More Data on the Density Range of Papers and on the Measurement of Printed Ink Film Thickness

by John MacPhee* and John T. Lind**

Abstract: Data are presented from a series of sixteen consecutive sheetfed press runs in which the only variable changed was the paper. Thirteen different offset papers were run ranging from newsprint to number one coated. In addition, a gravure paper was run, along with TYVEK, a polyethylene fiber based substrate. Data on density range and dot gain at a printed ink film thickness of 1.04 gms/m^2 is given together with further evidence on the validity of the method used to measure ink film thickness. Data is also presented on comparative IGT prints, made under a variety of conditions, which show the effect of printing pressure and roller material on ink lay.

Background and Introduction

This paper is a report on work done as an extension of the authors' 1991 TAGA paper (MacPhee and Lind, 1991-1) on the interaction of paper and ink properties. More specifically, it contains the results of press tests that were run in accordance with recommendations contained in the previous paper. Broadly speaking, data obtained from the prints run on press are used to show the effect of different substrates on the two print properties that determine the characteristic curve of a press: density range and dot gain.

The main body of this paper is made up of four sections. The first describes the press tests that were run, identifies the various substrates used, and presents the test data that characterize each of the sixteen press runs made. The second section presents the test data in terms of density range and includes data obtained on an IGT printability tester. Because of an anomaly in the latter data, printing pressure and roller material were varied on the IGT tester and data on these effects are also included in this section. The third section presents dot gain data obtained from the press prints and the last section is devoted to a summary and conclusions of the tests.

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Press Tests

The objective of the press tests was to print the same ink film thickness on a wide range of substrates, using the same ink and same press setup. The press employed was a 14 x 20 Heidelberg GTO and the procedure used was that described in an earlier paper (MacPhee and Lind, 1991-2). All of the tests were carried out sequentially and without interruption, except for the times needed to load a new batch of paper and to empty and refill the ink fountain. A special low tack magenta sheetfed ink was formulated to avoid the problem of picking on the poorer grades of paper used. Fourteen different batches of paper were collected consisting of three brands each of #1 coated, #3 coated, and #5 coated paper; one brand of #1 uncoated and two brands of #3 uncoated paper; and two brands of newsprint. All of these papers were offset, except for one of the #3 coated brands which was a gravure paper. Also, one of the two brands of newsprint was uncalendered. In addition, a supply of TYVEK, a synthetic (polyethylene) fiber based stock was procured. This provided a total of fifteen different substrates to print on. The actual tests consisted of sixteen press runs of nominally one thousand sheets each - with the last run being a repeat of the first in order to provide a check on test reproducibility. In three of the runs the number of sheets printed was significantly less than 1,000 because of a shortage of paper. The test form used had an image area of 94 square inches (33.6% coverage) made up of four two-by-nine inch solids arranged in a square; one solid and three screened half inch wide bars running across the sheet; and two UGRA targets.

In accordance with the procedure used, ink consumption during each run was measured gravimetrically and solid densities were measured in four places on every fiftieth sheet. Solid density was measured with a status T densitometer that correctly measured a T-Ref at the time. Figure 1 is a plot of the average values of each of these four density readings, along with the mean value for a typical run. In addition, density data from the first fifty sheets has also been plotted in Figure 1 and these data show that stable operation of the press, viz-a-viz print density, was achieved after the first ten sheets had been run. (It will be appreciated that the press had been made ready prior to the restart or test run referred to in Figure 1.)

Table I is a listing of the substrates used in the sixteen press runs along with the data on the measurements of ink usage and solid print density.

Table I Data on Press Runs

Run No.	Paper				Number of Impressions	Ink Usage		Solid Density			Density of Paper
	ID	Type	Finish	Grade		Total (gms)	Thickness (gms/m²)	Measured Mean	Std Dev	Corrected Mean	
1	L	Offset	Ctd	#1	1000	63.8	1.05	1.37	.03	1.36	.04
2	S	Offset	Ctd	#5	1000	64.4	1.06	1.36	.03	1.33	.09
3	C	Offset	Ctd	#3	1000	63.5	1.04	1.43	.03	1.43	.12
4	A	Offset	Ctd	#5	1000	64.1	1.05	1.38	.03	1.37	.12
5	T	Offset	Ctd	#5	1000	62.9	1.03	1.35	.02	1.36	.09
6	J	Offset	Ctd	#1	1000	63.8	1.05	1.40	.04	1.39	.05
7	U	Offset	Unctd	#3	735	48.5	1.08	0.97	.01	0.93	.07
8	O	Offset	Unctd	NwsPr*	704	42.9	1.10	0.99	.02	0.94	.18
9**	P	Offset	Unctd	NwsPr	938	57.7	1.01	0.99	.04	1.02	.20
10	Q	Offset	Ctd	#3	1000	62.4	1.02	1.35	.02	1.38	.05
11	H	Offset	Unctd	#1	1000	61.8	1.02	0.91	.02	0.93	.03
12	M	Offset	Ctd	#1	1000	60.7	1.00	1.32	.02	1.37	.04
13	R	TYVEK	-	-	1000	62.4	1.02	0.88	.03	0.90	.03
14	W	Gravure	Ctd	#3	1035	63.2	1.00	1.28	.02	1.33	.11
15	I	Offset	Unctd	#3	1000	64.6	1.06	.92	.02	0.90	.07
16	L	Offset	Ctd	#1	1000	60.7	1.00	1.31	.02	1.36	.04

* Uncalendered; ** Reduced speed at impression #300 because of many trips

The measured ink consumption data were converted to the equivalent average ink film thickness printed and these values are also given in Table I. The mean value of ink film thickness for all runs was 1.04 gms/square meter and the corresponding standard deviation was 0.03 gms/square meter. Thus the 95% confidence limit or error in the ink film thickness measurements is plus/minus 9%.

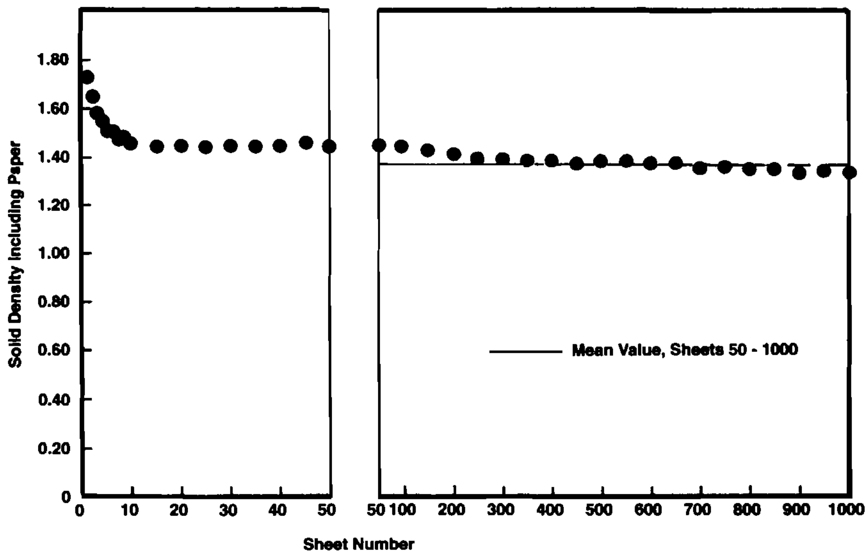

Figure 1 Plot of average density during Run 1 showing that stable operation was achieved after ten sheets had been run

The standard deviations of the solid density measurements, also given in Table I, were 0.03 or less for all except two runs where the deviation was 0.04. Examination of all sixteen density plots, as given in Figures 2(a) and (b), reveals however that density drifted downward during the course of most runs. Although the cause of this downward drift is not known, it appears to account for most of the variability reflected in the calculated standard deviations.

Considering the observed very modest variations in ink consumption over all the runs and of printed density within each run, it is the authors belief that the store of printed sheets collected do indeed have a common ink film thickness and can thus be used with confidence to gage the effects of the different substrates on the properties of the printed image.

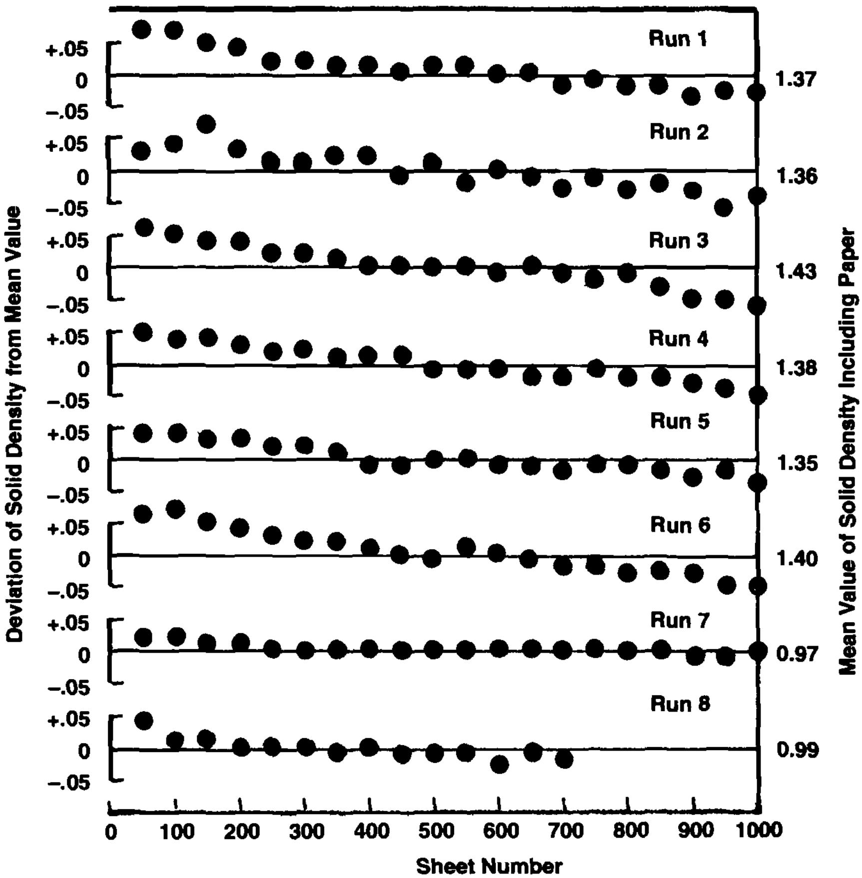

Figure 2(a) Mean density vs sheet number for runs 1 through 8

Density Range

The term density range is used here in the context of a tone reproduction curve and thus is defined as the difference between the maximum and minimum achievable print densities. For the printing conditions described here, the maximum print density is equal to the measured density of a solid film of ink, 1.04 grams per square meter thick, on a given substrate. The minimum print density is simply the density of the respective unprinted substrate and density range is the difference between the two. (Alternately, density range is simply solid density relative to the paper.)

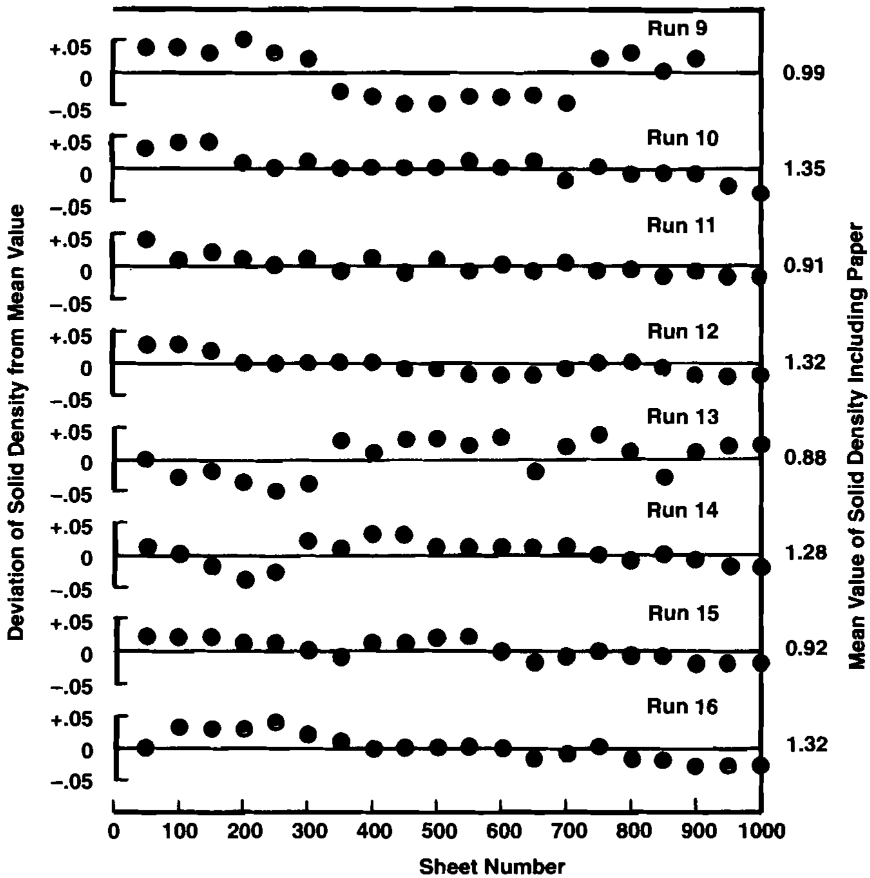

Figure 2(b) Mean Density vs sheet number for runs 9 through 16

The measured solid densities were corrected to the mean ink film thickness and these values are listed in the next to last column of Table I. The differences between these values and the densities of the corresponding substrates, the density ranges, are plotted in Figure 3 vs paper quality, as measured by grade and finish. In general, this plot exhibits no inconsistencies and confirms the conventional wisdom that density range follows paper quality, i.e., the lower the paper quality, the lower the density range. What may be surprising however is the small differences (.07 density units) between the best #1 and #5 coated stocks and the small difference (.01 density units) between the #3 uncoated and calendered newsprint stocks.

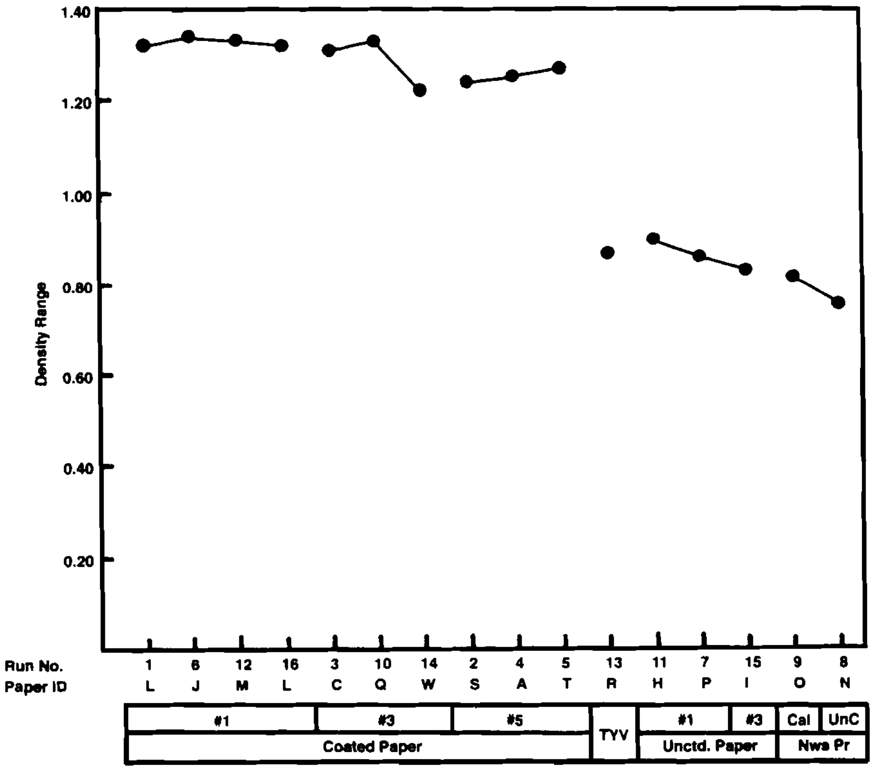

Figure 3 **Density range of each substrate, corrected to the mean ink film thickness of 1.04 grams/m^2**

One question about the lithographic process that has never been answered unequivocally is, "To what extent does the water or fountain solution affect density range?". Conventional wisdom holds that water emulsified into ink can produce more mottle and thus reduce density range. In contrast, earlier results obtained by the authors (MacPhee and Lind, 1991-2) using four different substrates, showed little differences between wet and dry prints at the same ink film thickness, using the same ink. In order to expand this data base it was decided to produce sets of dry prints (i.e., no water) using the same ink and the fifteen different substrates listed in Table I.

For each substrate, a set of dry prints having a range of different ink film thicknesses was produced using a Model AC2 IGT printability tester. The best fit of each data set to the Tollenaar equation (Tollenaar and Ernst, 1961) was determined and the resulting equations were used to calculate the density range of a dry print having the same ink film thickness as the corresponding wet print produced on press. Figure 4 is a plot which shows how the dry vs wet density ranges compare for the fifteen different substrates studied. In the case of ten of the substrates, the difference between press (wet) and IGT (dry) density range is 0.05 density units or less. In the remaining five however, the differences were greater, as given in Table II.

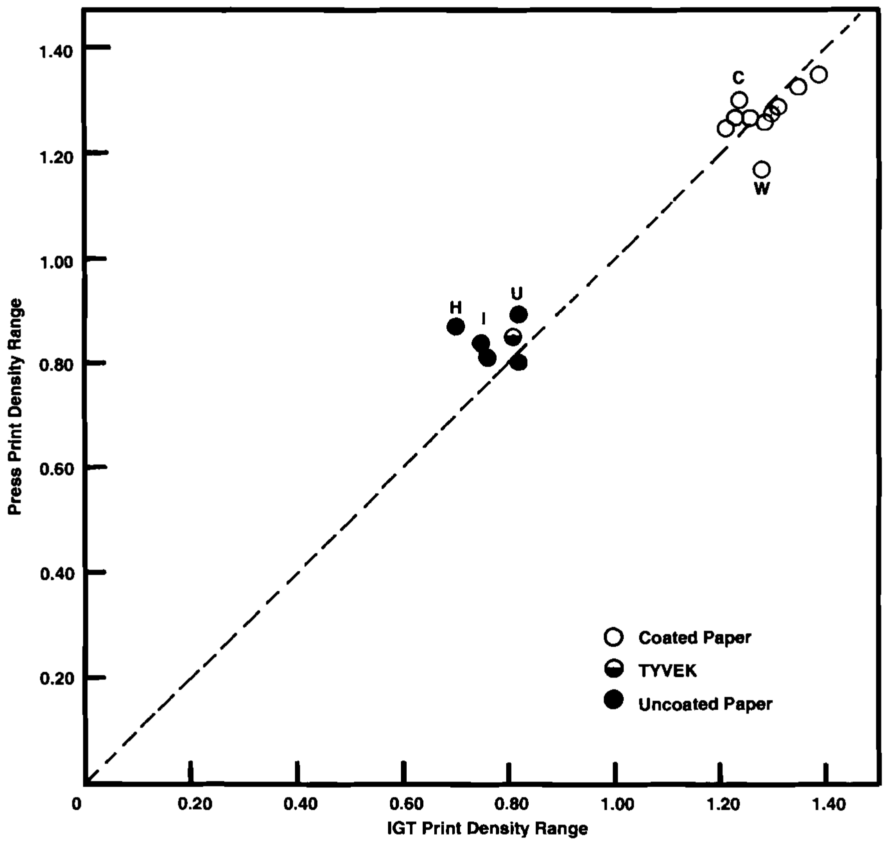

Figure 4 Comparison of press and IGT solids printed at same ink film thickness. Dashed line is plot of equal thickness. Letters denote the substrate ID's listed in Tables I and II.

Table II **Substrates exhibiting large differences between press and IGT print density range**

Paper			Press print density range minus IGT print density range
ID	Finish	Grade	
C	Coated	#3	+ 0.06
W	Coated	#3	- 0.11
H	Uncoated	#1	+ 0.17
I	Uncoated	#3	+ 0.09
U	Uncoated	#3	+ 0.07

Examination of these differences discloses the interesting fact that all three of the uncoated non-newsprint stocks exhibited relatively large differences whereas seven of the nine coated stocks exhibited small differences. Of the two coated stocks that had large differences, one was the gravure paper. Another interesting point is that for the substrates exhibiting large differences, the press print density range was greater than the corresponding IGT print density range, except in the case of the gravure paper.

The anomaly shown in Table II prompted the authors to question the extent to which IGT print density would vary with printing conditions, i.e., printing pressure, printing disk covering, and sector covering.* The IGT data plotted in Figure 4 were obtained from prints produced at an impression force of 80kg and a speed of 0.7 meters per second using a hard rubber covered printing disk and a blanket covered sector. These conditions had been selected on the basis of the years of experience at

*** The IGT printability tester comprises a freewheeling printing disk or roller, which is inked up prior to printing, and an impression cylinder consisting of a sector of a metal rimmed wheel, to which the paper to be printed is fastened. One or both of these two cylindrical elements is covered with a rubber-like material. Printing is accomplished by simultaneously pressing the disk against the sector with a preset force and rotating the sector.**

GATF that had shown them to produce visually acceptable prints. Conversations with representatives of Reprotest B.V., the manufacturer of the IGT printability tester, disclosed however that their recommendation was to use the hard rubber covered disk only for coated stocks and to use a blanket covered disk for uncoated stocks (Anonymous, 1990). It was recommended further that a bare metal sector be employed for printing on all stocks. In view of these recommendations it was decided to determine the extent to which density range would be affected by both different printing (disk) and different impression (sector) surfaces. Two substrates were selected for additional tests: a #1 coated paper (L) that had almost the same press and IGT density range (.02 density difference) and the #1 uncoated paper (H) that had exhibited a large difference (0.17 density units). Figures 5 and 6 are plots of the densities of IGT prints obtained with various combinations of disk and sector coverings including a custom fabricated (by the authors) disk covered with the same blanket material used in the GTO press runs. These densities are plotted against average printing pressure, on the assumption that pressure rather than force is the factor controlling ink transfer for a given set of printing and impression surfaces running at a given speed. (Average pressure in the printing nip was determined by measuring the width of the stripe and dividing impression force by stripe area.) The data in Figure 5 show that the densities of dry solids printed on the coated stock varied tremendously depending on which combination of disk and sector are used. In contrast, Figure 6 shows that the densities of dry solids printed on the uncoated stock is relatively insensitive to the choice of disk and sector material. Both plots also show that printing pressure had little effect, over the range studied. Additional tests were also run at slower printing speeds and tests showed that speed is not a significant factor.

One possible explanation of why the same printed ink film thickness on the same paper produced different densities, depending on printing conditions, is that the film thickness was not constant and that the extent to which it varied was dependent on one or more properties of the printing and impression cylinders, such as surface roughness. If this were the case, it was reasoned that the lower density prints would have a greater variation in print density, i.e., that a correlation would exist between average print density and the degree of mottle or quality of ink lay.

By the way of exploring this thesis, three different methods were used to rank and/or gage ink lay, i.e., random density variations that are blotchy in appearance. In the first method, four observers were asked to rank four

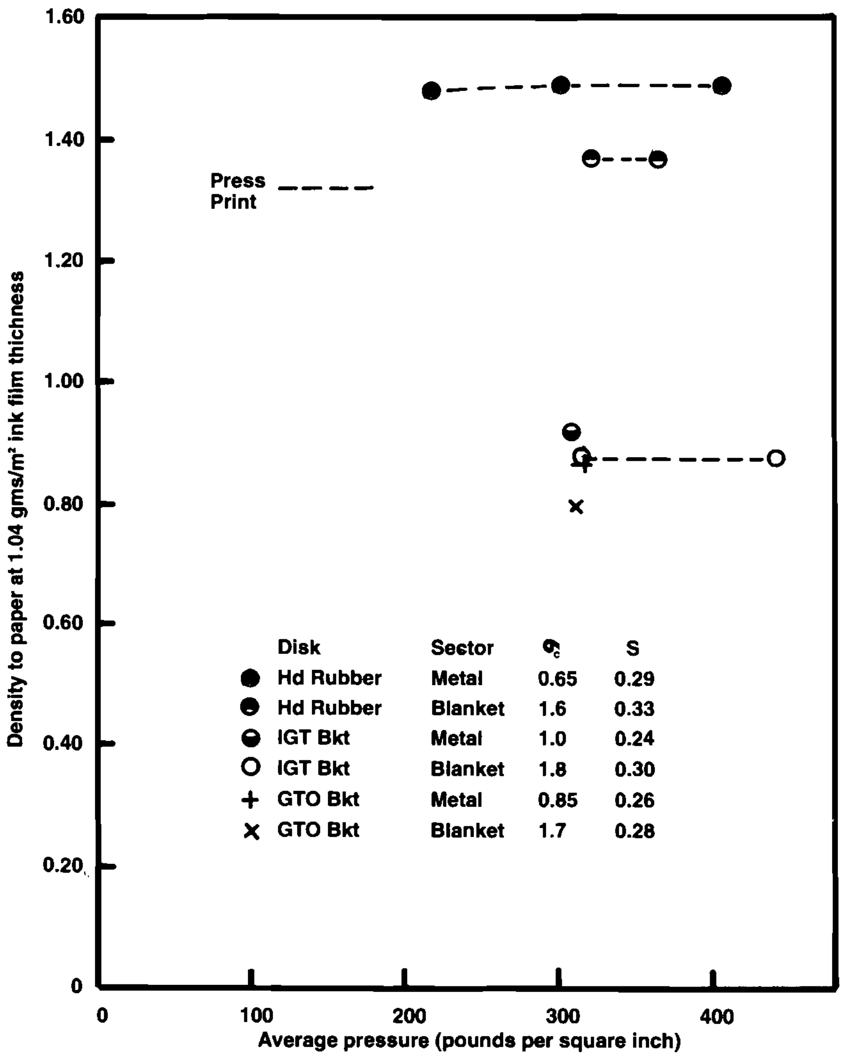

Figure 5 Effect of IGT roller surfaces on density when printing on number 1 coated stock used in runs 1 and 16. Composite roughness, σ_C, is equal to the square root of the sum of the squares of the disk and sector surface roughness in microns, as measured with a Surtronic instrument. Roller stripe, S, in inches was measured with force set at 50 kilograms.

IGT prints having the same nominal ink film thickness of 1.04 grams per square meter but printed using different surface combinations. The second and third methods utilized a series of forty one density measurements made over a span of one inch, utilizing a Cosar Autosmart automatic scanning densitometer (Cox, 1985).

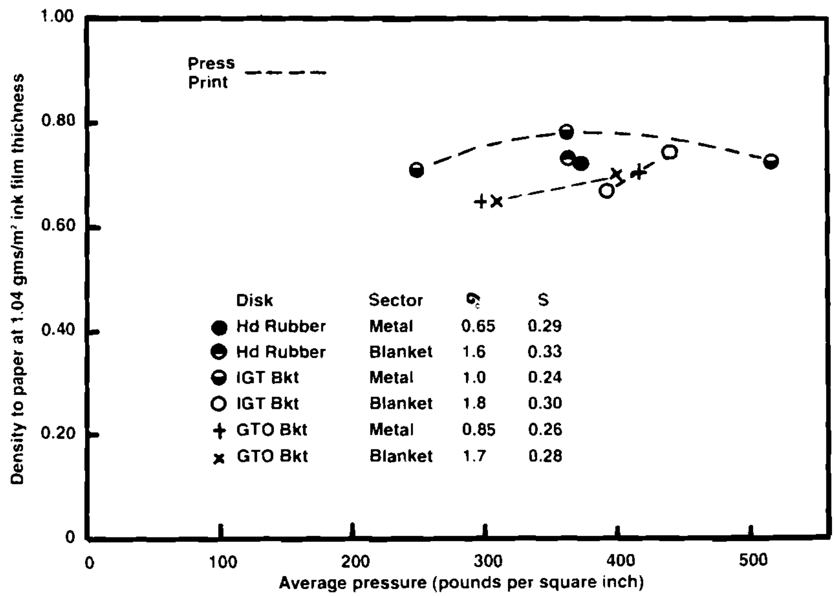

Figure 6 **Effect of IGT roller surfaces on density when printing on Number 1 uncoated stock used in Run II. Composite roughness, σ_C, is square root of the sum of the squares of the disk and sector roughnesses, in microns, as measured with a Surtronic instrument. Roller stripe, S, in inches, was measured with force set at 50 kilograms.**

The second method, suggested by Chester Daniels of RIT (Daniels, 1991), comprised a calculation of the variance or standard deviation of each such data set, based on his finding of a correlation between variance and observed mottle, i.e., the greater the variance, the worse the mottle. The third method comprised a calculation of the mean absolute density change over each traverse of 0.025 inches, based on a rationale given in another paper at this conference (MacPhee, 1992).

Table III **Rankings of ink lay on four different IGT prints by four different observers and by forty one density measurements along a one inch line on each print. Magenta ink on paper L, #1 coated, at nominal film thickness of 1.04 grams/square meter and nominal average printing pressure of 300 pounds/square inch.**

Ranking Method	IGT Roller Surfaces			
	Hard Rubber Disk, Metal Sector	Blanket Disk, Metal Sector	Blanket Disk, Blanket Sector	Hard Rubber Disk, Blanket Sector
Observer A	1*	3	4	2
Observer B	2	3	4	1
Observer C	1	3	4	2
Observer D	1	3	4	2
Density Variance Mean Std Dev	1 1.48 0.0092	4 0.93 0.0156	3 0.94 0.0142	2 1.38 0.0136
Mean Density Change	1 0.0057	4 0.012	3 0.0092	2 .0074

The results and rankings obtained by these three different methods are given in Table III. This shows that there is reasonable agreement between the methods and, more importantly, lower density does follow greater mottle or poorer ink lay. Nevertheless, the degree of mottle does not appear to explain the differences in average density between IGT and

* 1 is best, 4 is worst

press prints because the mean density change (Method 3) of a comparable press print (density of 1.32) was 0.0035 which is far less than for the two higher density IGT prints listed in Table III. Thus it would appear that some mechanism, in addition to ink film thickness variability (detectable by the methods used here) must account for the density differences that sometimes occurred at the same ink film thickness. Perhaps this other mechanism is ink absorption into the substrate.

Dot Gain

The effect of the fifteen different substrates on dot gain was determined by measuring the densities of the 30 and 50% UGRA dot screens and using the Murray-Davies equation to calculate dot area, on every fiftieth sheet saved from each press run. Table IV lists the mean value of the gains for each run, while the same data is plotted in Figure 7 versus paper grade. Examination of the dot gains disclosed a rather disturbing fact: the dot gains for Runs 1 and 16 differed significantly, in spite of the fact that the same paper was used. For example, the difference of 4.9% for the 50% dots was almost as large as the difference of 6.7% between the highest (Run 4) and the lowest (Run 15) gains in all the runs.

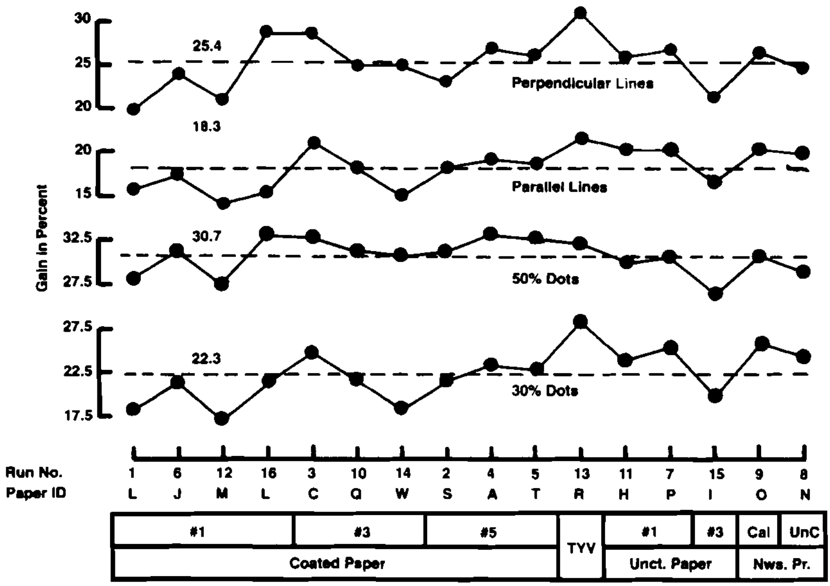

Figure 7 Mean values of film to print gain in various sections of UGRA target, for each substrate. Dashed lines show average value for sixteen runs. Screen rulings were 150 lines per inch for dots and 120 for lines.

Table IV Data on Percent Gain in UGRA Halftone Patches

Run No.	Paper				UGRA Solid		30% Dots		50% Dots		Parallel Line		Perpendicular Lines	
	ID	Grade	Finish	Dens	Mean Density	Std Dev	Mean Gain	Std Dev	Mean Gain	Std Dev	Mean Gain	Std Dev	Mean Gain	Std Dev
1	L	#1	Ctd	.04	1.42	.03	18.3	0.6	28.2	1.0	15.7	0.6	19.9	0.7
2	S	#5	Ctd	.09	1.42	.04	21.5	0.9	31.2	1.0	18.4	0.9	23.1	0.9
3	C	#3	Ctd	.12	1.45	.04	24.9	0.6	32.9	0.6	21.1	1.0	28.7	0.5
4	A	#5	Ctd	.12	1.43	.04	23.4	1.0	33.2	0.8	19.1	0.7	27.1	1.3
5	T	#5	Ctd	.09	1.41	.03	22.7	0.6	32.8	0.8	18.8	0.6	26.3	0.7
6	J	#1	Ctd	.05	1.44	.04	21.2	0.9	31.5	1.0	17.4	0.7	24.0	1.3
7	P	#1	UnC	.07	0.98	.01	25.3	1.1	30.7	1.1	20.6	0.4	26.9	1.6
8	N	Nws	UnC	.18	0.99	.01	24.2	1.4	29.0	1.0	19.9	1.1	24.6	1.4
9	O	Nws	UnC	.20	1.00	.03	25.8	3.0	30.9	2.7	20.3	1.9	26.5	3.3
10	Q	#3	Ctd	.05	1.40	.02	21.6	1.3	31.2	1.3	18.3	1.0	24.9	1.8
11	H	#1	UnC	.03	0.91	.02	23.8	0.9	30.1	1.3	20.2	0.7	26.1	1.4
12	M	#1	Ctd	.04	1.35	.01	17.1	0.8	27.5	0.9	14.3	0.6	21.0	1.4
13	R	TYV	-	.03	0.90	.03	28.2	3.5	32.2	2.5	21.8	1.6	31.2	2.9
14	W	#3	Ctd	.11	1.33	.01	18.2	2.0	30.7	2.1	15.1	0.7	25.0	4.0
15	I	#3	UnC	.07	0.93	.01	19.6	1.1	26.5	1.0	16.7	0.9	21.5	1.6
16	L	#1	Ctd	.04	1.36	.02	21.5	1.1	33.1	0.9	15.6	0.5	28.9	1.5
High Value							28.2		33.2		21.8		31.2	
Low Value							17.1		26.5		14.3		19.9	

This discovery prompted further analysis, in the form of similar measurements of the gains in the line screens used in the UGRA slur targets. The results of these measurements, listed in Table IV and also plotted in Figure 7, show that the gain differences between Runs 1 and 16 were a result of differences in dot spread in the direction of paper travel, since lines parallel to paper travel had the same gain in Runs 1 and 16, whereas the gain of lines perpendicular to paper travel differed by 9% for the same runs. Thus it can be concluded that the difference in dot gain on Run 1 versus 16 was due to a press variable and that the affect of the different substrates on gain could be gaged by examining the gains of the parallel line screens.

While these latter gains ranged from a high of 21.8% to a low of 14.3%, examination of the plot of this data in Figure 7 does not disclose a consistent trend with respect to paper grade. For example, the paper exhibiting the highest gain was a #3 coated stock (Run 3), rather than one of the newsprints as one would expect; and one of the #3 uncoated papers (Run 15) had a relatively low gain, comparable to that of the #1 coated grades. Perhaps, as a result of work now planned, these gains will correlate with one or more paper properties. For the present, however, it must be admitted that these gain variations cannot be rationalized.

Summary and Conclusions

Primary Results

The primary objective of the work described in this paper was to obtain more extensive and accurate data on the effect of paper grade on density range and dot gain at a given typical printed ink film thickness. The conclusions that can be drawn with respect to the work undertaken to achieve this end are summarized as follows:

1. A store of prints was produced on fifteen different substrates that have the same ink film thickness of 1.04 grams/square meter with a 95% confidence limit of plus/minus 9%. This ink film thickness is typical for offset printing on coated papers.

2. Density range, defined as the difference between the maximum and minimum densities that are printable, was found to vary directly with paper quality, where quality is defined in terms of the U.S. grading system and finish, i.e., coated vs uncoated. That is, the higher the quality the higher the density range. Figure 3 quantifies this conclusion.

3. Data on dot gain, obtained from the press prints, could not be used to gage the effect of different substrates on this print variable, because of the discovery that dot spread in the direction parallel to paper travel, changed during the course of printing due to some unidentified change in press performance. That is, dot gain on the same substrate was not constant throughout the production of the sheets printed on press. The gain in a line screen target (lines parallel to paper travel) was, however, constant in this respect and therefore judged to be a reliable gage of whether the variations in substrate had a significant effect on gain.

   Examination of the gains of these line screens, did indeed reveal a significant (7.5%) range in gains but no trend or correlation was evident viz-a-viz paper grade. It remains to be investigated whether this variation in gain, plotted in Figure 7, can be correlated to one or more properties of the substrates.

4. All of those findings are consistent with results reported earlier (MacPhee and Lind, 1991-1) that were based on less comprehensive data.

Ancillary Results

From time to time in the course of the primary work the authors undertook a number of ancillary investigations of general interest. The conclusions reached in these studies are summarized as follows:

a) With few exceptions, prints produced on an IGT printability tester using the same ink and substrates, had the same or slightly lower densities at the given ink film thickness of 1.04 grams/square meter as the prints produced on press. This good agreement was achieved using a hard rubber covered disk and a blanket covered sector on the IGT, which is contrary to the manufacturer's recommendations. This result would lead one to conclude that the water used in lithographic printing does not degrade print density. (One way to unequivocally resolve this question would be to measure ink film thickness on press using both wet and dry plates.)

b) IGT prints on the non-newsprint uncoated papers and the one gravure paper used (a #3 coated) had densities significantly different from prints produced on press - lower in the case of the three offset papers and higher in the case of the gravure paper. The reasons for these differences have not been explained, to date.

c) The type of surface used on both the IGT disk and sector were found to have a pronounced effect on the magnitude of print density at a given printed ink film thickness and printing pressure, especially on coated stock. Figures 5 and 6 display the data obtained in this regard.

d) The four different IGT print densities, resulting from producing prints on the same coated paper at the same ink film thickness using four different combinations of disk and sector were found to correlate with mottle, as ranked by three different methods. These data are given in Table III. Mottle measurements did not however correlate at all with the densities of IGT and press prints bearing the same ink film thickness.

e) A new method (at least to the authors) for measuring ink film mottle was tested. Although the test was very limited, the method did show promise.

f) The primary data collected provided further evidence that the procedure developed by the authors (MacPhee and Lind, 1991-2) for measuring printed ink film thickness on press is indeed reliable and accurate.

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