen because they represent measurable characteristics which are used to describe the printability of a paper.

Three previous studies of ink-film thickness and paper smoothness well illustrate their effect of dot gain. Buckler[2] showed that when a rough and smooth paper are both printed to the same ink-film thickness, the rough paper exhibits slightly more dot growth. Both rough and smooth papers, when printed to excessive ink-film thicknesses, show rapid dot gain--with the effect being greater on the rougher paper. When rough and smooth papers are printed to the same solid ink density, the rougher paper will show greater dot gain than the smooth sample. The reason for this lies mainly in the thicker ink films necessary to achieve the same density on a rough paper as a smooth stock.

Blokhuis and Kalff[3] examined the relationship between smoothness and dot gain more closely. The purpose of their study was not to investigate dot gain causes, but rather to test the feasibility of a dynamic smoothness tester for paper. Recognizing that the unevenness of tints was caused by local variations in dot gain, they compared microdensitometeric tracings of tints with dynamic smoothness measurements of the same paper. They concluded that the amount of tint unevenness could be predicted on the basis of the smoothness of the paper (as measured with their instrument).

Cooke and Hill[4], in an investigation of the effects of paper smoothness, ink-film thickness and ink viscosity on dot gain, found the following: That smoother papers will exhibit slightly less dot gain than rough papers when printed under normal conditions. When printed to extreme ink-film thicknesses, their results verified the findings of Buckler in that dot gain increases rapidly and to a greater extent on rough papers.

Rhodes' 1955 TAGA report is the pioneering source to investigate slur and fill-in as the two components of dot gain. In the study he describes test objects, printed on a press sheet, which are designed to detect slur and fill-in. The test object he found most sensitive to slur consisted of two patches, each of which was a 175 lines per inch line ruling The lines of one patch run at right angles to sheet travel

direction while the lines of the other run parallel to sheet travel. When directional smearing occurs, as it does with slur, the patch with lines perpendicular to sheet travel darkens as ink is smeared onto the white paper between the lines. In contrast to this, the patch with lines parallel to sheet travel does not darken, as slurring results only in a slight elongation of the lines. The difference in reflection density of the two patches provides a numeric measure of the degree of slur.

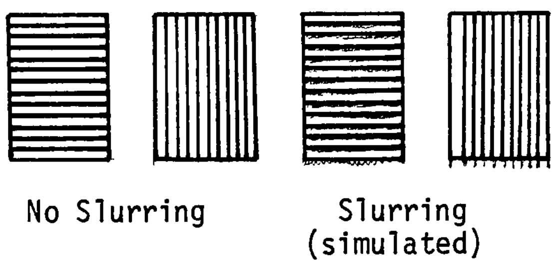


Figure 1: Rhodes' Test Object to Detect Slur

To measure fill-in, Rhodes designed a test object consisting, again, of two patches: a solid ink patch and a 300 lines per inch halftone patch. With such a fine line halftone, a small radial growth, or filling-in of the halftone dots results in an acute increase in reflection density (see appendix 1 for mechanism of filling-in and the resultant increase in relative dot area). Thus, this fine line halftone patch is very sensitive to filling-in. At the same time,

the solid ink patch will show no increase in reflection density. The ratio of the solid ink density to that of the halftone patch represents a measure of fill-in. As the ratio approaches 1:1, fill-in is increasing.

The purpose of Rhodes' experiments was to correlate his new objective measurements of print sharpness with subjective evaluations of halftones printed on the same sheet as the test objects. Observers, experienced in lithographic printing, ranked the halftone reproductions according to the degree of slur and fill-in in each. The same prints were then ranked using the objective measures obtained from the test objects. Good correlation was found between the subjective and objective ranking methods which permitted Rhodes to conclude that the test objects could be used to measure slur and fill-in.

Although Rhodes' test objects were sensitive to slur and fill-in independently, they provided no more than an arbitrary value for slur and fill-in. There was a need to express slur and fill-in in terms representing the amount of each phenomenon. The next section describes the evaluation of a compact test object based on Rhodes' conclusions and a means of expressing slur and fill-in in absolute terms.

THE YULE-NIELSEN EQUATION AND ABSOLUTE MEASUREMENT OF SLUR AND FILL-IN

John A. C. Yule proposed that the amount of dot gain could be expressed in micrometers, thus providing an absolute measurement of gain. Using reflection density readings of a solid and a halftone patch, the Yule-Nielsen equation[5] (equation 1) is used to calculate the relative dot area of the halftone.

$$a = \frac{1-10^{-D_t/n}}{1-10^{-D_s/n}}$$

Where: a= relative dot area
D_t= halftone density
D_s= solid ink density
n= light scatter coeff.

EQUATION 1: The Yule-Nielsen Equation

The relative dot area is then converted to absolute dot area. The methodology used is proprietary information of the Graphic Arts Research Center at Rochester Institute of Technology.

The absolute dot area of the film negative or printing

plate is then subtracted from the absolute dot area of the print. If the value is "0", then no dot gain has occurred. This method provides a means of measuring the total dot growth but does not distinguish between gain attributable to slur and that attributable to fill-in.

Pearson, also of RIT, took Yule's method a step further[6] by suggesting that Rhodes target be used for the reflection density measurements needed to solve the Yule-Nielsen equation. Pearson reasoned that independent values for slur and fill-in would be more useful to the pressman who does one thing to correct for fill-in and another for slur.

Pearson developed a compact test object designed to be small enough to fit in the trim or gutter margins of a press sheet, yet large enough to be read by a reflection densitometer (figure 2). The test object contains all the necessary configurations to calculate slur and fill-in by the Pearson Method.

Figure 2: Pearson's Slur and Fill-In Test Object

This enables a printer to determine the amount of slur and fill-in using a standard reflection densitometer and the Yule-Nielsen equation. Before this can be done accurately, however, the component "n" of the Yule-Nielsen equation must be provided. "n" is a correction factor for light lost (and density gained) in a halftone due to light scattering within the paper.

If this density difference is not accounted for, calculations of slur and fill-in will be inaccurate. The Yule-Nielsen equation requires an accurately determined "n" so that calculated relationships between dot area and density better represent the actual situation. The experiment for this thesis involved a comparison of dot gain values for four different papers printed with the same line ruling on a web offset press. As a result, it was vital to establish as accurate an "n" value as possible.

The section which follows explains the Yule-Nielsen equation, "n", how light scattering affects halftone density and an easy method for determining "n" for different papers.

THE INFLUENCE OF LIGHT SCATTERING ON HALFTONE DENSITY

The Yule-Nielsen Equation is similar to that published by Murray in 1936(7) with one essential difference. The Murray-Davies equation is identical to that shown in Equation 1 without the "n" value. It relates the density of a halftone with a given area to the solid ink density being used to print that halftone. Where Murray's equation is inaccurate is in compensating for the light scattering effect of paper printed with a halftone.

When light strikes the surface of a paper printed with a 50% halftone, it would seem logical that slightly less than half that light would be absorbed, since ink is an imperfect light absorber. More than 50% of the light should be reflected back to the viewer. To the contrary, in practice usually more than half the incident light is absorbed by the printed halftone, resulting in a reflection density greater than 0.30.

The loss of light occurs as follows: When light strikes an unprinted paper surface, that light enters the body of the paper and is spread sideways. The amount of spreading varies with the type of paper and across each paper. On an

unprinted surface, however, most of the light will leave the paper at places other than where it entered (see figure 3). If that same paper is printed with a 50% halftone pattern, half the light will strike the unprinted portion of the paper between the halftone dots. A portion of that light will enter the body of the paper and be spread sideways. Some of the spread light will end up beneath an inked dot and will be absorbed as it attempts to leave the paper through the dot (see figure 4). This absorption of light which originally fell on an unprinted surface results in a higher reflection density than would be predicted by the Murray-Davies equation.

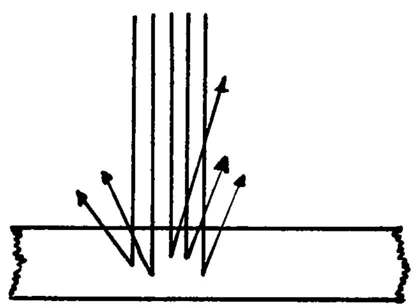


Figure 3: Light Scattering on an Unprinted Surface

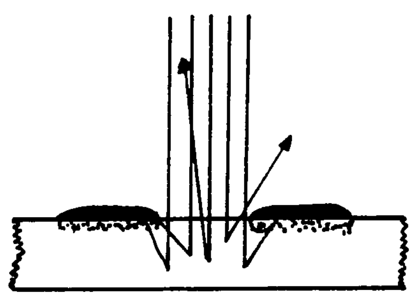


Figure 4: Light Scattering on a Paper Surface Printed with a Halftone Pattern

The light loss due to spreading is also affected by the frequency of the screen ruling used to print the halftone. With finer screen rulings, the light loss is greater. The distance between the center of the uninked area between the dots and the edge of the dot is less for fine screens than for course (see figure 5).

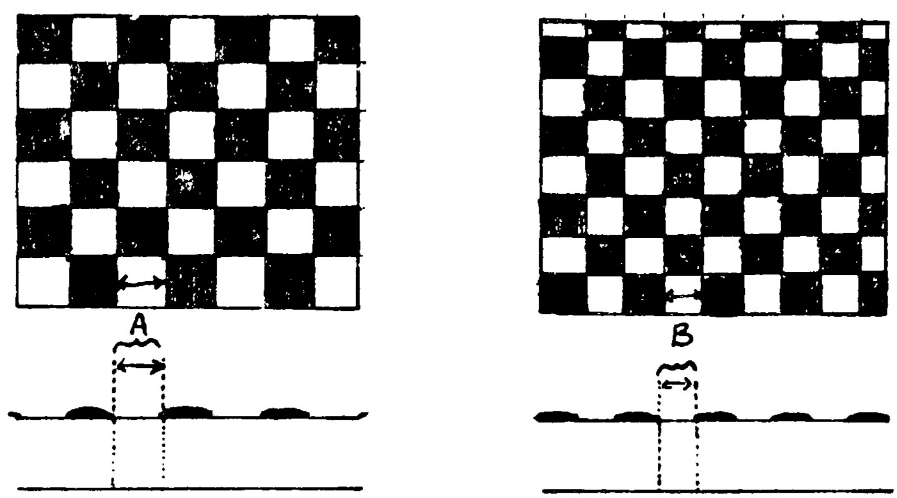


Figure 5: Course vs. Fine Screen Rulings and Difference in Light Loss Due to Scatter. Amount of Space for Light to Scatter Before Being Interfered with by a Halftone Dot is Greater in "A" than in "B"

If the extent of light spreading, as determined by the paper, remains unchanged, the likelihood of light reaching a dot is greater for the fine screen pattern because of the shorter distance to reach a dot. Therefore, more light can be absorbed and a finer screen will look darker than a course screen.

DETERMINATION OF THE YULE-NIELSEN "n" VALUE

The "n" value of Yule and Nielsen's version of the Murray-Davies equation provides a correction factor for this light loss due to scattering. The higher the value of "n", the greater the light loss for that paper/screen ruling combination. For very course screens on coated paper, "n" approaches the lower limit of 1.0. A value of 1.0 indicates that no light loss has occurred. Very fine screen rulings on the same paper produce "n" values usually between 1.2 and 2.0. On uncoated papers printed with fine screen rulings, "n" will usually exceed 2.0 and approach 3.0.

Historically, "n" determination has been based choosing a value believed to be representative of the light loss for the paper/screen ruling combination used. One accepted method was to measure, with a planimeter, the dot area of photomicrographs of a printed halftone. Dot area, along with reflection density values of the printed halftone and a solid patch, provides three of the four values needed to solve the Yule-Nielsen equation. Since it is not possible to solve the equation directly for "n", an iteration process is necessary. By this process, dot areas are calculated using different "n" values until the calculated dot area matches

the physically determined dot area. The "n" value used for the match is then an accurate correction factor for the equation.

The physical dot area determination method using a planimeter is quite time consuming and cumbersome when dealing with a large sample size. A new method for measuring dot area was suggested for this experiment[8]. A microscope, fitted with a calibrated movable hairline, was used to observe the line ruling patches of the test object (see figure 2). The widths of eight printed lines and eight unprinted spaces were measured for each patch to obtain an average relative line area. For each of the four types of paper used, eight such patches were measured.

Using the average relative line area of each of the patches, eight "n" values were determined and averaged to obtain "$\bar{n}$". The importance of this practice is that it was possible to determine an "$\bar{n}$", a standard deviation for "n" and a range of "n" for each paper under investigation. (See appendix 2 for complete listing of reflection densities and "n" for all patches measured.)

Previously it was felt that "n" determined at one location on a sheet was consistent across the sheet. This experiment has shown that this is not the case, as indicated in Table 1, Page 16. The variability of "n", as demonstrated by

the standard deviation and range, shows that measurement of "n" at one location may not represent the light loss due to scattering for the majority of the sheet.

PAPER TYPE	"$\bar{n}$"	St. Dev.	Range
Uncoated Lt.Wt.	1.41	.06	.20
Dull Coated	1.71	.17	.47
Gloss Coated	1.59	.06	.18
Cast Coated	1.57	.30	.96

Table 1: "$\bar{n}$", Standard Deviation of "n" and Range of "n" for Four Papers

EXPERIMENTAL METHODOLOGY

A large sampling for determination of the "n" value for the Yule-Nielsen equation insures dependable measurement of slur and fill-in on different types of paper. The intent of the experimental portion of this project was to choose seven paper characteristics likely to affect slur and fill-in and test the hypothesis that they are significant contributors to slur and fill-in. To accomplish this task, the experiment was performed in three phases:

Phase 1: Selection of roll paper and measurement of seven paper characteristics listed in description of Phase 1.

Phase 2: Press run of Goss C-38 Web Offset perfecting press and sampling for measurement of slur and fill-in.

Phase 3: Calculation of slur and fill-in. Analysis of data using statistical inference techniques.

Details of each phase follow.

Phase 1: Selection of Paper and Measurement of Paper Characteristics

The papers used for the experimental press run were isolated from a selection of nine rolls of web paper in the Graphic Arts Research Center warehouse. The nine were chosen based on availability for use. Each roll was sampled and measured for each of the following paper characteristics.

Hunter Gloss	Formation
IGT Absorption	Sheffield Smoothness
Caliper	Physical Density (g/cm^3)
Opacity	

A complete description of the instrumentation used and procedures followed is contained in Appendix 3.

The objective in selection was to choose four values for each paper characteristic which were sufficiently separated to allow for linear correlation analysis between slur and fill-in and the characteristics, singly. To accomplish this,

four papers were chosen which represented a fair spread of each of the seven paper characteristics (table 2).

Top of Web

Characteristic	Uncoated	Dull Coat	Gloss Coat	Cast Coat	
Gloss	5.6	23.7	72.1	82.1	
Formation	.027	.016	.013	.021	
Opacity	86.8	95.6	93.6	90.2	
Smoothness	132.8	55.3	33.1	11.0	
Absorption	22.9	11.4	8.6	10.0	
Physical Density	.072	.083	.115	.084	g/cm^3
Caliper	2.6	4.6	3.2	3.8	

Bottom of Web

Characteristic	Uncoated	Dull Coat	Gloss Coat
Gloss	6.6	22.9	71.3
Smoothness	149.6	81.9	64.3
Absorption	21.2	11.2	7.9

Formation, physical density, caliper, and opacity for the bottom of the web are not listed as they do not exhibit two-sidedness characteristics.

Table 2: Paper Selection for Press Run

Definition of Terms

Gloss is the specular reflection of the paper surface relative to a standard. Light is directed at the paper surface and the amount reflected is measured by a photo-detector and expressed in percent gloss (light reflected). Both the light source illuminating the paper and the

photodetector measuring the reflected light are at 75 degrees relative to a line perpendicular to the paper surface (see figure 6).

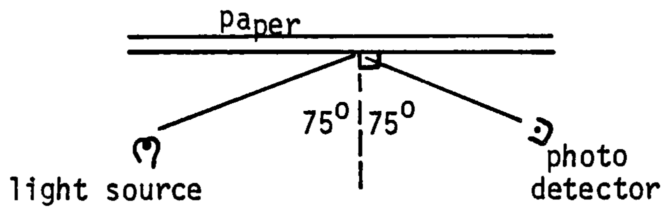


Figure 6: Diagram of Gloss Meter Measurement Mechanism

Opacity is the degree to which paper absorbs light. It is determined by measuring the amount of light reflected by paper backed first by a white, then by a black backing. The relationship of these two values is the percent opacity of the paper.

Physical density is a measure of the bulkiness of the paper. The weight per unit volume of a dried sample is its physical density.

Absorption is the degree to which paper absorbs oil. It is expressed as:

$$\frac{1000}{\text{mm stain length}}$$

where the stain length is the length of an ellipse made by forcing a given volume of oil through the nip of an IGT Printability Tester fixed with a paper sample strip.

Smoothness is the term applied to surface irregularities caused by wire marks, felt patterns, coating piles, projecting fibers, etc., on paper. An air passage test is performed which measures the resistance of the paper surface to the passage of air between an orifice clamped to the sheet and a hard glass backing.

Formation is a measure of the uniformity of fiber distribution across a sheet of paper. The standard deviation of random transmission density readings on the sheet provides a formation value[9].

Caliper is the thickness of the sheet, expressed in mils. The mean value for a number of samples is used as the caliper value.

Press Run and Sampling for Measurement of Slur and Fill-In

The selected rolls were printed on the Goss C-38 four-unit web perfecting press at the Graphic Arts Research Center (RIT). The fourth unit only was used for printing. Roll printing order was determined on the basis of roll size and ink requirements. The following printing order was used:

1. Lightweight Uncoated
2. Dull Coated Two Sides
3. Gloss Coated Two Sides
4. Cast Coated One Side

The test form used was designed to allow the press crew to visually evaluate the images and determine proper solid ink density for commercial quality reproduction (see appendix 4 for test form reproduction). The reasoning behind this was to provide results indicative of commercial printing applications. Since solid ink density was set off the uncoated sheet and carried over three coated sheets, the SID level for the coated sheets was less than that found in commercial applications (table 3). The image quality of the halftones and solid areas were, however, quite acceptable and indicative of normal printing, owing to the ink holdout of the coated sheets.

Paper	Avg. SID
Uncoated-Top	1.04
Bottom	1.02
Dull Coated-Top	.98
Bottom	1.06
Gloss Coated-Top	1.15
Bottom	1.11
Cast Coated	1.12

Table 3: Average Solid Ink Density

During printing, each roll was printed until the head pressman indicated that a commercial quality level had been reached. At that time, the press signature counter was activated and three thousand impressions were printed.* From that three thousand, five samples were taken--each two

*Only 1380 impressions were printed on the full coated sheet due to limited roll size.

hundred fifty impressions--allowing for thirteen sampling intervals for each roll. In addition, series of one hundred consecutive signatures were pulled at the beginning of each run and every one thousand impressions.

After each run, the press was stopped, blanket accumulation samples were taken, and plates and blankets were cleaned. During the press run, web tension, ink-film thickness, fountain solution pH and chill roll torque were monitored. Observations were made throughout the run to spot excessive web flutter or other dynamic variables capable of influencing results (see appendix 5 for complete documentation).

Measurement of Slur and Fill-In for Analysis

To facilitate calculation of slur and fill-in, two computer programs were written. The first allowed for measurement of test objects with a reflection densitometer and storage of density values. The second took the information stored by the first program and calculated slur, fill-in, average densities and percent dot gain.

The method used for calculation of slur and fill-in and listings of the programs are not included here as they

reveal proprietary information belonging to the Graphic Arts Research Center, RIT.

On each of the five sheets taken at two hundred fifty impression intervals, two printed test objects were measured. The slur and fill-in values derived from these two sets of measurements were averaged to provide the slur value and the fill-in value for that one sheet. This procedure was repeated on each of the five sheets in each interval sampling. The sheet slur and fill-in values were then averaged to provide a sampling interval value. To obtain a dot gain, slur and fill-in value for a paper type, the interval values were averaged.

ANALYSIS OF DATA

The analysis techniques utilized in this project were chosen to fulfill four tasks: 1) To gain an understanding of the interrelationships between individual paper characteristics, 2) To probe the relationships between individual paper characteristics and slur and fill-in, 3) To discover which groups of paper characteristics are the greatest contributors to slur and fill-in, and 4) To provide a means whereby the variability of slur and fill-in could be graphically displayed, thus indicating which of the four paper types exhibit the best process control.

1) Interrelationships Between Individual Paper Characteristics

The method used for the first objective was to build a matrix of correlation coefficients (table 4). The purpose of this technique was to find which characteristics were so closely tied to one another that they could be considered dependent. As an example: gloss and smoothness correlate and cannot be separated when discussing their effect on slur.

The correlation coefficient, r, is a value between -1 and +1 which indicates the relationship between two variables. It is derived using the following equation:[10]

$$r = \frac{\text{covariance (XY)}}{\sqrt{(\text{variance X})(\text{variance Y})}}$$

As r approaches +1 it means that one variable increases as the other increases. A value approaching -1 indicates that one variable decreases as the other increases. An r close to 0 infers that no relationship exists between the two variables in question.[11]

To produce this matrix, the paper characteristics for the felt and wire sides of the paper were pooled to provide more data points. Before this was done, however, assurance was gained that the pooling of paper values would be applicable to the pooling of the responses, slur and fill-in, for the two sides of the sheet.

A Student t test was performed on the data from the top and the bottom of the web to verify that the responses, slur and fill-in, were representative of the same population.[12] The Student t test is a statistical method whereby two sets of data are compared to test the hypothesis that they are members of the same general population. By this method it was shown that although the top and bottom halves of the printing unit display unique printing characteristics, the patterns are the same and, therefore, available for combination.

	Form	Opac	Smth	Glss	Absb	PhyD	Calp
Form	1.00						
Opac	-.92*	1.00					
Smth	.70	-.61	1.00				
Glss	-.60	.34	-.86*	1.00			
Absb	.92*	-.82*	.88*	-.81*	1.00		
PhyD	-.82*	.54	-.58	.76*	-.77*	1.00	
Calp	-.56	.81*	-.55	.12	.59	.01	1.00

Table 4: Correlation Matrix of "r" Values for Each Paper Characteristic Against all Others. Form=Formation, Opac=Opacity, Smth=Smoothness, Glss=Gloss, Absb=Absorption, PhyD=Physical Density, Calp=Caliper.

Note: As Sheffield Smoothness Values Decrease, Paper Becomes Smoother. Increased Formation Values Indicate Poorer Formation. In all Other Cases, Higher Values Indicate a Greater Degree of That Particular Characteristic.

Eight paper surfaces were available for evaluation. However, the uncoated side of the cast coated sheet was not used in the analysis. This surface showed highly irregular printed results. An investigation into the properties of this surface indicated that it was unsuitable for printing and intended for gumming as a label paper. Based on this, it was decided that rather than subject the experiment to erroneous results, the slur and fill-in values for that surface would be discarded.

By using seven sets of input paper characteristics and seven sets of slur and fill-in responses, the critical value of significance for the correlation coefficients in table 4

is .75 at an alpha of .05. This means that any coefficient greater than .75 infers a statistically significant relationship with a .05 chance of being wrong. Asterisks in table 4 designate those relationships shown to be significant.

2) Relationship Between Individual Paper Characteristics and Slur and Fill-In

Phase two of the analysis of data involved the establishment of correlation coefficients between each paper characteristic individually and the two responses, slur and fill-in (see table 5). Again, the critical level of significance is .75 at an alpha of .05. Asterisks denote significance.

	Fill-In	Slur
Formation	.86*	-.42
Opacity	-.80*	.38
Smoothness	.94*	-.86*
Gloss	-.80*	.65
Absorption	.96*	-.61
Physical Dens.	-.66	.32
Caliper	-.66	.44

Table 5: Correlation Coefficients: Slur and Fill-In Versus Paper Characteristics.

Note: As Sheffield Smoothness Values Increase, the Paper Becomes Rougher. In the Above Example, as the Paper Becomes Smoother, Fill-In Decreases, and Slur Increases, Even Though the Signs Indicate the Opposite.

3) Relationship Between Groups of Paper Characteristics and Slur and Fill-In

The third evaluation process involved the use of the stepwise backward regression technique of data analysis. Raw data for each of the paper characteristics and each of the response variables, slur and fill-in, were entered into regression. By this method, those input variables (paper characteristics) which account for the greatest amount of observed variability in the response variables (slur and fill-in) are isolated. This indicates which combination of paper characteristics have the greatest influence on slur and fill-in.

Before regression analysis could be performed, any strong correlation between input variables had to be eliminated. Any two inputs which are too closely related will create false results. Absorption and smoothness, being closely related, were not entered at the same time as input variables.

When slur was entered into regression against all characteristics except absorption, the following "best model statistics" resulted when thickness, smoothness, opacity, and physical density were chosen as the main contributors:

Multiple R = .933
R^2 = .87
Standard Error of the Residual (s_e) = .8035

Multiple R is a measure of goodness for the model chosen. As R approaches 1.0, the model is improving. R^2 is the amount of variability of the response variable explained by the group of input variables. In the above case, .87 or 87% of slur is explained by the four selected paper characteristics. Standard error of the residual is a measure of unexplained error present in the model. To measure the true effectiveness of a regression model, R^2 and s_e are observed. If, when adding or subtracting elements to the model, R^2 increases while s_e decreases, the model is improving. The model did not improve when absorption was substituted for smoothness as an input variable.

The same regression technique was then used with fill-in as the response variable. Again, absorption was eliminated due to its strong correlation with other input variables. The same four paper characteristics provides the best model, based on these statistics:

Multiple R = .9936
R^2 = .9872
s_e = 2.87

However, since absorption correlated with fill-in to a greater extent than smoothness (.96 vs. .94), absorption was substituted for smoothness as an input variable in the analysis. From this set, the following statistics were determined:

Multiple R = .994
R^2 = .994
s_e = 1.97

Since R^2 increased at the same time s_e decreased, it can be concluded that the presence of absorption in the regression model provides a better model of fill-in.

4) Graphic Display of Slur and Fill-In

The fourth method used for analysis was to plot percent dot gain, amount of slur and amount of fill-in against impressions in control chart form. This provides a graphic display of the behavior of a printed image at the printing stage from four different papers. Appendix 7 contains these charts. Below is listed the average slur, average fill-in and the standard deviation of slur and fill-in for the seven paper surfaces.

Paper Surface	Slur Avg.	Slur St.Dev.	Fill-In Avg.	Fill-In St.Dev.
Cast Coated	4.2 µm	1.9 µm	6.9 µm	1.92 µm
Uncoated Lightwt.-Top	1.1 µm	0.9 µm	36.9 µm	1.80 µm
Uncoated Lightwt.-Bot.	1.0 µm	0.7 µm	42.9 µm	1.0 µm
Dull Coat Top	3.9 µm	1.8 µm	11.5 µm	0.6 µm
Gloss Coated Top	3.1 µm	1.4 µm	9.7 µm	1.0 µm
Gloss Coated Bottom	2.3 µm	0.7 µm	9.1 µm	1.7 µm

Table 6: Slur and Fill-In Averages, Standard Deviations

CONCLUSIONS

The hypothesis tested in this screening experiment is that gloss, physical density, caliper, absorption, opacity, formation and smoothness are contributors to the two components of dot gain: slur and fill-in. Based on observations made during this project, the physical properties of paper have an affect on dot gain, and the subject is worthy of further investigation. Below are detailed the results of the experiment.

SLUR & FILL-IN

In reference to slur, the smoothness of paper is shown to be the most significant contributor to this phenomenon. Table 5 (page 27) demonstrates that as the paper surface becomes smoother, slurring increases. The relationship, as expressed by the correlation coefficient r, is strong. Smoothness is also part of the regression model which accounts for 87% of the variability of slur. Also present in the regression model are thickness (caliper), opacity and physical density. Physical density and caliper, although

insignificant in linear correlation, appear significant in multiple regression. As each of these three characteristics increase, slur increases. According to the analysis methods and papers used in this experiment, these four characteristics of paper are the major contributors to slur.

Based on this experiemnt, fill-in appears to be a function of all surface qualities of paper, especially absorption. Table 5 indicates that, in addition to absorption, formation, opacity, smoothness and gloss correlate with fill-in significantly. Fill-in increases as the paper becomes more absorptive, rougher, less glossy, less opaque and poorer in formation. Each of these traits indicate that as the sheet becomes more "open" (less perfect printing surface), fill-in increases.

VARIABILITY OF SLUR AND FILL-IN

Table 7, page 34, shows the standard deviations of slur and fill-in expressed as a percent of slur and fill-in averages for each of the four paper types used (from table 6, page 31 and graphs, appendix 6). This method affords comparability of values for the four sheets and an easy method of determining which paper type exhibited the greatest amount of variability of slur and fill-in.

Paper Type	Slur-St.Dev % of Avg	Avg of Top,Bot.	Fill-In St.Dev % of Avg.	Avg of Top,Bot.
Cast Coated	45%	45%*	28%	28%*
Lightweight Uncoated-Top	80%		5%	
Lightweight Uncoated-Bot	70%	75%	2%	3.5%
Dull Coat-Top	46%		5%	
Dull Coat-Bot	46%	46%	5%	5%
Gloss Ctd-Top	45%		10%	
Gloss Ctd-Bot	30%	37%	19%	14%

Table 7: Standard Deviations of Slur and Fill-In as Percent of Average. (*Avg=Value from 1 side)

Of the four papers tested in this experiment, the cast coated sheet showed the greatest amount of variability of fill-in (28%). The gloss coated sheet exhibited the second greatest amount of variability (14%). The lightweight uncoated (3.5%) and dull coated (5%) sheets provided the best process control. The lightweight uncoated sheet showed the least amount of process control with regards to slur (75%). The cast coated (45%) and dull coated (46%) sheets were essentially the same and the gloss coated sheet exhibited the least amount of variability (37%). Throughout the experimental press run, the amount of slur was low (see appendix 6).

The process control chart-type graphs for each paper are found in appendix 6.

The section that follows, "Discussion and Recommendations

for Future Investigations," outlines some possible reasons for the above conclusions and lists experiments to uncover further information on the relationship between paper characteristics and slur and fill-in.

DISCUSSION AND RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

The purpose of the formal portion of this thesis was to identify which characteristics of paper appear to influence the amount and variability of dot gain in web offset lithography. The reported results are based on analysed data and reflect specific responses to carefully chosen input. As in any experiment, many questions arose during this experiment as to why certain paper properties correlate with slur and fill-in. This section takes the liberty of speculation and conjecture, discussing possible reasons. It also outlines future experiments which may answer some of the questions regarding the relationship between paper and dot gain.

SLUR

The presence of smoothness, both in the regression model for slur and as the strongest linear correlation to slur, fortifies Rhodes' belief that slur is caused by slippage at the printing nip at the moment of impression. When paper passes through the nip point between blanket and impression cylinders, the ink film on the blanket serves as a lubricating layer. On blanket-to-blanket perfecting presses, such as the Goss C-38 used for this experiment, the opposing blanket is considered the impression cylinder. With an increase in paper smoothness, the tendency for the two surfaces to lose traction also increases and slurring occurs.

Even though the linear correlation between slur and physical density is insignificant (table 5, page 27), the addition of this element to the regression model improved that model. As a sheet of paper becomes more dense, there is less tendency for the paper to give under the impact of the printing nip. With less shock absorbing capacity within the sheet, it is possible that this energy manifests itself as slippage, causing slur. Thickness enters into the picture for the same reasons; as the caliper of the sheet increases, the force required to compact the sheet in the printing nip

increases, creating a tendency to slip and slur. Pressmen often correct for excessive slur through reducing the squeeze at the nip.

The role of opacity in affecting slur is speculative. Opacity is built into printing papers by the addition of minerals with differing refractive indices. This is especially true in the case of coated papers. Titanium dioxide, ground limestone, calcium carbonate, clay and others constitute the pigment portion of paper coatings. It is possible that as the sheet structure is modified with mineral particles, the compressibility of the sheet decreases, creating an increase in slur by the action described earlier. Appendix 7 illustrates the relationship between percent mineral content and the amount of slurring on each sheet. Mineral content does not statistically correlate with slur or fill-in, but further study may bear this hypothesis out.

FILL-IN

Fill-in, on the basis of observations made in this project, may be caused by radial absorption of ink at the edges of images. The strongest linear correlation to fill-in is absorption (.96). Regression analysis indicates that

absorption, physical density, caliper, and opacity provide the best grouped explanation of fill-in using the four papers of this experiment.

The key characteristics in this model are absorption and physical density. Figures 7, 8, and 9 are photomicrographs of 50%, 150 lines/inch halftone dots on the bottoms of the lightweight uncoated, dull coated, and gloss coated sheets, respectively at 220X magnification. The absorption values for these paper samples are 21.2, 11.2 and 7.9. Figures 10, 11, 12, and 13 are photomicrographs of the tops of the lightweight uncoated, gloss coated, dull coated, and cast coated sheets, respectively. These four sheets have (respectively) absorption values of 22.9, 11.4, 8.6, and 10.0. Physical density values for the four sheets (respectively) are .072, .083, .115, and .084.

Looking closely at the edges of the halftone dots in each photomicrograph, one sees irregular extensions of the printed dots. These "tails" are lighter in density than the major portion of each dot and decrease in severity as the sheet becomes less absorptive and more dense. This leads to the following question: From the moment of impression until the ink film immobilizes, is there a migration outward from the image of both vehicle and pigment?

This migration of ink may be attributable to capillary action as the ink travels along the joining surfaces of wood

Figure 7

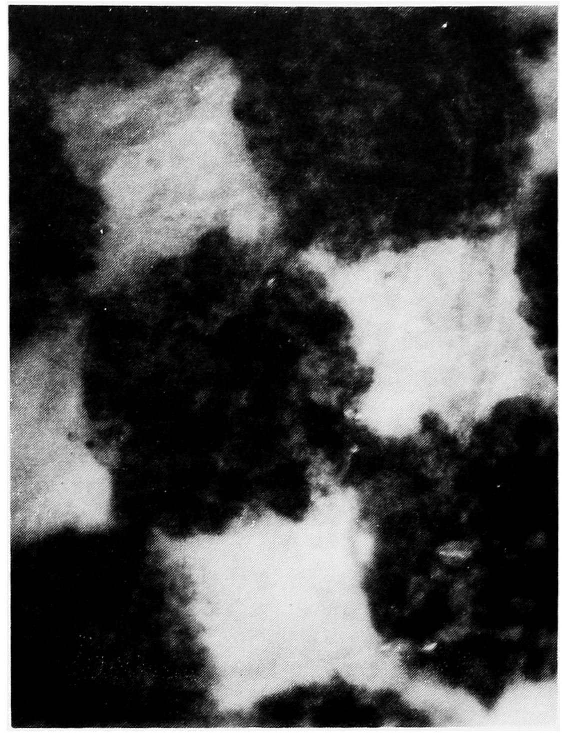


Figure 8

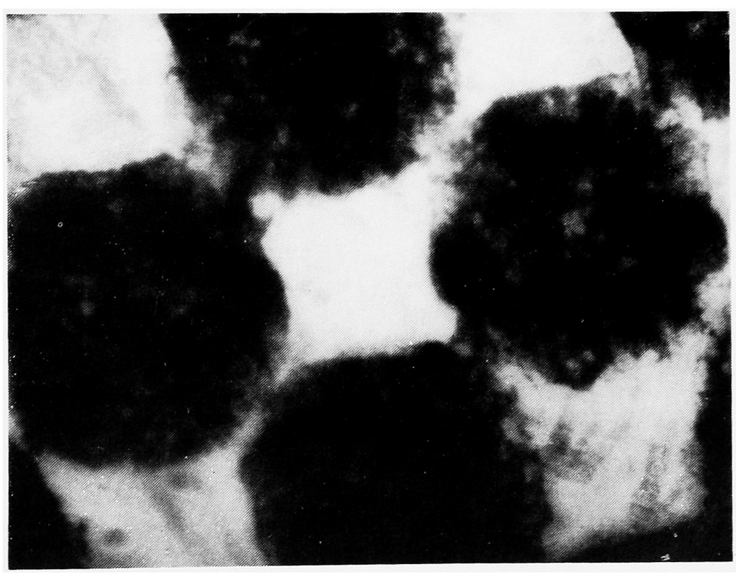


Figure 9

Figure 10

Figure 11

Figure 12

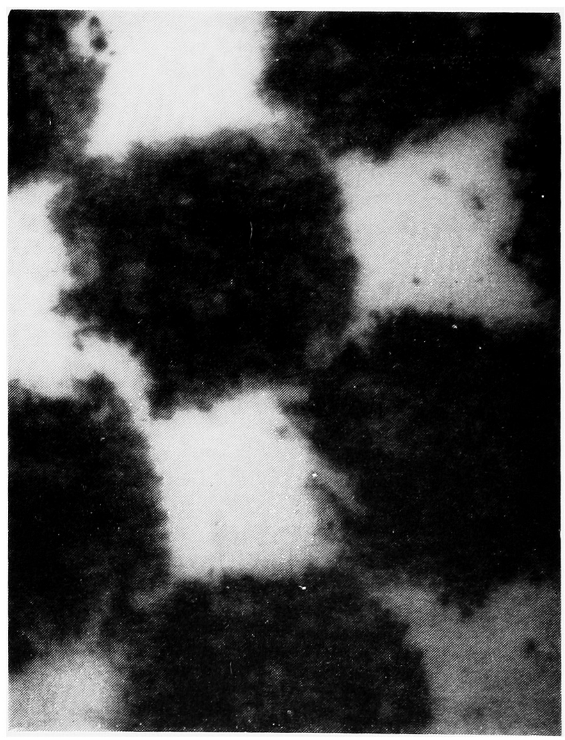


Figure 13

fibers in intimate contact. A small amount of migration may be the result of capillary action in the hollows of cellulose fibers and in the air space between fibers. As the sheet becomes more dense and less absorptive, the free space available for migration decreases, as does the action of filling-in.

The only departure from this process is on the top of the cast coated sheet (figure 14). In the cast coating process, the coating materials are not scraped from the surface of the sheet as they are in the trailing blade or other conventional coating processes. Rather, they are applied, then dried in intimate contact against a polished chromed steel drum, imparting a mirror image of the drum onto the coating. This process allows a thick, even coating to be applied to the surface, effectively covering the paper fibers. Cast coating is considered one of the best coatings for printing paper surfaces, since ink rarely comes into contact with fibers. With little contact between fibers and ink, the mechanism of filling-in, as hypothesized above, is limited.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

Following is a list of some of the unanswered questions that arose during the course of this study.

1) What happens, on a microscopic scale in both time and distance, from the moment of impression until an ink film is immobilized? Does the ink pigment and/or vehicle migrate, creating the phenomenon of fill-in? To accomplish this task, a special ink with a tracer material in the vehicle would have to be prepared. An electron microscope would be useful in determining the path of ink pigments.

2) What is the relationship between the coefficient of friction for a printing paper surface and the amount of slur which occurs on that sheet? This experiment would help explain the slippage at the nip/slur relationship.

3) What is the role of the printing blanket on distorting images? Does dot gain occur on the blanket, and does it remain constant?

4) What is the exact role mineral content plays in the printability (as it relates to dot gain) of a paper?

5) Can a functional relationship be established between paper characteristics and dot gain? An extremely large sampling of surfaces would enable the use of computer statistical techniques. On a broader scale: Can a functional predictor relationship be established between all press variables and printing performance?

In order for any of these questions to be answered, an experiment would have to be designed which would test more papers than were tested for this screening experiment. The number of input variables should be as large as is manageable, to take advantage of a press run.

Footnotes

(1) Rhodes, Warren, "Study of Objective Methods for Evaluating Sharpness in Lithography" TAGA Proceedings, 1955, pp. 109-122

(2) Buckler, G.F., "The Influence, on Print Quality, of Materials Used for Making and Transferring Printed Images" Proced, 14th EUCEPA Conf., 1971, Paper no. 20.

(3) Blokhuis, G., "Measurement of High and Low Frequency Unevenness in Prints," Proced, 13th IARIGAI Conf., 1975

(4) Cooke, G.P. and Hill, C.A., "Some Factors Affecting Dot Growth in Lithography," PIRA Report 17ii, 1969 (Unpublished)

(5) Yule, J.A.C. and Nielsen, W.J., "The Penetration of Light Into Paper and its Effect on Halftone Reproduction," TAGA Proceedings, 1951, pp. 65-76

(6) Private Communication: Milton Pearson, Graphic Arts Research Center, Rochester Institute of Technology

(7) Murray, "Monochrome Reproduction in Photoengraving," Journal of the Franklin Institute, Vol. 221, pp. 721-744

(8) Private Communication: Irving Pobboravsky and Milton Pearson, Graphic Arts Research Center, Rochester Institute of Technology

(9) Pobboravsky, I., Unpublished, untitled report

(10) Rickmers, A.D. and Todd, H.N., Statistics, an Introduction, McGraw-Hill, Inc., 1967, pp. 266

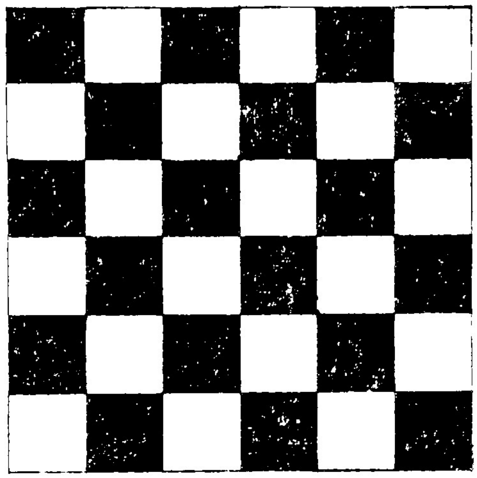
(11) Ibid, page 265

(12) Ibid, page 85

APPENDICES

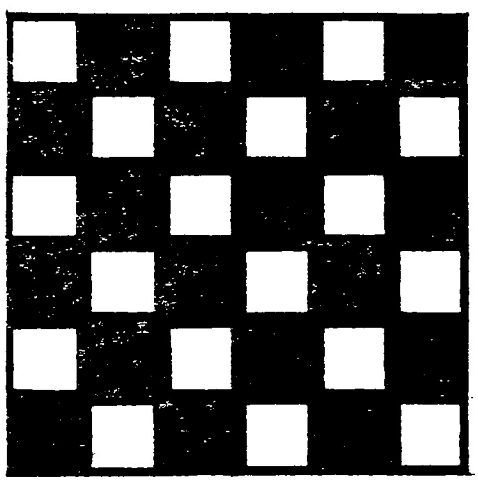
APPENDIX 1

MECHANISM OF INCREASED DOT AREA WITH FILL-IN



"Dot" size: 1 cm^2

Relative area: 50%



"Dot" size: 1.44 cm^2

Relative area: 68%

An increase of 1 mm on each side of each "dot" results in an increase of relative dot area by 18%.

APPENDIX 2

Summary Table, Area, Solid Ink Density, Line Ruling Density, "n." From Lightweight Uncoated, Dull Coated, Gloss Coated, and Cast Coated Sheets

APPENDIX 2

Target Number	Line Area	S.I.D.	Line Dens	"n"	Paper Type
1a	.72	.99	.53	1.46	
1b	.74	.99	.56	1.48	
2a	.71	1.02	.52	1.39	
2b	.71	1.02	.52	1.40	Lightweight
3a	.72	1.04	.54	1.34	Uncoated
3b	.72	1.04	.56	1.53	
4a	.72	1.01	.53	1.32	
4b	.71	1.01	.52	1.40	
MEAN	.719	1.018	.535	1.414	
ST.DEV.	.009	.017	.014	.070	
RANGE				.203	
1a	.59	1.00	.41	1.54	
1b	.59	1.00	.41	1.53	
2a	.57	.95	.40	1.79	
2b	.58	.95	.39	1.60	Dull Coated
3a	.57	.94	.40	1.90	
3b	.57	.94	.39	1.68	
4a	.57	.93	.39	1.68	
4b	.55	.93	.39	2.00	
MEAN	.571	.957	.398	1.715	
ST.DEV.	.013	.031	.011	.170	
RANGE				.477	
1a	.55	1.11	.39	1.50	
1b	.56	1.11	.41	1.58	
2a	.55	1.13	.41	1.69	
2b	.57	1.13	.42	1.51	Gloss Coated
3a	.55	1.11	.40	1.60	
3b	.65	1.11	.42	1.66	
4a	.56	1.09	.41	1.66	
4b	.56	1.09	.40	1.59	
MEAN	.560	1.112	.409	1.599	
ST.DEV.	.008	.016	.010	.068	
RANGE				.181	
1a	.58	1.06	.37	1.24	
1b	.57	1.06	.39	1.37	
2a	.57	1.07	.41	1.57	
2b	.54	1.07	.39	1.71	Cast Coated
3a	.55	1.09	.41	1.72	
3b	.54	1.09	.44	2.20	
4a	.57	1.06	.39	1.45	
4b	.54	1.06	.36	1.35	
MEAN	.558	1.071	.395	1.577	
ST.DEV.	.016	.017	.026	.305	
RANGE				.963	

APPENDIX 3 - INSTRUMENTATION

Gloss:

Instrument: Hunter Glossmeter
Angle of Light Source: 75° Angle of Photodetector: 75°
Procedure: According to TAPPI Standard T 480 os-72

Opacity:

Instrument: Diano BNL-1 Opacimeter
Procedure: According to TAPPI Standard T 425 m-60

Physical Density:

Instrument: Analytic Scale with heating element used for determining moisture content of paper.
Procedure: Samples 10 cm x 10 cm each are placed on scale dish and heated at approximately 100° F. for 5 minutes each. At this time the weight of each is recorded and the weight per unit volume determined (g/cm^3).

Absorption:

Instrument: IGT Printability Tester Model A-1.
Procedure: Using 2 cm printing disc and IGT rubber blanket, a drop of Dibutylphthalate weighing between 5.56 and 6.04 mg. is released through a syringe needle 25 mm in length and 0.355 mm inside diameter onto the rubber blanket. Under falling IGT pendulum weight, a stain elipse is impressed at 70 kg/2 cm onto the paper sample strip (1" x 11") attached to the pendulum cylinder. The absorption value is the reciprocal of the stain length expressed in millimeters.

Smoothness:

Instrument: Sheffield Smoothchek.
Procedure: After calibration, a paper sample is placed

APPENDIX 3 (Cont)

on the glass bed of the instrument and the testing head lowered to the paper under its own weight. The smoothness value is read from the gauge and is expressed as "Sheffield" smoothness.

Formation:

Instrument: MacBeth Transmission Densitometer
Procedure: 15 random measurements are made on each paper type in question. The standard deviation of these measurements is the formation value.

Caliper:

Instrument: TMI Model 549 Electric Thickness Gauge.
Procedure: 15 random measurements are made on each paper type in question. The mean of these measurements is the caliper value.

Computers:

Regression Analysis:

Hewlett Packard Model 2200. University of Rochester Graduate School of Business Administration.

Linear Correlation:

Xerox Sigma 9. Rochester Institute of Technology.

Dot Gain Calculations:

Digital Equipment Corp. PDP 8-E. Rochester Institute of Technology, School of Printing.

APPENDIX 4 - Test Form

Reproduction of Test Form at
33% of Original Size

ZODIAC

Build A Gallows

(ZNS)—Are you ready to teach your kids about the Old West ...

Some Fantasy

(ZNS)—Mick Jagger and other members of the rolling stones are reportedly looking into the legal possibilities of preventing the public ... of a new book called *The Man Who Killed Mick Jagger*.

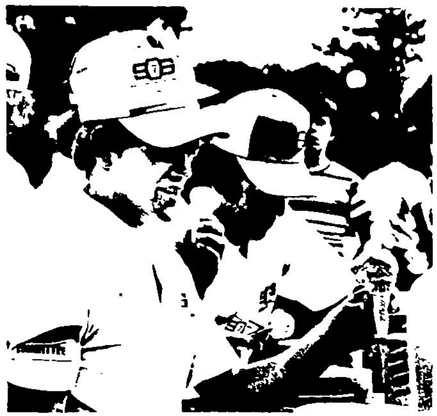
Your Rights?

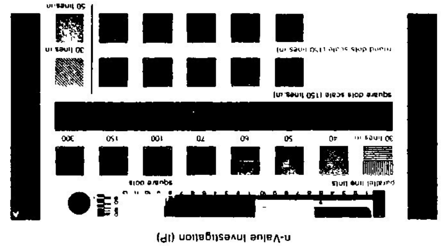
(ZNS)—New York's Consolidated Edison Utility Company has done it again.

Anti-Staring Statute

(ZNS)—Does a person have the constitutional right simply to stare at somebody else ...

Biggest Bore



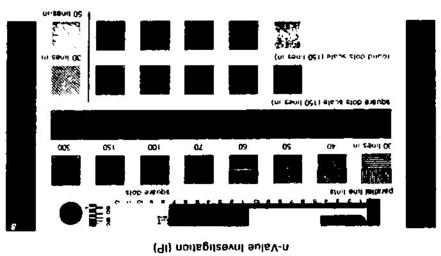


150 LINE

100 LINE

Rochester Institute of Technology

College of Graphic Arts & Photography
Graphic Arts Research Center
One Lomb Memorial Drive
Rochester, New York 14623



TOP

REPORTAGE

Senate Starts Year

The Student Association (SA) Senate held its first meeting of the new school year this week ...

In other business, the Senate passed a resolution in which each college's seat allotment in the Senate would be changed each year according to enrollment. ...

TAP To Increase

There is a good chance next year that the maximum award offered under New York State's Tuition Assistance Program (TAP) will be increased ...

NMT Program Accredited

The Nuclear Medicine Technology program (NMT), established in 1973 to meet the increased demand for specially trained technologists, has been granted full accreditation from the American Medical Association (AMA).

APPENDIX 5 - Press Run Documentation

Order Listed is order in which rolls were printed.

Roll 1 - Lightweight Uncoated:

Run Speed: 610 fpm
Web Tension: 30
Chill Roll Torque: 18

Roll 2 - Dull Coated:

Run Speed: 600 fpm
Web Tension: 18
Chill Torque: 18

New blanket on top of unit 4, after smash from attempt to run cast coated sheet.* Packing: top + .005"

Roll 3 - Gloss Coated:

Run Speed: 610 fpm
Web Tension: 34
Chill Torque: 18

Roll 4 - Cast Coated:

Run Speed: 610 fpm
Web Tension: 29
Chill Torque: 18
Web Break at 690 Impressions
Press Stoppage at 790 Impressions

Packing:

Start of run: +.004 top and bottom. +.008 squeeze.
End of run: +.0038 top and bottom. +.0078 squeeze.

Drying:

Hot air only. Web temperature at oven exit: 280° F.

pH of Fountain Solution:

3.93 at start and end of run.

APPENDIX 5 (Cont)

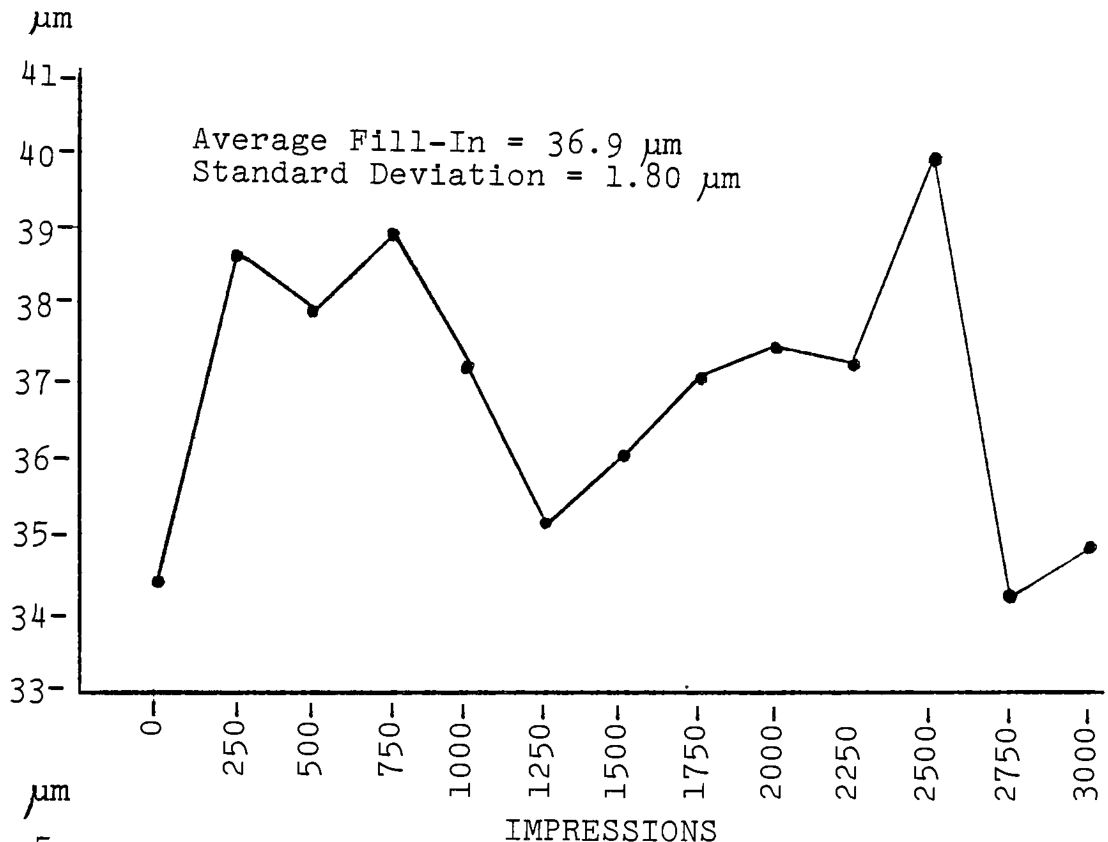
Ink-Film Thickness monitored using "Interchemical" Thickness Guage

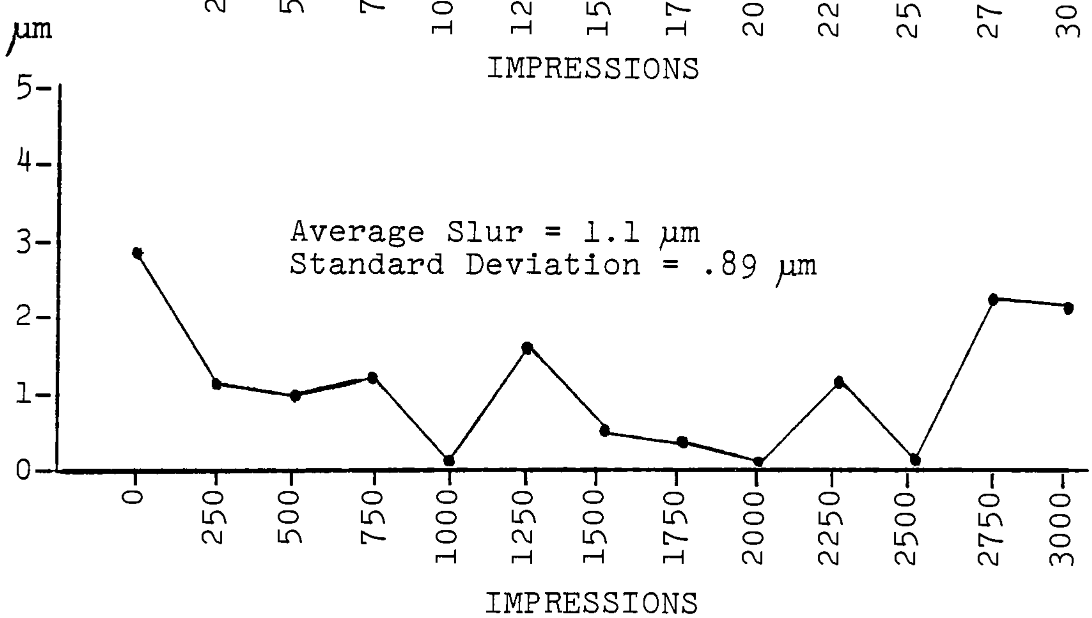
* The cast coated sheet was to be run in the second position. The web break and blanket smash resulted in the decision to try to run the roll after others were run. If no success was met, the roll was to be discarded.

APPENDIX 6

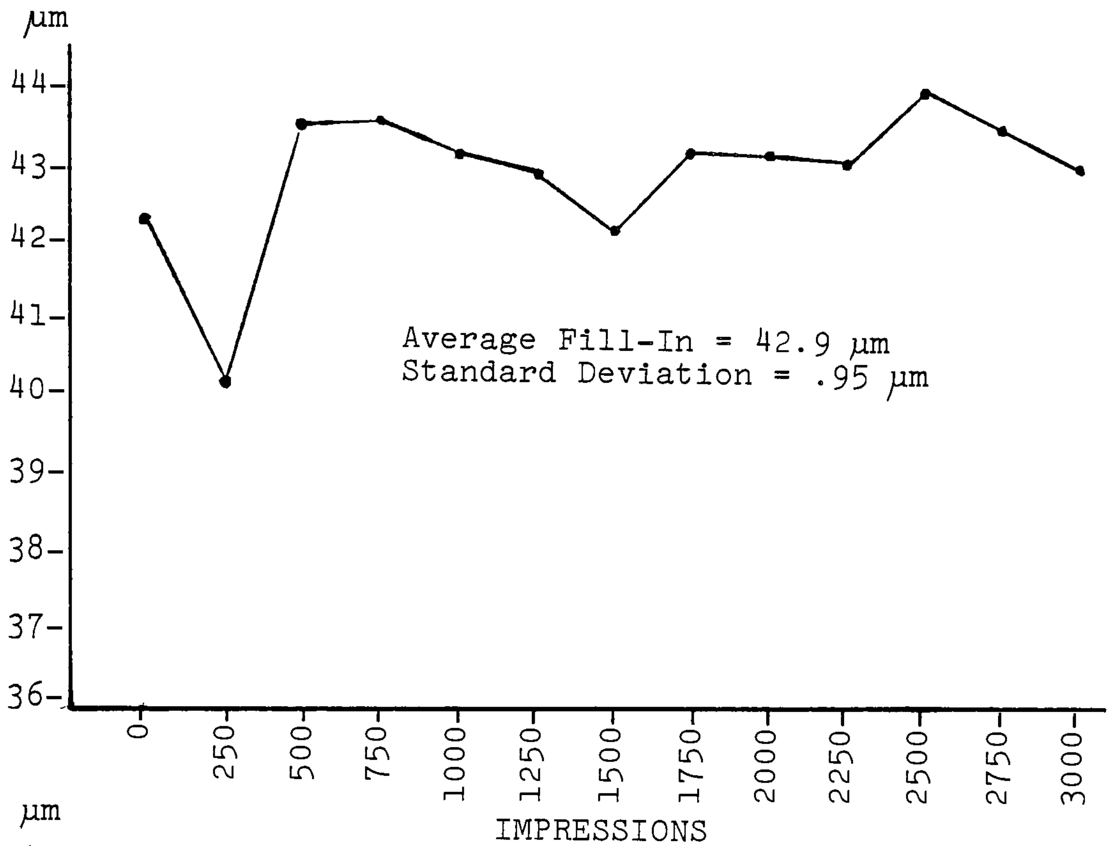
Slur, Fill-In, Percent Dot Gain vs. Impressions

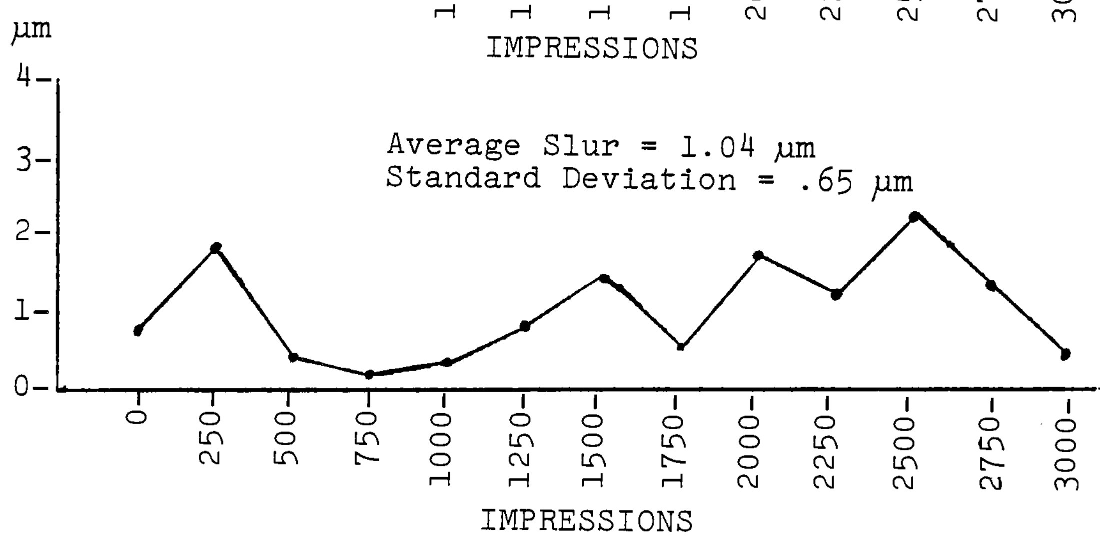
LIGHTWEIGHT UNCOATED - TOP OF WEB

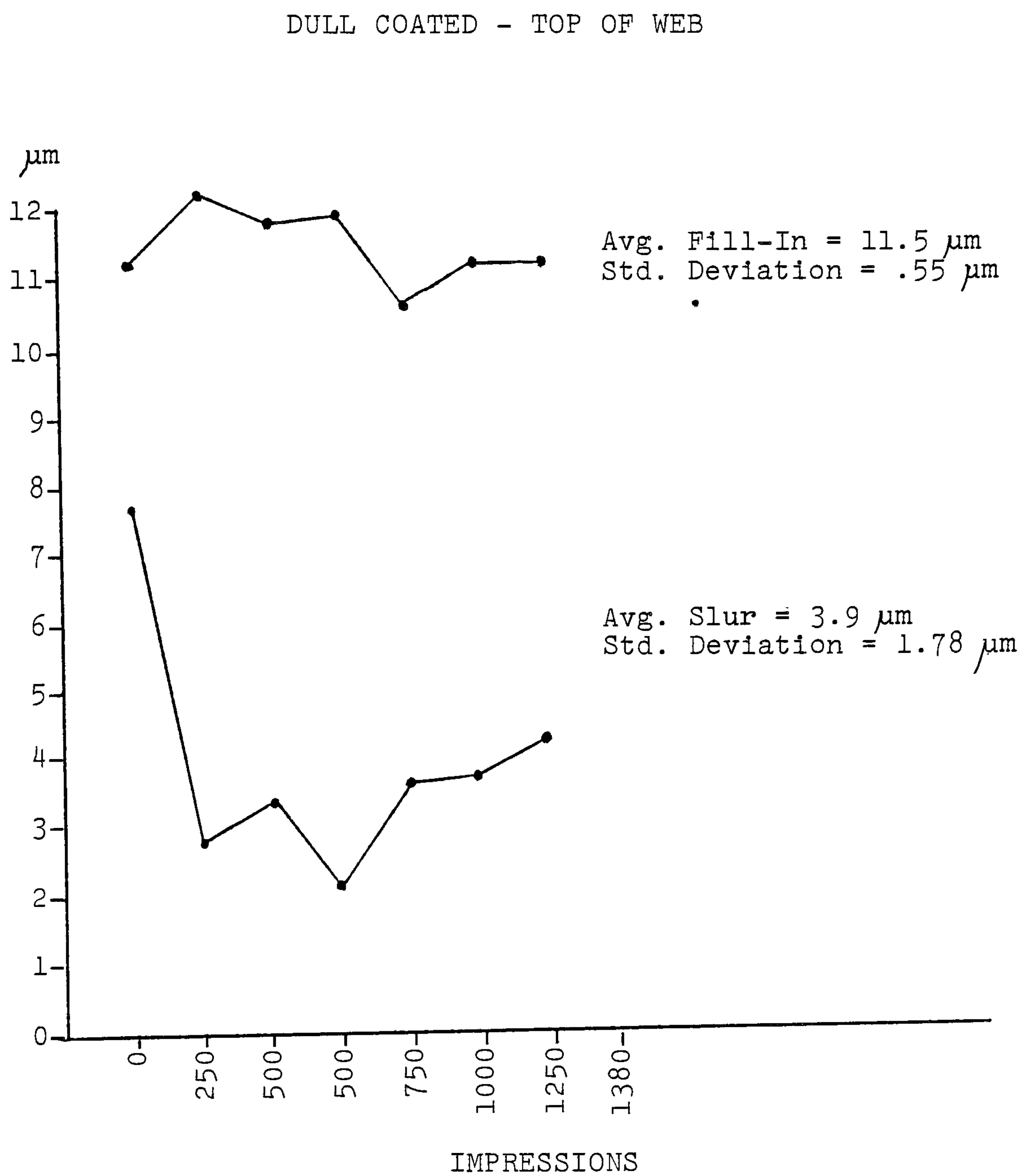




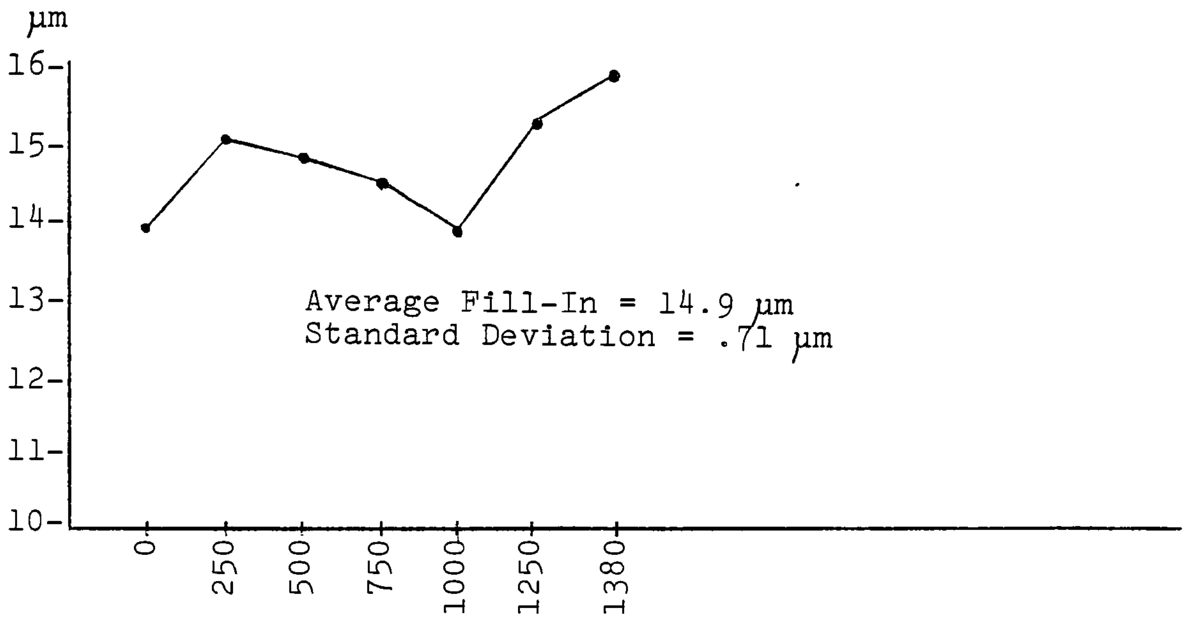
LIGHTWEIGHT UNCOATED - BOTTOM OF WEB

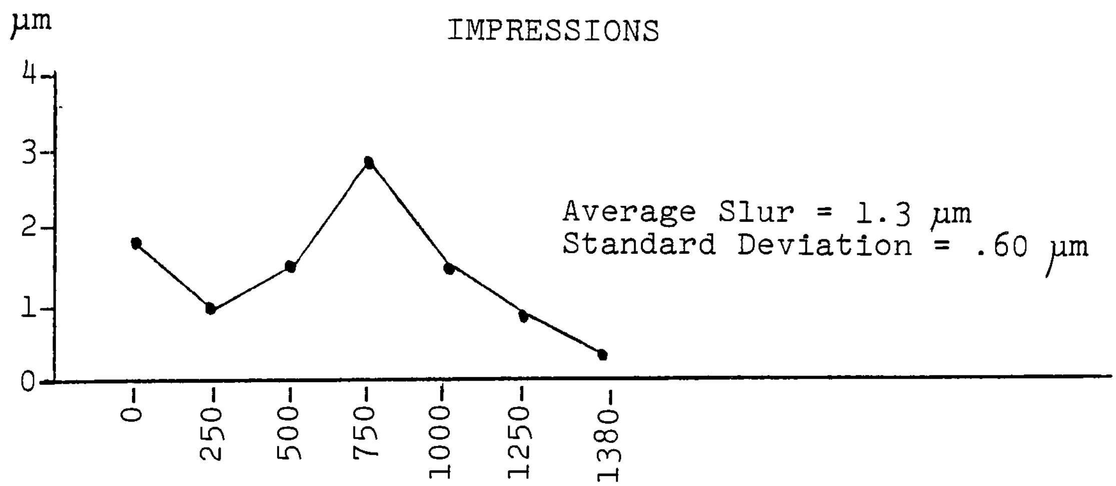




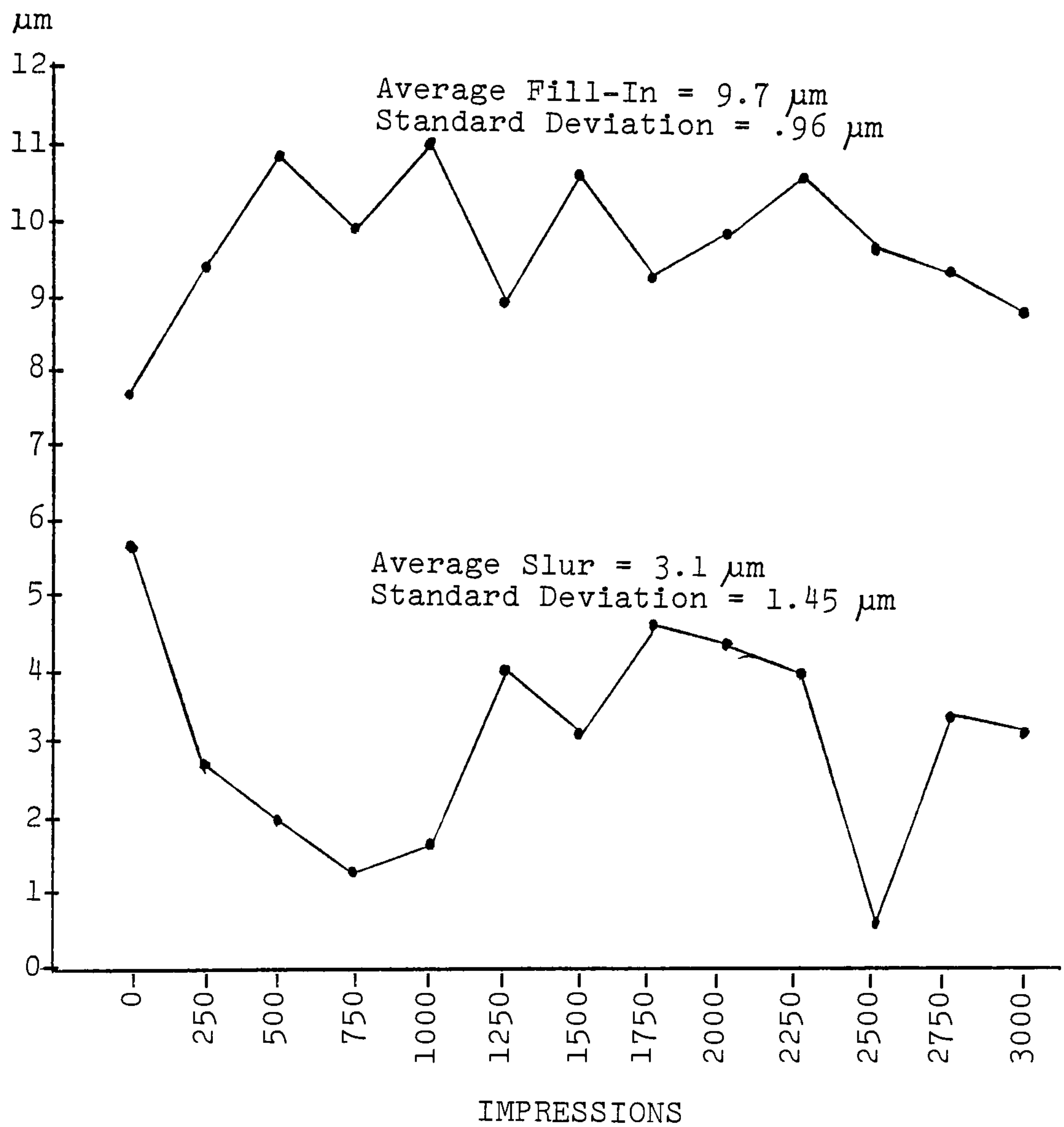

DULL COATED - TOP OF WEB
µm
12
11
10
9
8
7
6
5
4
3
2
1
0
Avg. Fill-In = 11.5 µm
Std. Deviation = .55 µm
Avg. Slur = 3.9 µm
Std. Deviation = 1.78 µm
0
250
500
500
750
1000
1250
1380
IMPRESSIONS

DULL COATED - BOTTOM OF WEB

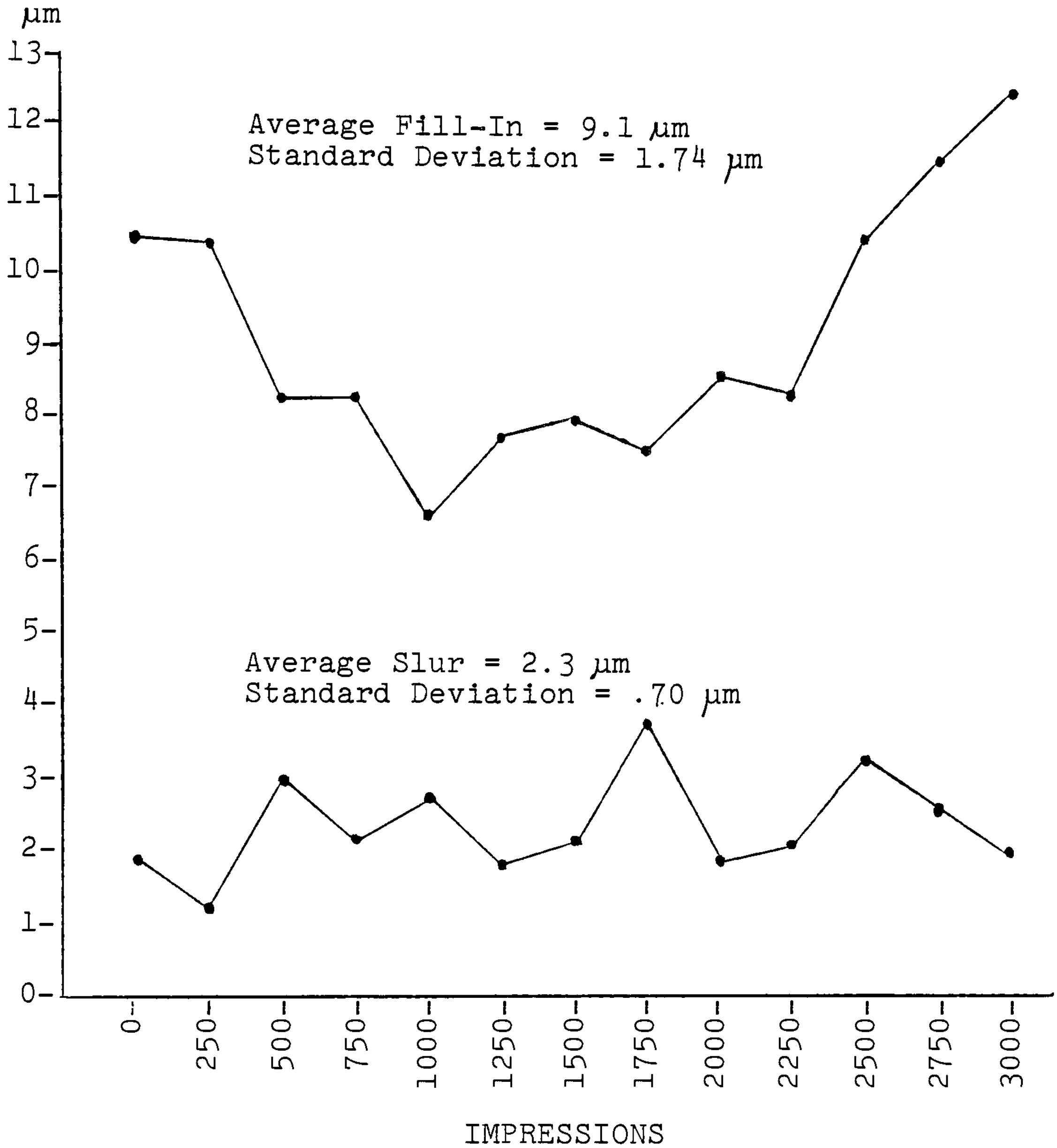




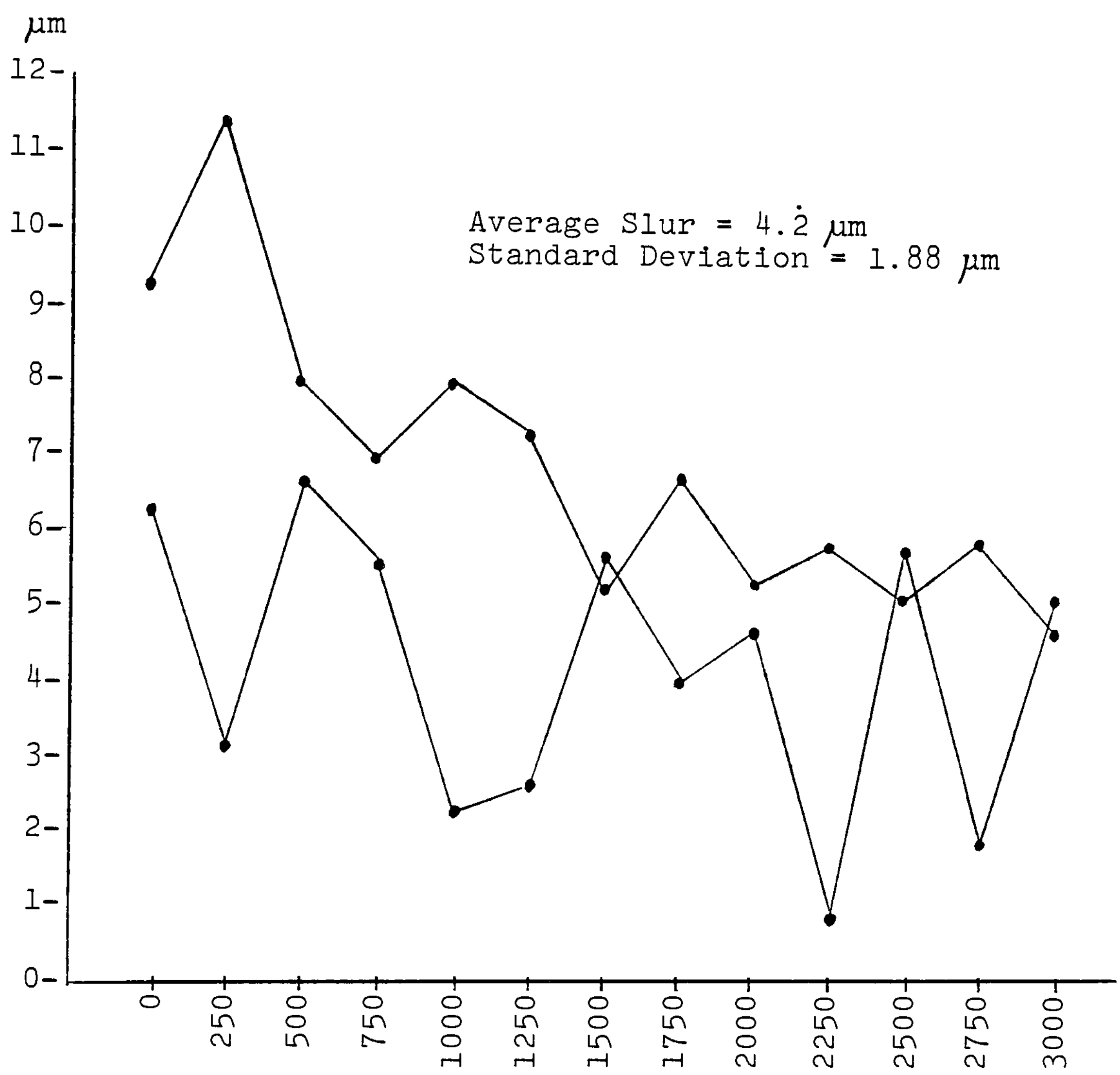
GLOSS COATED - TOP OF WEB



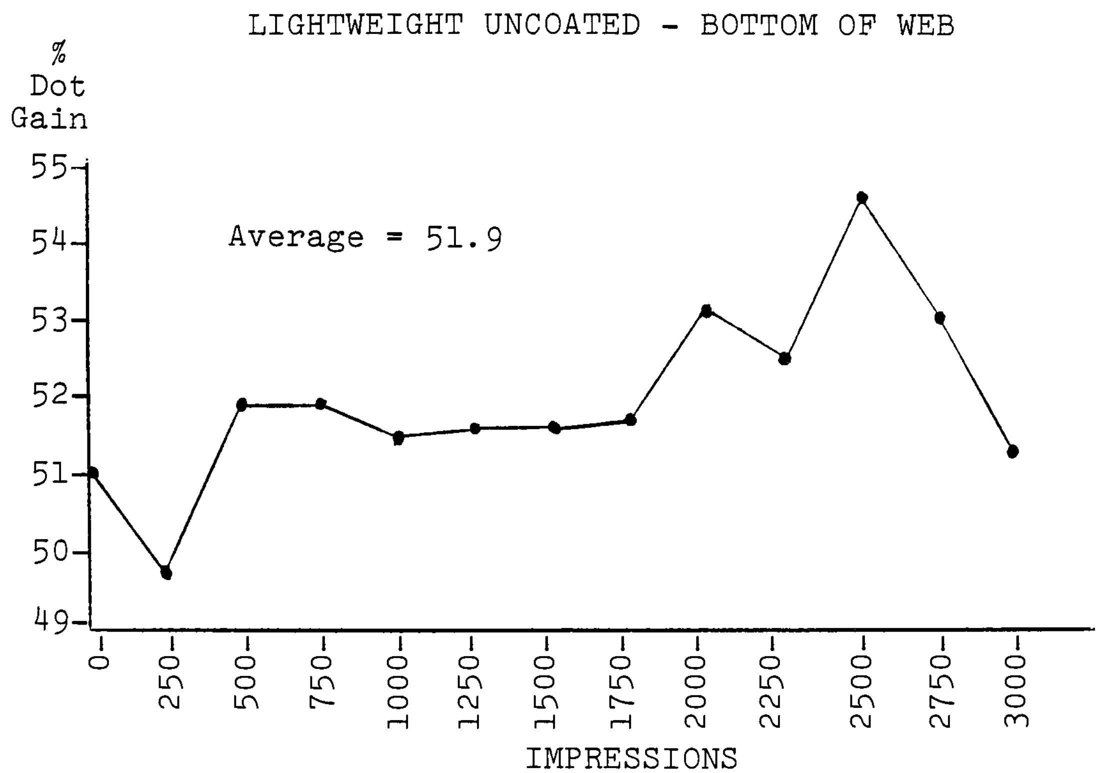
GLOSS COATED - BOTTOM OF WEB

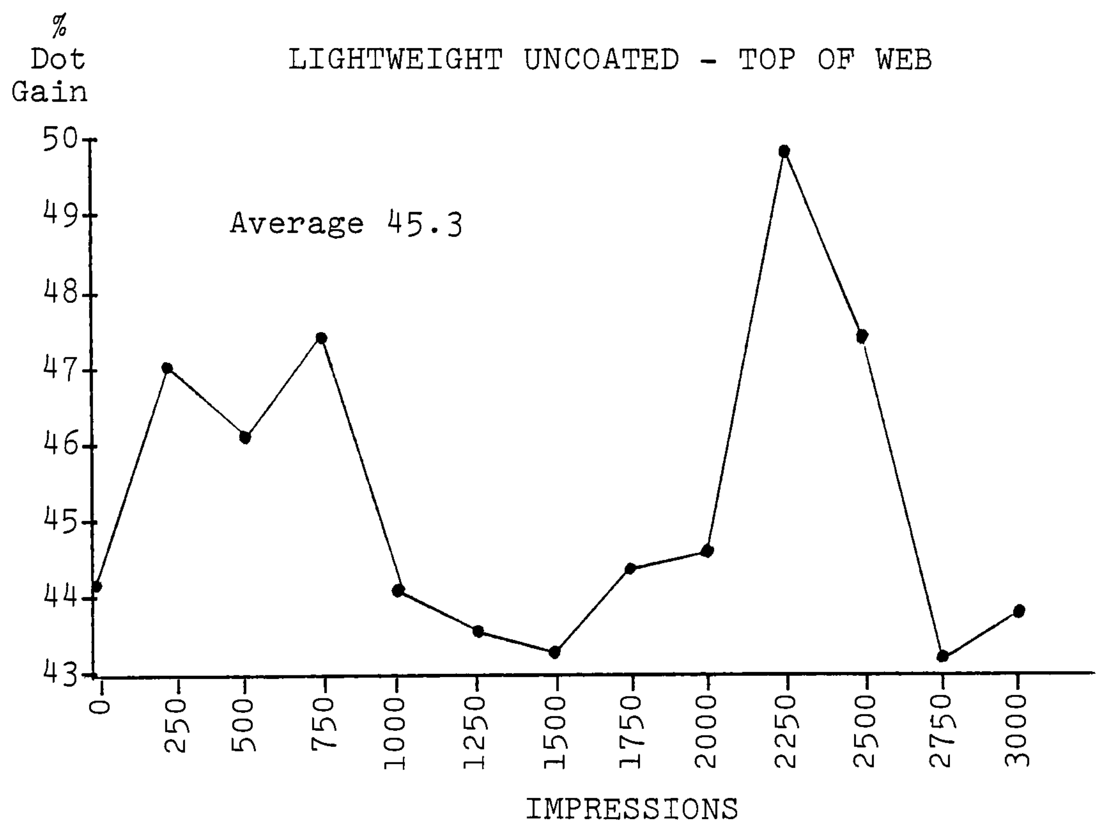


CAST COATED - TOP (COATED SIDE) OF WEB

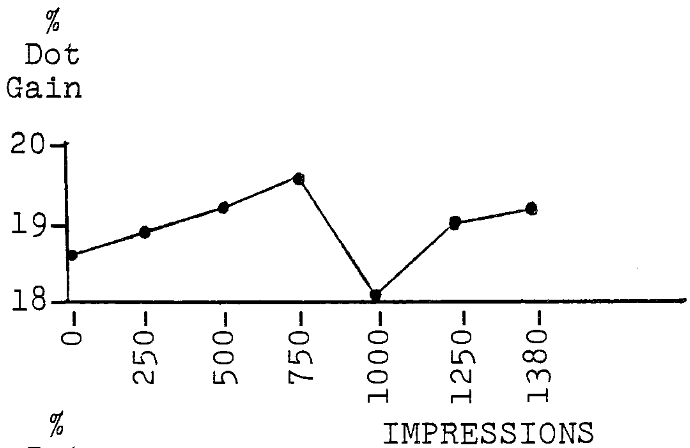


(Upper Line) The downward trend exhibited by fill-in invalidates the meaning of the average and standard deviation.

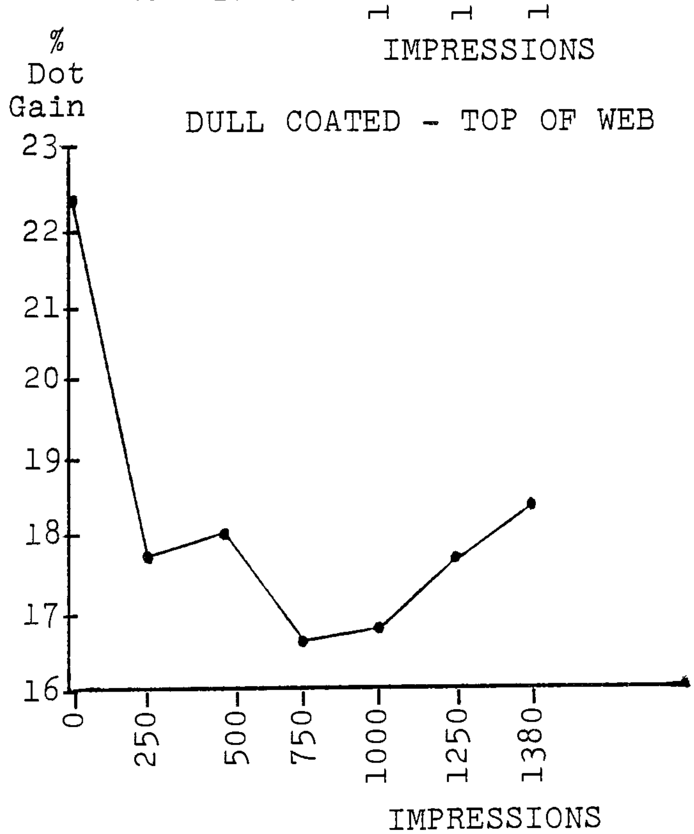

LIGHTWEIGHT UNCOATED - BOTTOM OF WEB
% Dot Gain
55
54
53
52
51
50
49
Average = 51.9
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
IMPRESSIONS

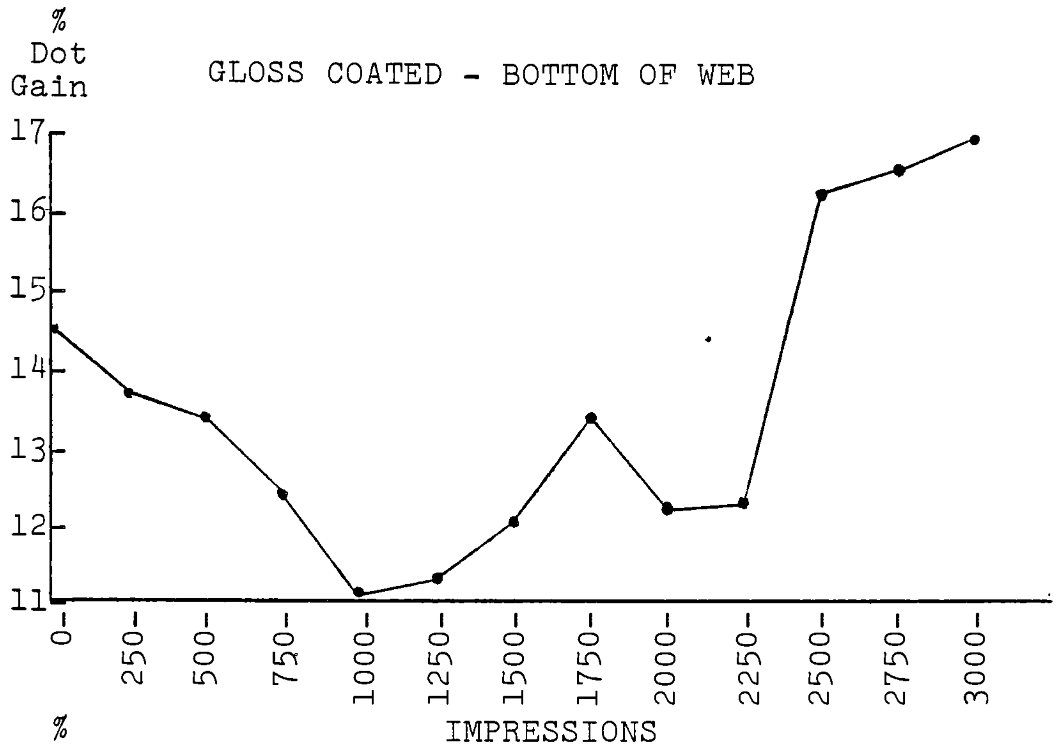

% Dot Gain
LIGHTWEIGHT UNCOATED - TOP OF WEB
50
49
48
47
46
45
44
43
Average 45.3
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
IMPRESSIONS

DULL COATED - BOTTOM OF WEB



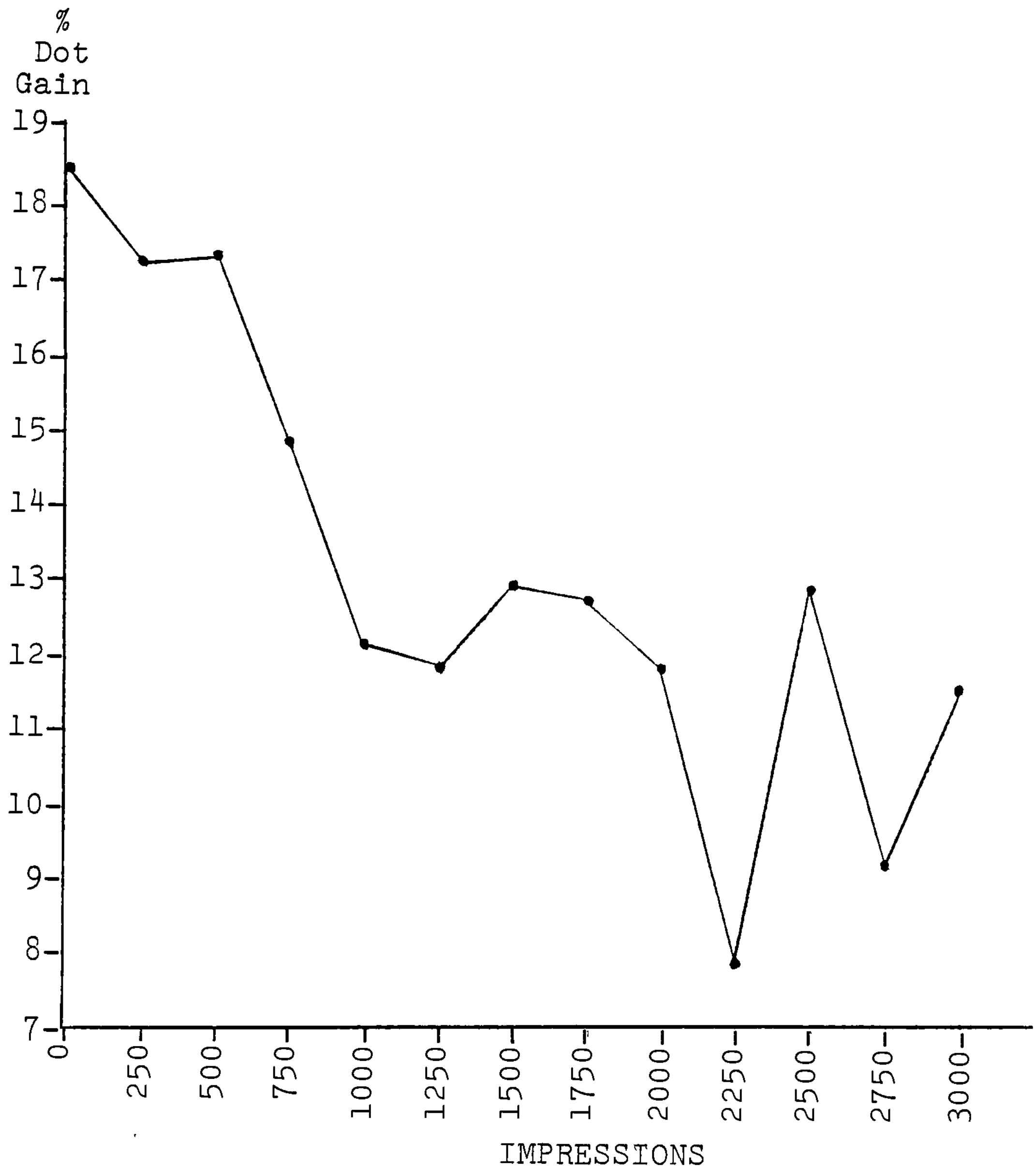
DULL COATED - TOP OF WEB




%
Dot
Gain
GLOSS COATED - BOTTOM OF WEB
17
16
15
14
13
12
11
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
IMPRESSIONS


%
Dot
Gain
GLOSS COATED - TOP OF WEB
18
17
16
15
14
13
12
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
IMPRESSIONS

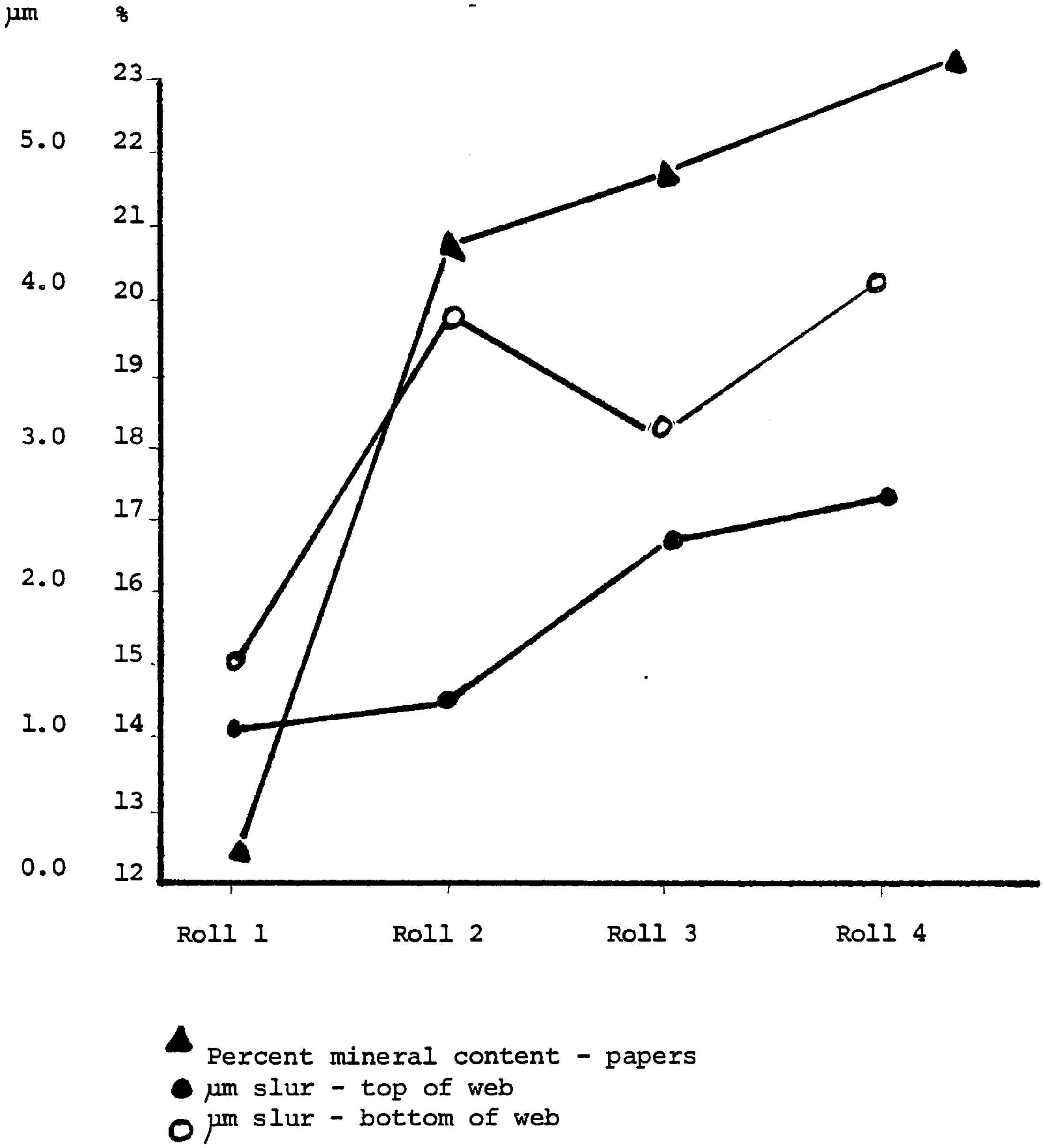
CAST COATED - TOP (COATED SIDE) OF WEB



APPENDIX 7

Relationship Between Slur and Percent Mineral Content

APPENDIX 7


µm
%
23
5.0
22
21
4.0
20
19
3.0
18
17
2.0
16
15
1.0
14
13
0.0
12
Roll 1
Roll 2
Roll 3
Roll 4
Percent mineral content - papers
µm slur - top of web
µm slur - bottom of web