FLEXOGRAPHIC PRINTING OF LINERBOARD

David I. Orloff*, James Challas*, and Isaak Rudman*

Keywords: Flexo, Printability, Quality, Papermaking, Mottle

Abstract: This paper addresses issues that are important to high quality flexographic printing of linerboard. The research includes a comparison of an objective measure of print quality to a subjective measure. The paper also identifies sheet properties that lead to improved print quality and the papermaking process variables that contribute to the development of those properties.

An excellent correlation was obtained between subjective and objective measures of print quality. Hence, simple, readily available, cost-effective image analysis software and hardware may be used. The work also shows that print mottle is the overriding factor influencing perceived print quality.

By correlating sheet properties to print quality, a number of sheet physical properties that contribute to good printing were isolated. Those properties include L*a*b* color, Gurley air permeability, and to a lesser extent freeness and micro roughness. Additionally, it was observed that printing press clearance (loading) can have a major impact on print quality.

By correlating sheet physical properties to papermaking process variables, it was determined that method of pressing, press impulse, calendering, and freeness impact these important sheet physical properties.

Background: The work reported in this paper was initiated to identify the critical properties of linerboard that affect printability. Past experience has indicated that surface wettability of linerboard is an important factor in ink receptivity during the operation of the printing press. Conventional wisdom has a host of believers that smoothness is another important parameter for print quality. Still others specify freeness or Gurley porosity.

* Engineering and Paper Materials Division, Institute of Paper Science and Technology, Atlanta, Georgia, 30318. 404-853-1872. Email : dorloff@pop.ipst.edu.

Private communications from some mills indicated that Sheffield roughness should be 350 or less, with a target around 325, while Parker Printsurf should be in the low 6 range. Other mills feel that freeness should be in the 500 ml CSF or less, while Gurley porosity should generally be in the 45 to 55 range.

Nearly all the mills contacted indicated that the presence of print mottle was the biggest single factor in printing complaints. Mottle is something that is difficult to measure, but readily discernible to the human eye. As the human eye can detect very minute color variations, one of the most useful subjective methods of evaluating print quality has been by a panel of judges.

Many technical service groups, that pursue printing complaints in the field, additionally report that the source of good print quality is twofold. A good printing surface on the linerboard can result in a poor print job from the press. A relatively poor surface in turn can result in a very acceptable job from a good press operator who has kept his press in good mechanical condition. Hence, good print quality requires attention at the printing press as well as at the paper mill.

Experimental Plans And Methods

The work was structured to determine which of the many physical properties that the mills can measure truly influence the ultimate printing results. Sheets formed on a Formette Dynamique covered a range of surface properties such as roughness, density, porosity, and color.

Over 750 samples from the Formette Dynamique were double back taped to single wall corrugated for the press run on a new commercial 110" wide McKinley flexo press at Aeon Box company in Norcross, Georgia.

A 15-member panel was formed. In addition to the evaluations by the panel, computer image analysis was conducted on 21 samples chosen for the paired comparisons from all the Formette Dynamique samples. Image analysis yielded gray value histograms. Where there was little or no mottling in solid tone areas, a narrow spectrum results. The presence of mottling yields a much broader spectrum.

Handsheet Preparation

Refining: Unbleached Kraft obtained from an AFPA member mill was shipped to IPST. Once received the pulp was washed, centrifuged, fluffed, and bagged. The bags of dewatered pulp was then refined to four levels of Canadian Standard Freeness on a 1.5 lb. Valley beater. Freeness levels of 650, 500, 350, and 200 ml CSF were chosen. The volume of each beater batch was 100 liter, while the consistency was fixed at 2%. After refining, the pulp was stored in a cooler. As each batch was sufficient for the production of 50-54 Formette sheets, three batches were typically run per freeness level.

The refining curve, shown in Figure 1, was used to determine beating time to achieve various freeness levels.

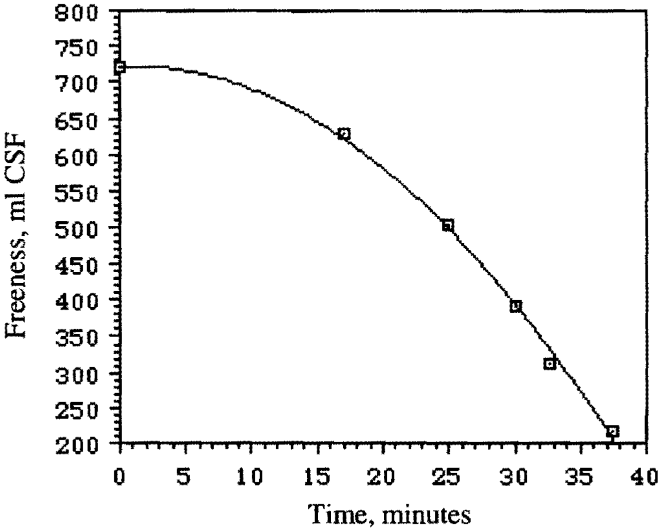

Figure 1. Beater Curve.

Sheet Forming: Single-ply, 42 lb./1000ft^3, linerboard sheets were formed on a Formette-Dynamique. Jet to Wire ratios were set on the Formette to achieve sheet MD:CD tensile ratios of 2:1. The sheet was formed at a speed of 800 m/min and drained at 1050 m/min.

Sheet Pressing: After draining, the handsheets were removed from the forming wire, stacked in groups of 8 to 10 sheets with two blotters on the top and bottom of each sheet, and pre-pressed on a Baldwin platen press at a pressure of 50 psi. Table 1 shows the prepressing conditions employed.

Table 1. Prepressing Conditions.

Freeness, ml CSF	Wet Weight, g	Dry/ Wet Weight Ratio	Pressing Conditions	
			Pressing Time, sec	Solids Out, %
650	323	.139	270	31.4
500	347	.128	540	29.5
350	350	.127	900	28.3
200	360	.123	1320	26.5

Additional room temperature pressing, at two levels of impulse, were conducted on a pilot roll press in both single- and double-felted press modes. Final press dryness was targeted at between 40 and 50%.

The number of times through the press and press load was chosen to ensure outgoing sheet density in the range (0.7-0.8 g/cm^3) of commercial linerboard. The press load was fixed at 2600 lb., while roll speed was varied to either 25 or 12.5 ft/min to simulate pressing at high and low impulse. Press impulse was estimated to be 61.2 psi· sec at a roll speed of 25 ft/min and 122.3 psi· sec at a roll speed of 12.5 ft/min.

Trial pressings were conducted on the roll press to determine the number of pressings to be carried out. Measured outgoing solids and densities for the single-felted configuration are cited in Table 2. Densities were calculated using oven-dry basis weight measured after drying of the trial pressed sheets on an electrical heater. In the same way, trial pressings were conducted for the double-felted configuration as shown in Table 3. Based on the data in Tables 2 and 3, it was decided to press sheets twice in subsequent experiments.

Table 2. Single-felted Pressing.

Freeness, ml CSF	1st pressing		2nd pressing		3rd pressing	
	Solids Out,%	Density g/cm^3	Solids Out,%	Density g/cm^3	Solids Out,%	Density g/cm^3
	Roll speed of 25 ft/min					
650	43.0	0.52	46.3	0.59	48.4	0.67
200	35.3	0.67	37.8	0.68	39.4	0.73
	Roll speed of 12.5 ft/min					
650	52.4	0.58	52.7	0.64	54.0	0.68
200	45.4	0.75	49.5	0.78	53.0	0.78

Table 3. Double-felted Pressing.

Freeness, ml CSF	1st pressing		2nd pressing	
	Solids Out,%	Density g/cm^3	Solids Out,%	Density g/cm^3
	Roll speed of 25 ft/min			
650	43.0	0.54	45.4	0.58
200	39.8	0.63	41.2	0.69
	Roll speed of 12.5 ft/min			
650	44.2	0.57	47.3	0.64
200	40.6	0.63	43.0	0.68

Sheet Drying: After pressing, the sheets were dried on a batch pilot cylinder dryer with one blotter on the top of the sheet and one blotter on the bottom. Steam pressure was 17 psig, while the pressure in cylinders that develop tension for the felt was 10 psig. Drying time, set to achieve outgoing solids of 90%, was from 3 to 9 minutes with greater time required for the low-freeness sheets.

To evaluate average hard-platen density of the dried sheets, five sheets were selected from each group. Caliper was measured at three locations per chosen sheet. In estimating density, basis weight was assumed to be 205 gsm. The actual oven-dry basis weight was in the range 205 ± 10 gsm. These results are cited in Table 4.

Table 4. Estimated Density of Dried Sheets.

Freeness, ml CSF	1st pressing		2nd pressing	
	12.5 ft/min	25.0 ft/min	12.5 ft/min	25.0 ft/min
	Density, g/cm^3	Density, g/cm^3	Density, g/cm^3	Density, g/cm^3
650	0.70	0.68	0.69	0.67
500	0.73	0.71	0.76	0.74
350	0.73	0.72	0.78	0.78
200	0.74	0.70	0.75	0.76

These preliminary data showed that sheet density was in the range 0.67 to 0.78 g/cm^3. Taking into account scatter in the basis weight, the range of densities was expected to be somewhat broader.

Calendering: Half of the sheets were then calendered on a "Soft-Nip" pilot calender. The calender was set up so that the soft roll contacted the wire side of the sheet. The calender was run at constant gap and at constant temperature.

The calender consisted of two stainless steel rolls 6.67 in. diam. on top and 5.62 in. diam. on bottom. The calender was operated at ambient temperature. A calender load of 1880 lb. was set. This yielded a calender load of 268.6 pli and an impulse 107 psi·sec at a speed of 12.58 ft/min. Calender load and speed were set to provide a compression rate corresponding to commercial magnitudes. Compression rate, CR, was defined as:

$$CR = (t_p - t_a) / t_p$$

where,

t_p = sheet thickness prior to calendering
t_a = sheet thickness after calendering

The estimated values of compression rates for conditions considered are cited in Table 5.

Table 5. Compression Rate, CR, During Calendering.

Freeness ml CSF	Double-felted pressing		Single-felted pressing	
	High Speed	Low Speed	High Speed	Low Speed
650	0.096	0.083	0.084	0.070
500	0.064	0.051	0.069	0.064
350	0.055	0.047	0.061	0.055
200	0.056	0.049	0.063	0.067

In total, 32-sheet production conditions were investigated as shown in Table 6. In total, 16 sheets at each process condition were produced, yielding a total of 512 sheets.

Table 6. Sheet Production Conditions.

Freeness, ml CSF	650				500				350				200			
Press Configuration	SF		DF		SF		DF		SF		DF		SF		DF	
Press Impulse	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
Calendering	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n	y n

Nomenclature: SF=Single-felted, DF=Double-felted, H=High Impulse, L=Low Impulse, y/n=yes/no

Handsheet Testing

Once the handsheets were produced, they were tested to provide sheet physical properties that were expected to contribute to print quality. Table 7 describes the physical properties that were determined, the testing methods to be used, the number of sheets tested per production condition, and the number of tests required per sheet.

Table 7. Handsheet Testing.

Physical Property	Test Method	TAPPI Test	Sheets / Condition	Tests/ Sheet
Apparent Density	Hard & Soft Platen Density	T411, T551	5 5	10 10
Compressibility	Compressive Stress vs. Strain	None	5	10
Macro-Roughness	Parker Printsurf (H20) Sheffield Smoothness	TNEW T538	5 5	10 10

Micro-Roughness	Stylus Method	None	5	1
Absorptivity	Surface Wettability (Ink On Paper)	T458	5	2
Permeability	Gurley Air Permeability	T460	5	10
Color Intensity	L*a*b*	T524	5	3

Testing was performed on the felt-side of selected sheets. The area of sheet tested was minimized so that remaining parts of the sheet could be used in subsequent tasks. The ink used in absorptivity measurements was the same as that used in printing the handsheets as described later.

Flexographic Printing

Supplies and Equipment: The ink used in printing was a typical black ink used in a box plant. A commercial sheet-fed flexo press was chosen as the printing process. A schematic of the printing press is shown in Figure 2. The print copy to be chosen was to include both block and fine lettering and an appropriate test pattern.

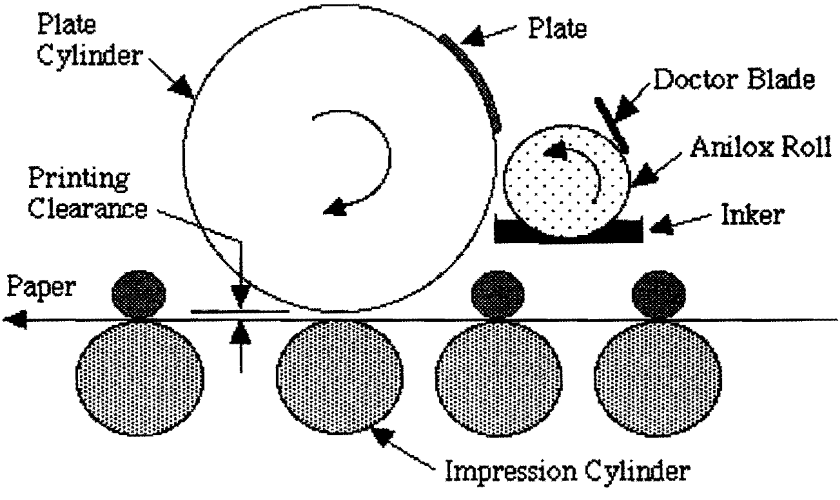

Figure 2. Schematic of the Flexographic Press.

Printing Conditions: The 32 sheet structures were each printed under the printing conditions shown in Table 8. The printing conditions were chosen in discussions with the printers as representing typical variables under their control. The ink used in the absorptivity measurements was used in the printing experiment and was designated as the high viscosity ink. The low viscosity ink was obtained by diluting the ink with water. This matrix allowed four sheets of each of the 32 production variants to be printed at each printing condition. By randomizing the sheets, variability with respect to printing sequence was eliminated.

Table 8. Ink and Printing Variables.

Ink Viscosity	High		Low	
Printing Pressure	High	Low	High	Low

Print Evaluation

Criteria for Choosing Sheets: Once sheets were printed, they were evaluated for print quality by a subjective panel test and by objective image analysis tests. The panel test was designed to rank 21 different sheets in a pair-wise comparison. This required 210 comparisons. To achieve acceptable statistical confidence in the results, the comparison was repeated 15 times with different panelists. One person ranked all 512 samples based on six print quality attributes. The 21 samples to be paneled and subjected to image analysis were then chosen to span the range of print quality while at the same time spanning the full range of sheet production process variables and printing variables.

Objective Print Quality Evaluation: The objective evaluation of print quality was determined using image analysis techniques described in this paper. Both print mottle and edge definition of printed letters were assessed.

Subjective Print Quality Evaluation: A panel test was used to subjectively evaluate the print quality of the 21 selected sheet samples that were evaluated by objective methods. Fifteen panel members, having normal vision and representing a range of previous exposure to paper testing, were chosen. The panel test was conducted using a paired comparison technique in which each sheet was compared to each of the other 20 sheets. Personnel conducting the panel test were instructed to force a preference for each paired comparison.

Experimental Results

Fiber Identification and Length Analysis

For each furnish, samples from the prepared sheets were sent for fiber analysis. The samples contained softwood unbleached Kraft (hard cook) and a trace of hardwood Kraft. The softwood contained species of southern yellow pine, while the hardwood species included species of gum and oak. Table 9 summarizes the average fiber dimensions.

Table 9. Fiber Dimensions.

Freeness ml CSF	Length (mm)			Width (mm)	Perimeter (mm)	Cell Wall Thickness (mm)	Coarseness (mg/100m)
	Arith	LW	WW				
200	1.41	1.90	2.41	37.6	88.0	3.2	28.4
350	1.66	2.21	2.73	33.0	77.2	2.8	27.0
500	1.61	2.22	2.73	39.5	89.8	2.7	27.0
650	1.83	2.52	3.11	39.5	89.6	2.8	27.2

Paper Physical Properties

In subsequent figures of this paper, the following identifiers will be used to designate the conditions under which sheets were produced.

Pressing: "S" = single-felted Calendering "U" = not calendered
"D" = double-felted "C" = calendered
"H" = higher speed
"L" = lower speed

For example, the designation SHU implies that the sheet was pressed on a single-felted press at the higher speed and was not calendered prior to printing.

Figure 3 shows a plot of soft platen density as a function of freeness. As expected, it was observed that increasing refining, using a double-felted press, lengthening the time in the press nip, and utilizing calendering all tend to increase the apparent soft platen density of the sheet.

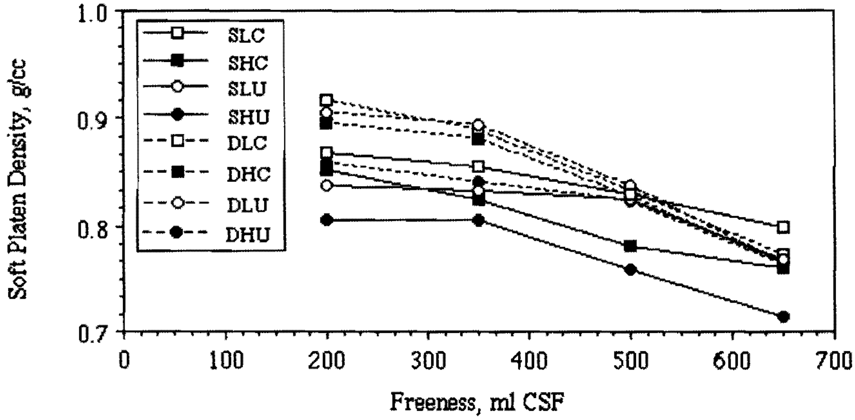

Figure 3. Soft Platen Density as a Function of Freeness.

As the ratio of soft platen to hard platen density may be related to the amplitude of the surface roughness of the sheet, that ratio has been plotted as a function of freeness in Figure 4. Based on this method of measuring sheet roughness, calendering as well as pressing method had the greatest effect on sheet roughness. Very little, if any, dependence on freeness was observed.

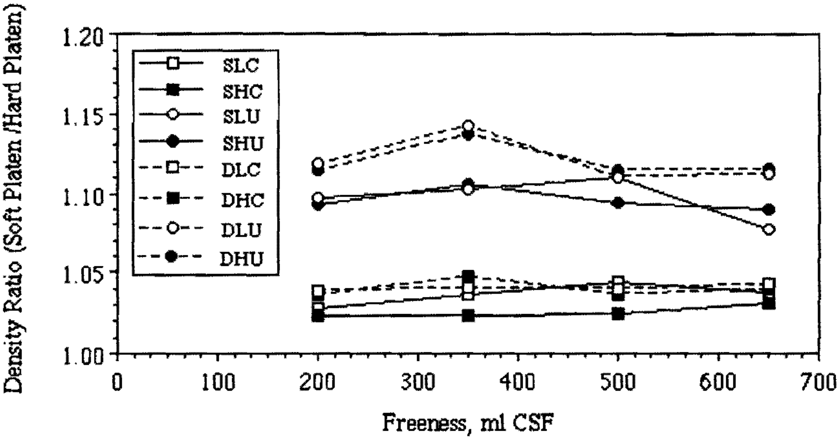

Figure 4. Density Ratio as a Function of Freeness.

Additional methods of measuring surface roughness were also applied to the sheets. Sheffield roughness has been plotted as a function of freeness in Figure 5. The data confirm that sheet roughness was primarily influenced by calendering and by method of pressing, while the effect of freeness was not observed. As Sheffield roughness and Parker Printsurf correlate well to each other, see Figure 6, the same result can be observed in plots of Printsurf as a function of freeness, as shown in Figure 7.

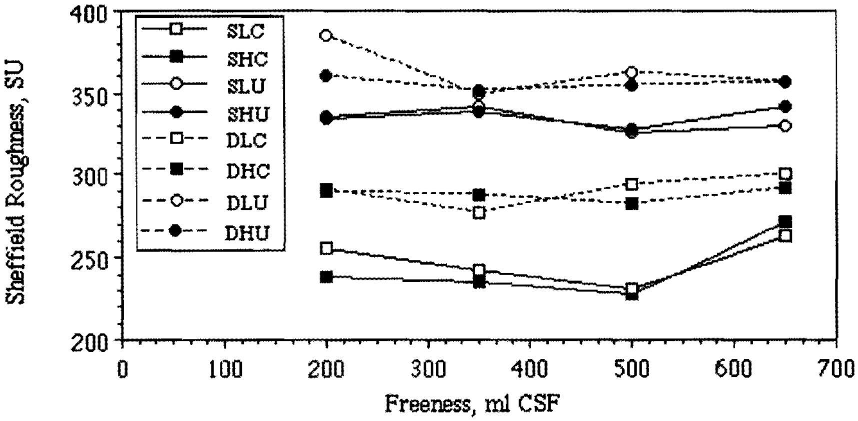

Figure 5. Sheffield Roughness as a Function of Freeness.

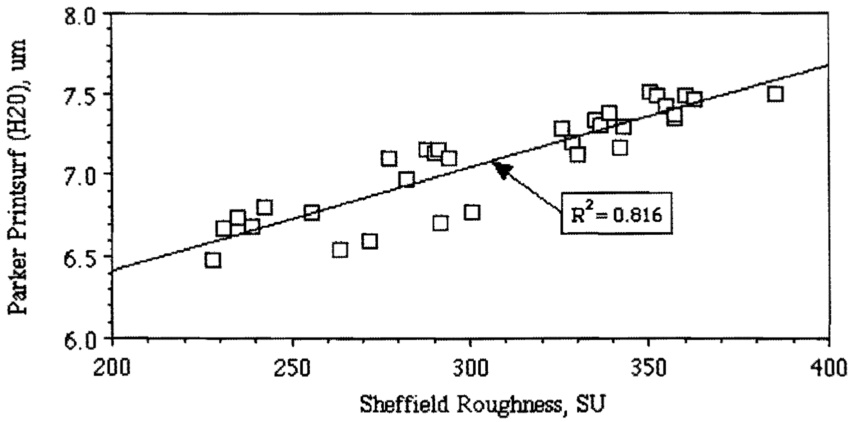

Figure 6. Parker Printsurf as a Function of Sheffield Roughness.

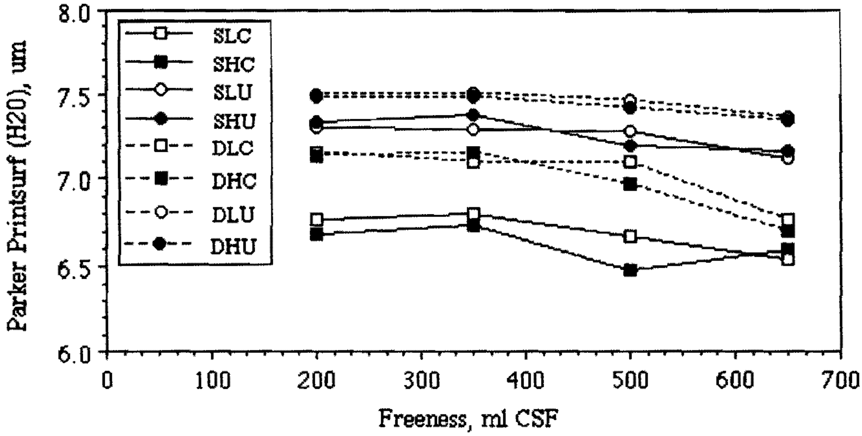

Figure 7. Parker Printsurf as a Function of Freeness.

In order to fully characterize the surface roughness of the sheets, surface roughness was also measured using a stylus method. For this purpose, samples were tested on an EMVECO Model 210-R smoothness profiling system. The test measured 300 test points at 0.1 inch spacing per sample. In total, 159 samples were tested. Data were reported as a Micro-Average Number. EMVECO suggests using Table 10 in predicting how well linerboard will print in cases where surface smoothness is a factor.

Table 10. EMVECO Printing Quality Rating System.

Microaverage Number	EMVECO Print Quality Scale
0.25 and below	Excellent
0.25 - 0.30	Very Good
0.30 - 0.34	Good
0.34 - 0.36	Fair
0.36 - 0.40	Poor
0.40 and above	Very Poor

The Micro-Average Number test data are plotted as a function of freeness in Figure 8. Review of Figure 8 shows that increased refining tended to improve the smoothness of the sheets as measured by the stylus method. Notice also, that the previously observed effects of calendering and pressing method on smoothness were not observed. An explanation for this somewhat contradictory result is that Sheffield roughness and Parker Printsurf, both air leakage methods, tend to measure large-scale roughness. Large-scale roughness can result from sheets taking on the surface topology of the felt and/or roll surface that it comes in contact with during the pressing and or calendering steps. Microroughness, however, records surface roughness on a smaller scale where large-scale topological details are not recorded.

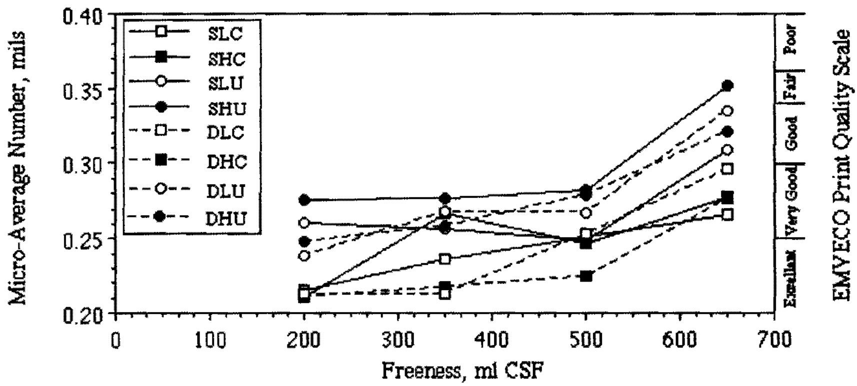

Figure 8. Microaverage Number as a Function of Freeness.

The average values of air permeability (Gurley Porosity) are plotted as a function of freeness in Figure 9. The figure shows the expected result that increased refining significantly decreases the air permeability of the sheet. Also demonstrated is the fact that pressing method and press impulse have an influence on air permeability.

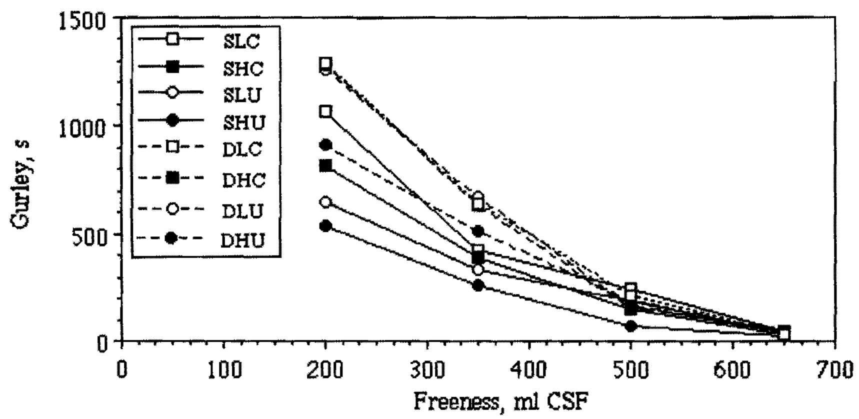

Figure 9. Gurley Air Permeability as a Function of Freeness.

It is also expected that the color of the unprinted regions of printed linerboard will have an influence on perceived print quality. Hence, L*a*b* color measurements were made on un-printed sheets and are plotted as a function of freeness in Figures 10 through 12.

Figure 10 shows that pressing method has a significant influence on the sheet brightness. When sheets were double-felted pressed, increased refining resulted in substantial darkening of the sheet. Also, for the double-felted pressed sheets, increased press impulse and calendering further darkened the sheets.

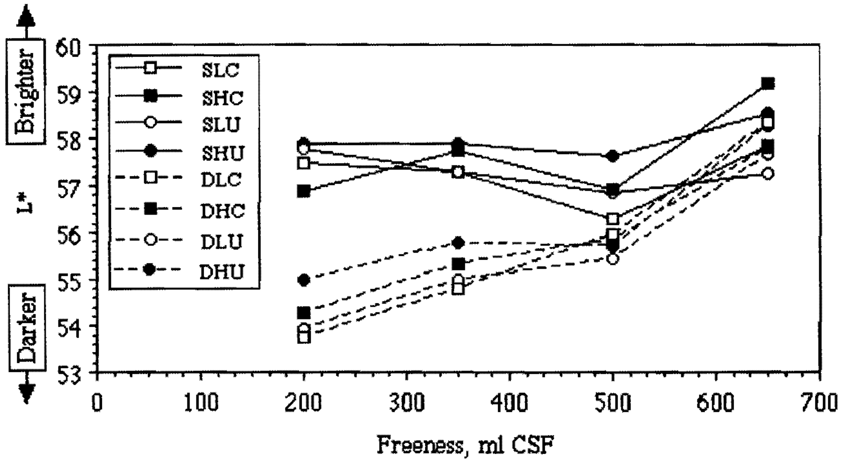

Figure 10. L* as a Function of Freeness.

Figure 11 shows that the choice of pressing method influences the redness/greenness of the sheet. Figure 12 shows that the variables included in the present experiments had little influence on the yellow/blue color of linerboard.

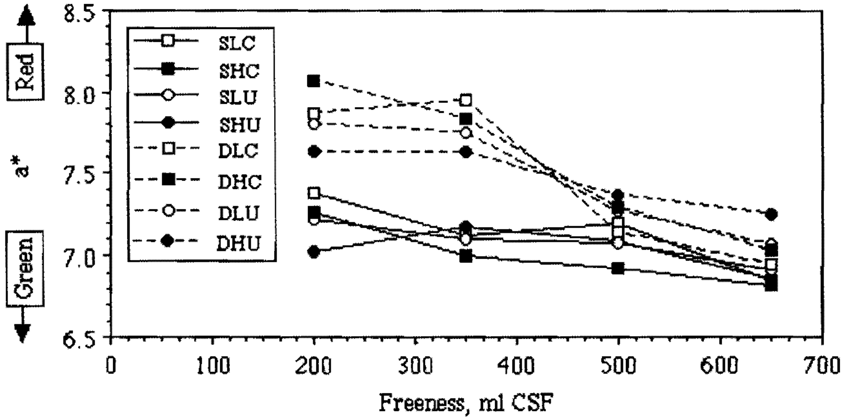

Figure 11. a* as a Function of Freeness.

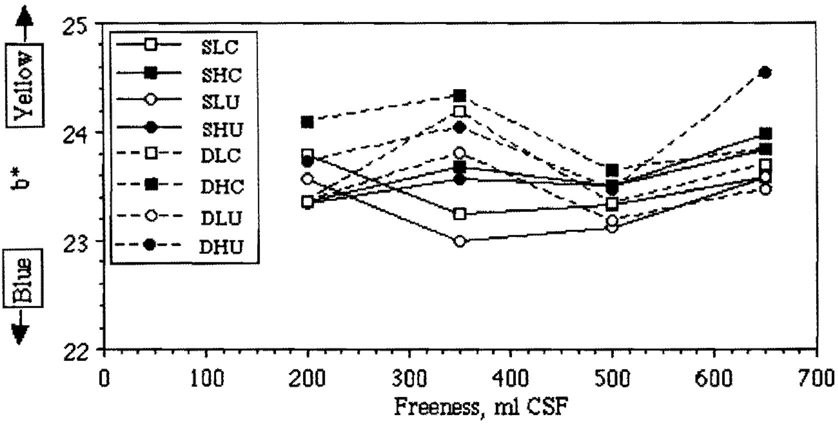

Figure 12. b* as a Function of Freeness.

Figures 13 and 14 show that surface wettability was not significantly influenced by the process variables of the experiments.

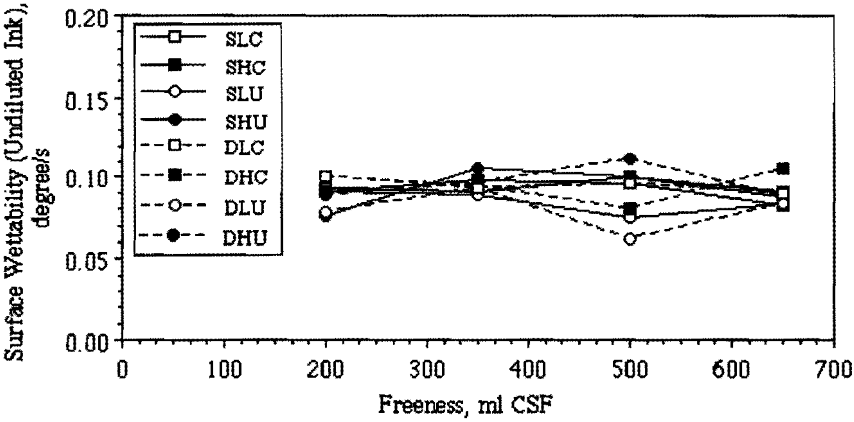

Figure 13. Surface Wettability to Undiluted Ink as a Function of Freeness.

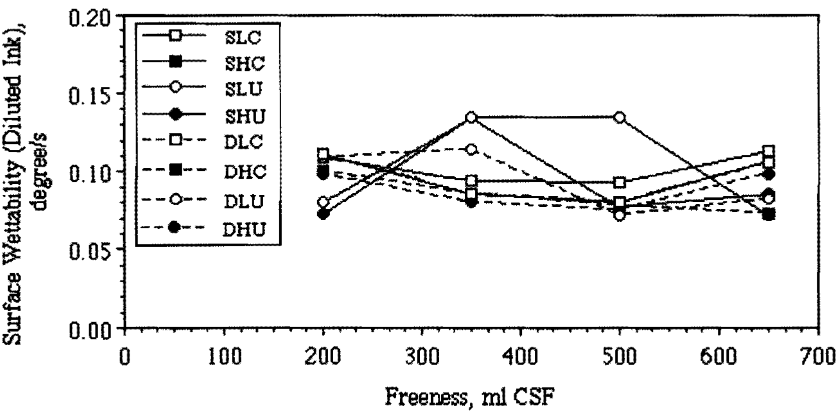

Figure 14. Surface Wettability to Diluted Ink as a Function of Freeness.

Figure 15 shows a plot of zd-compression modulus as a function of freeness. It was observed that calendering tended to decrease the compression modulus. For uncalendered sheets, increased press impulse and double-felted pressing also tend to reduce the compression modulus.

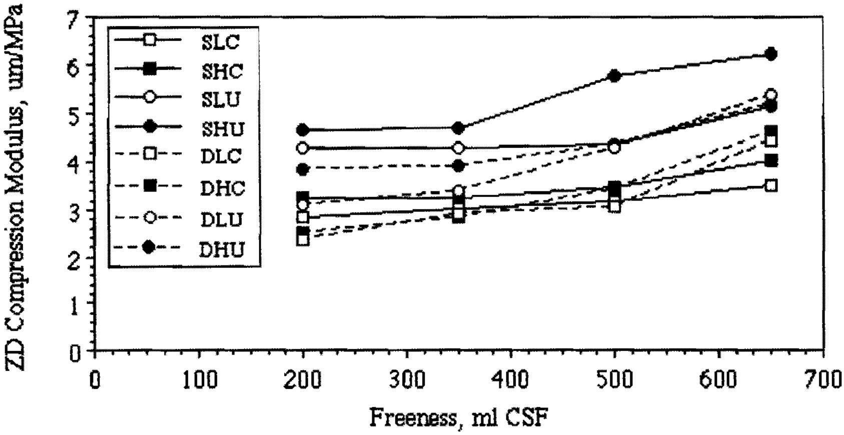

Figure 15. ZD Compression Modulus as a Function of Freeness.

Panel Evaluation of Print Quality

The flexographic printing experiments included two printing variables. These were printing clearance and ink viscosity. The print quality of 21 selected sheets was determined by a 15-member panel. Each member of the panel performed a pair-wise comparison of each sheet to every other sheet. A panel score was developed by summing the total number of positive preferences for all panelists for each sheet. The highest panel score had the best print quality, while the sheet having the lowest score was the sheet judged to have the worst print quality. Based on the panel score, the sheets could be panel ranked from the best to the worst.

Of the 21 sheets selected for print quality evaluation, 19 sheets were printed with undiluted ink having a viscosity of 23. Of those, 10 sheets were printed using a printing clearance setting of 244 (high pressure), and 9 sheets were printed at a printing clearance setting of 250 (low pressure). The remaining 2 sheets were printed at high pressure using a diluted flexographic ink (of reduced viscosity).

As printing clearance was a significant printing variable, subsequent plots distinguish between high clearance (low pressure) and low clearance (high pressure) printing. Figure 16 shows that setting the printing press at the low clearance (high pressure) generally resulted in improved print quality. It should be noted, that in commercial practice, excessive printing pressure can result in board crushing. Hence, printers are generally constrained from loading their presses to achieve the desired print quality.

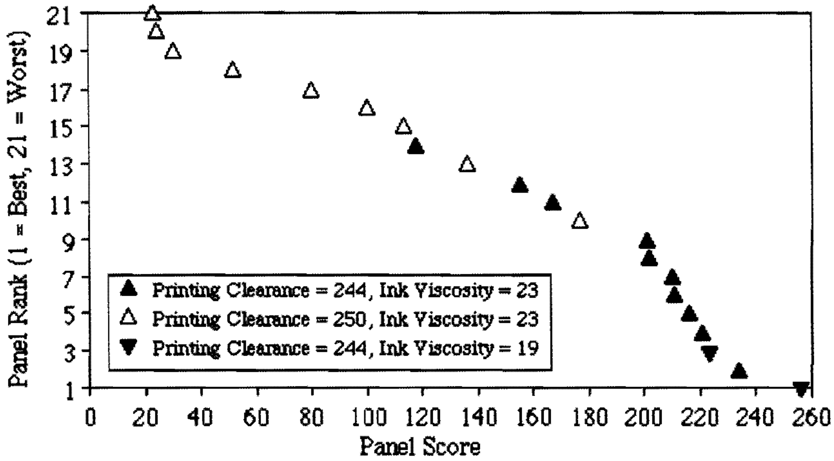

Figure 16. Panel Rank as a Function of Panel Score.

The non linearity of Figure 16 suggested that subsequent comparisons should be made to panel score rather than panel rank. This is because panel score results in a measure of how much better or worst one sheet is compared to another.

Figures 17 through 19 show the effect of sheet color on perceived print quality. For sheets printed at low pressure, panel score correlated with sheet color. In particular, sheets having more red and yellow and being darker were found to have better print quality. For sheets that were printed at high pressure, sheet color did not correlate to panel score.

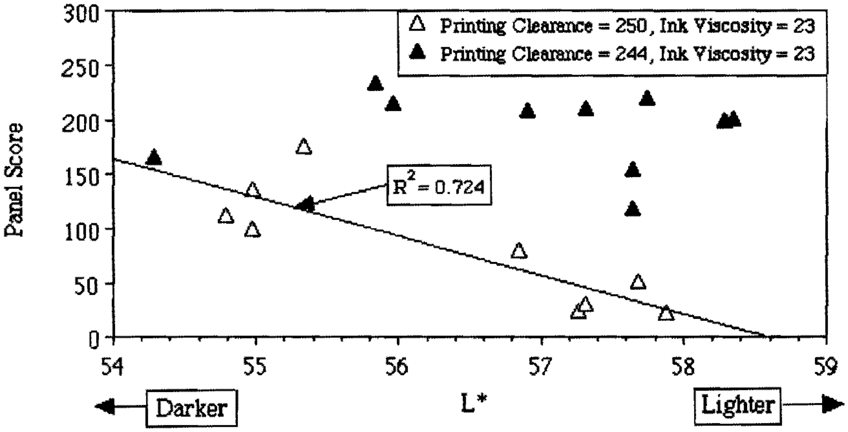

Figure 17. Panel Score as a Function of L*.

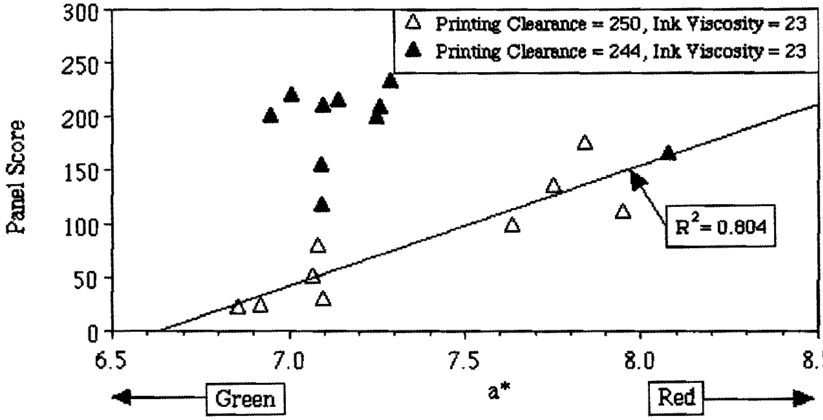

Figure 18. Panel Score as a Function of a*.

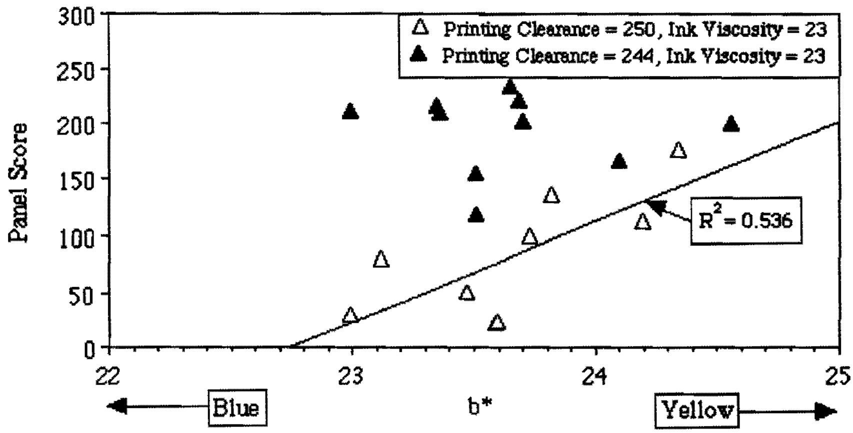

Figure 19. Panel Score as a Function of b*.

Figure 20 shows that the print quality of sheets printed at low pressure was influenced by the Gurley porosity of the sheets. Sheets that are less permeable to air flow tend to have better print quality. The print quality of sheets printed at high pressure showed no correlation to Gurley porosity.

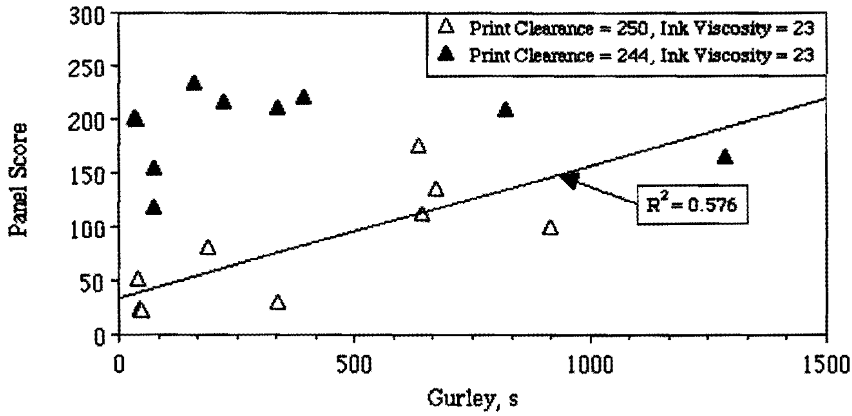

Figure 20. Panel Score as a Function of Gurley Air Permeability.

Figure 21 shows a weak correlation of panel score to freeness for sheets printed at low pressure. When printed at high pressure, print quality did not correlate to freeness.

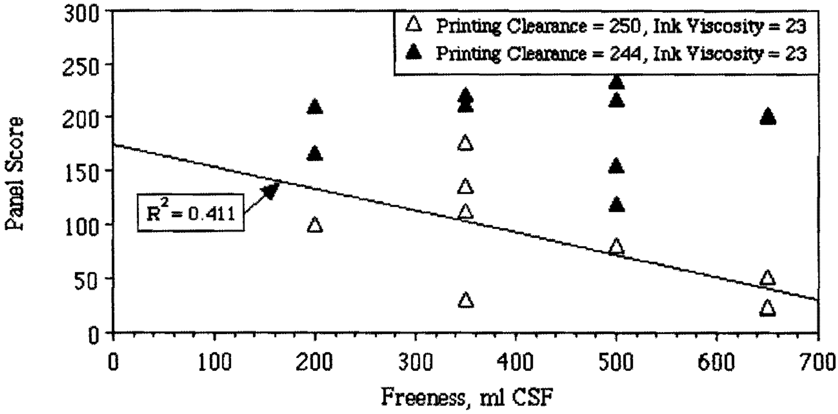

Figure 21. Panel Score as a Function of Freeness.

Figures 22 through 24 explore whether sheet macro-roughness correlates to print quality. The figures show that macro-roughness as measured by Sheffield roughness, Parker Printsurf, and density ratio does not correlate to print quality.

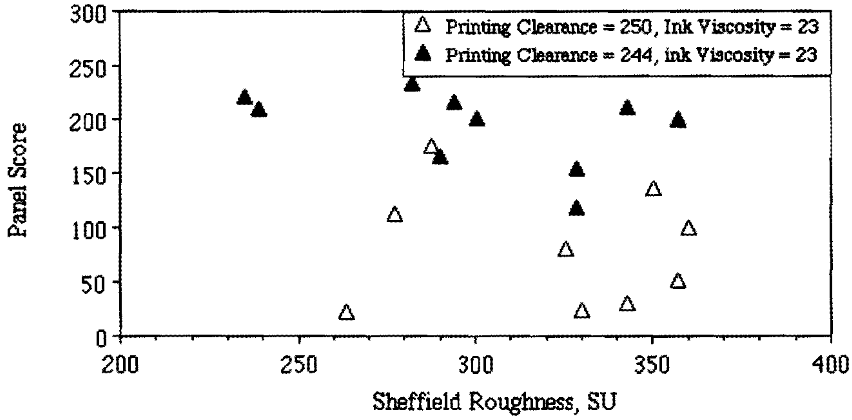

Figure 22. Panel Score as a Function of Sheffield Roughness.

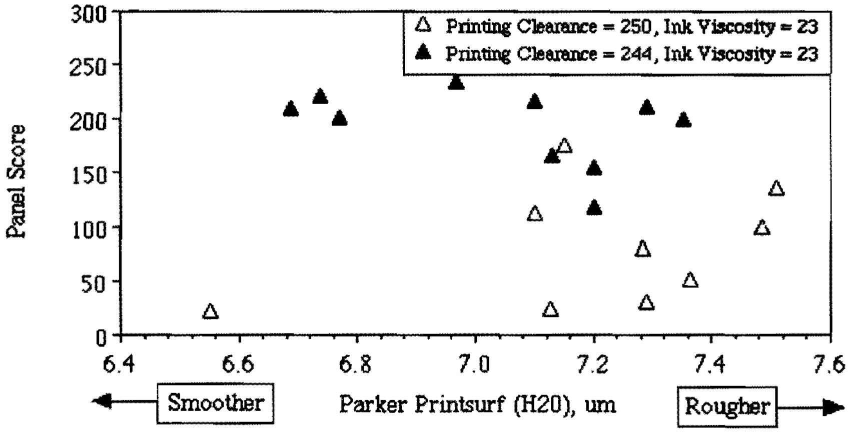

Figure 23. Panel Score as a Function of Parker Printsurf.

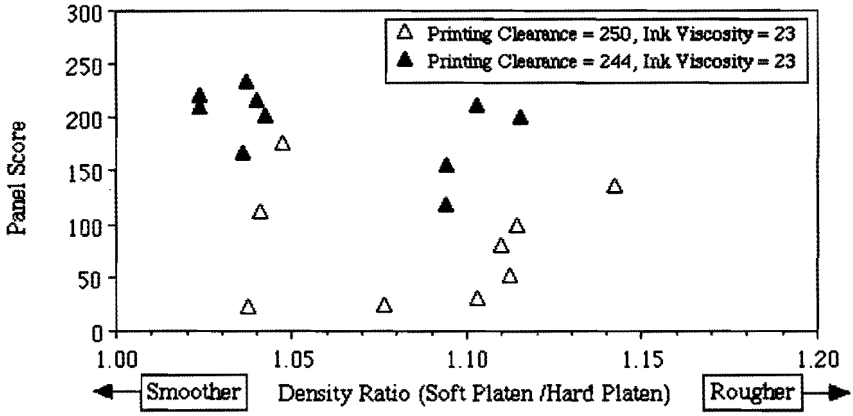

Figure 24. Panel Score as a Function of Density Ratio.

Figure 25 shows that for sheets printed at low pressure, sheet micro-roughness weakly correlates to print quality.

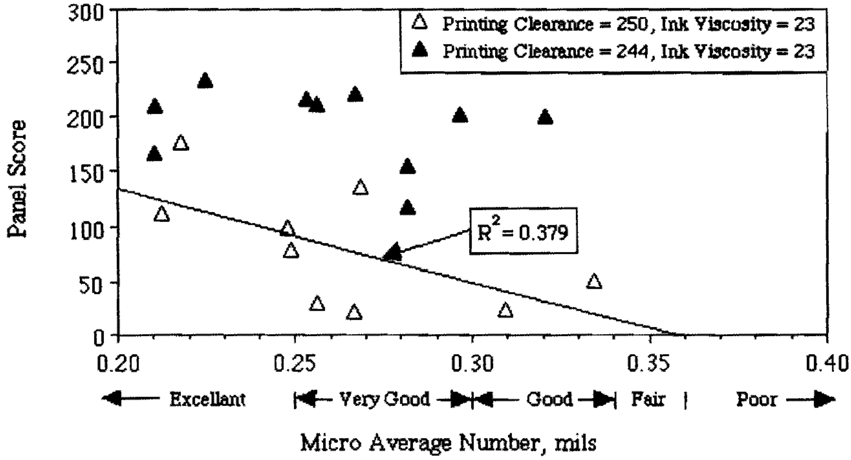

Figure 25. Panel Score as a Function of Microaverage Number.

All of the sheets printed in this study were evaluated for various aspects of print quality by a single observer. The single observer examined six quality attributes of the printed samples. One of those attributes was mottle, which the observer ranked on a scale of 1 to 6, where 1 corresponds to no mottle, and 6 corresponds to the worst mottle observed. Figure 26 shows that the panel score which included all aspects of the visual appearance of the sheet correlates very well with mottle as determined by the single observer. This result was interpreted to mean that the panelists judged the samples primarily on the basis of mottle.

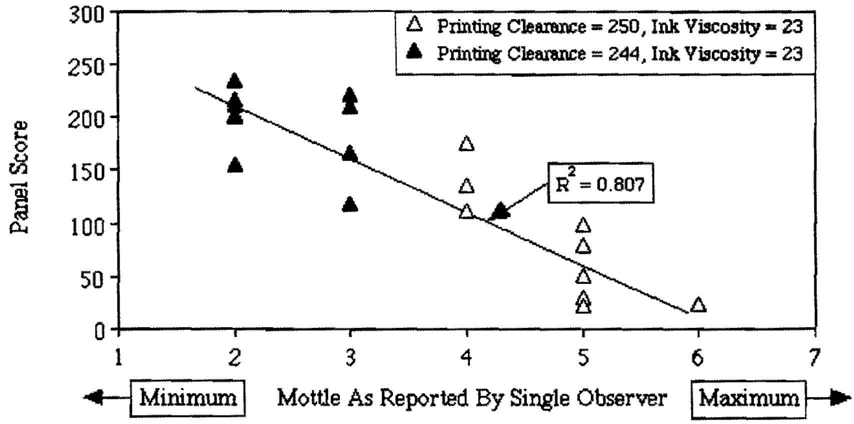

Figure 26. Panel Score as a Function of Mottle as Reported by a Single Observer.

Image Analysis and Panel Tests Compared

While panel testing is a practical and reliable way to assess the relative quality of a small number of samples, it is impractical for measuring the quality of a large number of samples or for quality control applications. For these purposes, image analysis can provide a convenient rapid measure of print quality.

Image analysis techniques were applied to the 21 panel tested samples that have been previously discussed. Scanned images of the printed surfaces were analyzed using a public domain image analysis program developed by the U.S. National Institutes of Health. The program, *Image 1.49* [1], was easily adapted to this application.

The program could be used to measure many characteristics of the printed image. In this paper, two of these measurements are reported. The first is a quantitative measure of mottle of the solid printed areas, while the second is a measure of the raggedness of the edges of printed letters.

Using the image analyzer, mottle was measured by recording the cumulative frequency of pixels that were not black in a region of the printed surface that would be entirely black if there were no mottle at all. Figure 27 shows a comparison of the cumulative frequency (image analysis) to the panel score for the same samples. The good correlation further confirmed that mottle was the primary print quality issue as judged by the panel, and that the image analyzer could be used to replace the panelists.

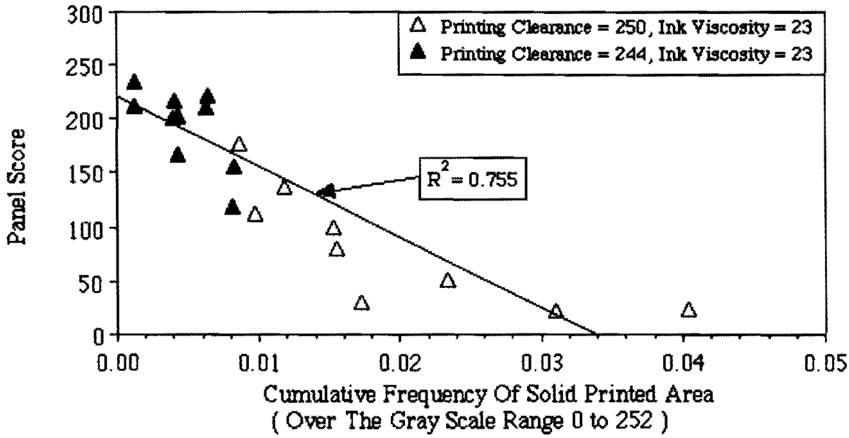

Figure 27. Panel Score as a Function of Cumulative Frequency of Solid Printed Area.

The choice of the upper gray scale limit for the cumulative frequency (252) was somewhat arbitrary. To test the sensitivity of the measurement to the choice of the upper gray scale limit, various upper limits were chosen, and correlations similar to that shown in Figure 27 were determined. The results of those calculations are shown in Figure 28. Good correlations to the panel test results were observed over a wide range of upper gray scale limits.

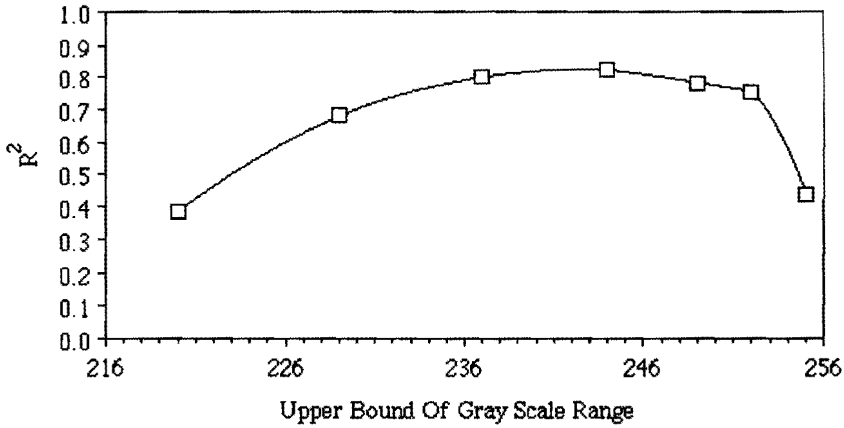

Figure 28. R^2 as a Function of the Upper Bound of Gray Scale Used to Calculate the Cumulative Frequency of the Solid Printed Area.

Figure 29 shows a plot of panel score as a function of the measured perimeter of a selected group of letters in the printed image. The perimeter measurement quantifies the raggedness of the edges of the printed letters. As perimeter did not correlate with panel score, it may be concluded that perimeter was not a major consideration of the 15 panelists.

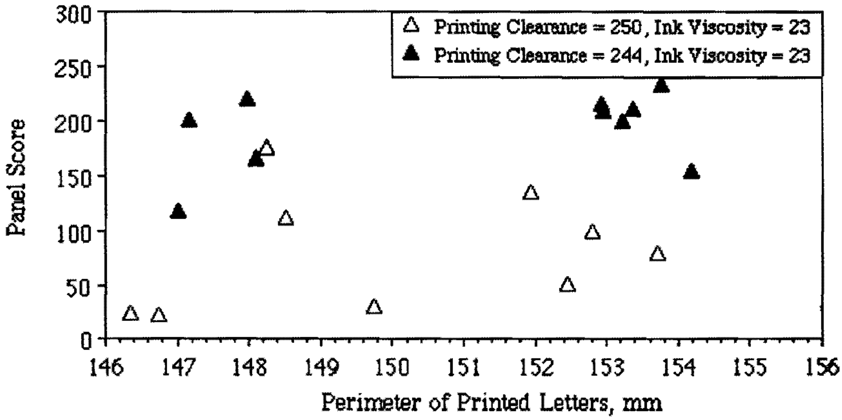

Figure 29. Panel Score as a Function of Printed Letter Perimeter.

Conclusions

The results of this study may be categorized into three main areas: a comparison of objective and subjective measures of print quality, determination of the sheet properties that lead to improved print quality, and determination of papermaking process variables that contribute to the development of those important sheet properties.

The work has shown excellent correlation between subjective and objective measures of print quality. Simple, readily available, cost-effective image analysis software and hardware have been used to perform the objective measurements of print quality. The work confirms that mottle is the overriding factor influencing subjective measures of print quality.

By correlating sheet properties to a subjective measure of print quality, a number of sheet physical properties that contribute to good printing have been isolated. Those properties include L*a*b* color, Gurley air permeability, and to a lesser extent freeness and microroughness. Additionally, it was observed that printing clearance can have a major impact on print quality.

By correlating sheet physical properties to papermaking process variables, it was determined that the following variables impact L*a*b* color, Gurley air permeability, and microroughness. Those process conditions are method of pressing, press impulse, calendering, and freeness.

Recommendations

The work described in this paper should be considered as a starting point in a program to develop a clearer understanding of the influence of papermaking variables on the printability of linerboard. As image analysis techniques have been demonstrated to correlate well to panel tests, the authors recommend performing image analysis measurements on the remaining Formette and commercial sheets. It is felt that this additional work will expand the knowledge-base to include the effects of ink viscosity, and the additional volume of data will allow more rigorous statistics that can better isolate the relative impact of papermaking process variables and combinations of process variables on print quality.

References

1. NIH *Image 1.49* is a public domain image processing and analysis program for the Macintosh. It may be obtained from NTIS (National Technical Information Service), 5285 Port Royal Road, Springfield, VA 22161.

Acknowledgments

The work reported was supported by the Technical Division of the Containerboard and Kraft Paper Group of the American Forest & Paper Association. Their support is gratefully acknowledged.

The authors would like to acknowledge the assistance of Fritz Rascherburg, Jimmy Gilreath, and Steve Clack of the Aeon Box Company for conducting the flexographic printing experiments.

Finally, the authors would like to thank Joe Batelka for conceptualizing this project and the personnel of the IPST Research Services Division for conducting much of the physical testing.