Print Quality Test Methods for Linerboard

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Abstract: We printed a wide range of brown linerboards on a commercial web flexo press and on the IGT F1 flexo proof press. The print results from the web press and the proof press were well-correlated, showing that the F1 press can predict web press performance. Profilometric roughness provided the best predictions of print quality. The correlation between visual assessment and the common Sheffield roughness was very poor. This is of concern, considering the number of mills that still use the Sheffield test. We printed a wide range of white top and solid bleached linerboards on the F1 proof press only, and the print results were also well-correlated with profilometric roughness.

INTRODUCTION

As shown previously [1,2,3], relatively little work has been done on understanding the print quality of packaging grades such as linerboard, compared to the large body of information that exists for newsprint and coated paper. Therefore, the goals of this study were:

1. To understand how commercial flexo print quality can be predicted from subjective assessment and instrumental methods.
2. To further understand the relation between physical properties and print properties.
3. To find a laboratory method to predict how linerboard samples will print commercially; particularly to evaluate the model F1 flexo proof press manufactured by Reprotest BV.

In the first part of this report, we compare web press quality of brown linerboards to the F1 proof press and laboratory tests. In the second part, we examine white-top and coated linerboard using only the F1 press and laboratory tests. This project was co-sponsored by the Containerboard Group of the American Forest and Paper Association.

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Background to Flexo Proof Press Studies

Several workers have examined flexo proof printing. Lindström *et al*. [4] examined a flexo attachment developed by Reprotest BV for their popular IGT A1C2-5 tester. While three different labs rated samples in the same order, lab-to-lab reproducibility was poor. We have tested this attachment at Paprican, along with the new F1 flexo proof press, and believe that the F1 press is the superior. Chalmers [5] was the first to report in detail on the F1 press. He stated that the F1 press could become the "first satisfactory laboratory flexographic printer". He also stated (without providing data) that the F1 prints were similar to commercial prints. Waech [6] showed that the IGT F1 press could self-consistently rank samples in preprint mode. While this was a major step, F1 proof prints were still not compared to *commercial* prints.

EXPERIMENTAL

Brown Linerboard Samples

Fourteen brown linerboard samples were printed and examined on both sides. All had a nominal basis weight of 205 g/m^2. Printed and unprinted properties are given in the Appendix. Samples are noted as “inside” or “outside” of the roll as they were received.

White-Top and Solid Bleached Samples

Including a small number of solid bleached samples printed on both sides, 40 samples were examined. Sample properties are given in the Appendix.

Flexo Printing — Web (Brown Linerboard Samples)

Brown samples were printed on an Arrowflex web press at the Quebec Institute for Graphic Communications, Montreal. Inks were supplied by Sun Chemicals, and were run at a viscosity of 35 s on a Shell No. 3 cup viscometer, equivalent to 0.050 Pa·s.

The halftone plate was printed with an anilox cylinder with a nominal ink volume of 7.14 cm^3/m^2, which is appropriate to this grade. The halftone area was screened at 85 lines per inch. The test form included a black and white photograph (Paprican test image) and a series of halftone blocks (10%, 25%, 50%, and 100% coverage). We set the press up using sample 1 (bottom or inside). All samples were then run without changing press conditions. A solid band with an ink volume of 5.55 cm^3/m^2 (giving a range from badly mottled and speckled to fully covered) was used for printing of a larger all-solid area.

Flexo Printing — Proof Press

Laboratory flexo proof printing was done on the F1 press from Reprotest BV, shown in Figure 1 [6]. The anilox to plate line pressure was 70 Newtons, as was the plate to substrate pressure. The printing speed was 0.3 m/s. Inks were supplied by Sun, and were diluted to a viscosity of 35 s on a Shell no. 3 cup (about 0.050 Pa·s). The ink pH was controlled to 8.5.

Three different anilox cylinders were used for the F1 press. These were manufactured at Paprican, and were coated and engraved by Harper Corp. The high volume Anilox 470 has a nominal ink volume of 11.6 cm^3/m^2, and was used only on the brown linerboards and the dry-finish white linerboards. The medium volume Anilox 472 has a nominal ink volume of 7.06 cm^3/m^2. This was used on all of the white linerboards. The low volume Anilox 471 has a nominal ink volume of 3.82 cm^3/m^2. This was used on all the linerboards. This was also the only anilox used for the halftone prints.

The brown linerboard samples were printed only with black ink, for print density measurements. The white top and solid bleached samples were printed with both cyan and black inks. The black prints were used for print density, print gloss, and mottle measurements. The cyan inks allowed the amount of ink transferred to the solid prints to be determined, through neutron activation analysis of the copper-based pigment, at École Polytechnique, Montreal.

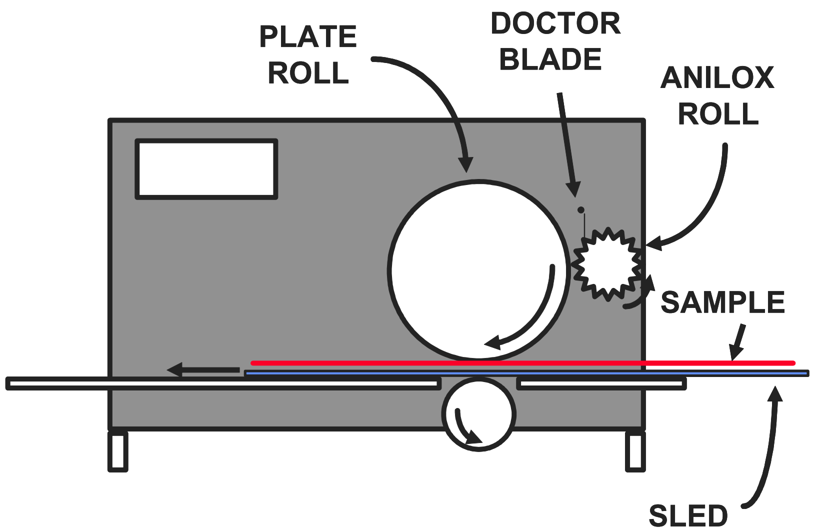

Figure 1. Schematic of the F1 flexo proof press [6], with permission.

The solid and halftone plates both had a hardness of 55° Shore A. To improve solid print uniformity, the underpadding beneath the solid plate was softer than the underpadding beneath the halftone plate, which is common commercial practice. Similarly, a softer underpadding was used beneath the solid areas of the halftone image plate.

Testing of Unprinted Samples

The following measurements were performed on the unprinted linerboards

- Basis weight, caliper, mass density.
- Parker Print Surf S-20, Sheffield roughness.
- Roughness was also measured on a modified Parker Print Surf (designated the NPPS), developed by Dr. John Parker, and described in a patent application [7].
- Emveco 210-R micro-deviation profilometric roughness [8]. The Emveco micro-deviation is an internally generated value, based on the point-to-point difference in roughness, with a greater weighting from deeper pores.
- The RMS roughness about the average surface plane, as measured by the Talyscan mechanical surface profilometer [9]. The radius of the stylus tip is 5 μm and Z directional resolution of the profilometer is 0.024 μm. The scanned area was 1 mm × 1 mm. The scanning speed was 5.0 mm/s.
- ISO brightness, L* a* b* colour coordinates.
- Contact angles with water were measured on the FTA 200 device, and were extrapolated to zero time.

Subjective Evaluation

Subjective print quality was evaluated using the Proscale package described by Donderi and Aspler [10]. For the brown linerboards, Paprican's monochrome test image (Figure 2) from the web press were evaluated. For the white top and solid bleached samples, proof press solid black prints were judged. Samples often must compete against the next higher grade. Therefore, two separate subjective ratings were carried out with the white samples: coated and surface sized samples, and surface sized and dry finish samples.

Testing of Printed Samples

Ink density measurements were done on a SpectroPlus densitometer, with an aperture of 4 mm. Mottle is given as the coefficient of variation in the print density. For the brown liners, ImagePro software was used to determine the speckle in the solid areas. Since all samples had very small scale speckle, and since human perception is more sensitive to larger scale speckle, the speckle was also filtered to remove features with an area less than 0.04 mm^2.

RESULTS AND DISCUSSION: BROWN LINERBOARD SAMPLES

Correlations between subjective ratings and unprinted brown linerboard properties are given in Table I. Other correlations with print properties are given in Table II. Table III compares key single linear regressions with multi-linear regressions.

Halftone Image — Web Print

All the judges were influenced by detail — particularly around the face and hands, and within the chess pieces. Most stated that detail was influenced by speckle. Figure 2 shows the test image for samples 1 inside (best), 10 outside (intermediate), and 13 outside (poorest). Figure 3 shows the 3-D topography from the Talyscan profilometric data. The best surface is smooth and uniform, while the poorest is very rough and uneven, showing many coarse surface fibres.

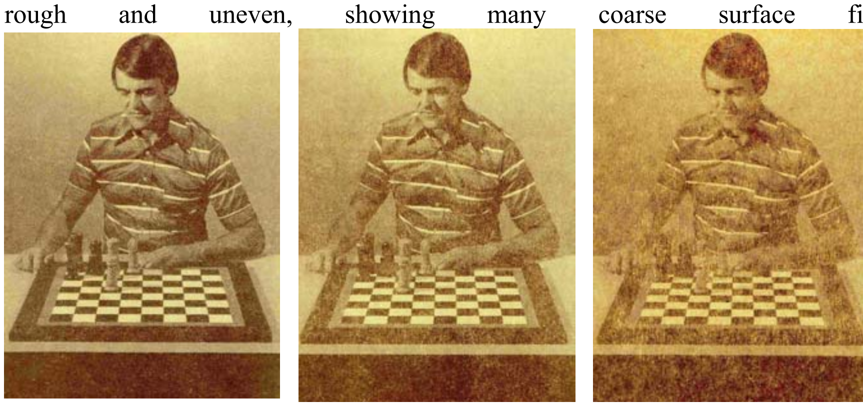

Figure 2. Halftone test prints: left to right: Samples 1 inside (best), 10 outside (intermediate), and 13 outside (poorest).

Halftone image and roughness

Table I shows that there is a good correlation between subjective rating of the halftone image and the conventional Parker Print Surf roughness, $R^2 = 0.795$. Other roughness-related measurements also correlated with the visual rating of the halftone image. The Emveco micro-deviation correlates with subjective rating of the halftone image with $R^2 = 0.819$, with an exponential fit, Rating = 12.0 exp(−0.0071*Emveco).

The subjective rating had an even better correlation with the Talyscan RMS roughness ($R^2 = 0.946$, also exponential fit, as shown in Figure 4). While the Talyscan mechanical profilometer is easy to use, the instrument is not sufficiently robust for routine use. However, non-contact laser profilometry holds promise for a more robust test. No laser profilometers were evaluated in this work. For further information, see www.taylor-hobson.com, www.cotec.fr, www.digitalsurf.fr, or www.hommelwerke.de.

TABLE I: Brown linerboards – Printed/unprinted property regressions

	Rating - halftone	Rating solid	L*	Emveco	Talyscan	Sheffield	PPS	PD web solid	PD web halftone
Rating – halftone	1.0								
Rating – solid	0.610	1.0							
L*	0.309	0.020	1.0						
Emveco	0.844†	0.536	0.187	1.0					
Talyscan	0.946†	0.589	0.211	0.824	1.0				
Sheffield	0.517	0.269	0.278	0.382	0.441	1.0			
PPS	0.795	0.331	0.398	0.670	0.794	0.588	1.0		
PD web solid	0.757	0.502	0.547	0.609	0.614	0.527	0.665	1.0	
PD 50% web halftone	0.855	0.619	0.378	0.597	0.745	0.429	0.682	0.840	1.0

†Non-linear (exponential) regressions. See text for details.

TABLE II: Brown linerboards – Web/proof press property regressions

	Rating – halftone	Rating – solid	Web solid PD	Standard deviation in web solid PD	Speckle	Proof press solid PD, high ink level	Proof press Solid PD, low ink	PD of 50% halftone, web press	PD of 50% halftone, proof press
Rating – halftone	1.0								
Rating – solid	0.610	1.0							
Web solid print density	0.757	0.502	1.0						
Standard deviation in web solid PD	0.138	0.387	0.163	1.0					
Speckle	0.726	0.489	0.569	0.267	1.0				
Proof press solid PD, high ink level	0.775	0.495	0.895	0.129	0.597	1.0			
Proof press solid PD, low ink level	0.874	0.467	0.819	0.073	0.615	0.855	1.0		
PD of 50% halftone, web	0.855	0.619	0.840	0.145	0.700	0.802	0.813	1.0	
PD of 50% halftone proof	0.739	0.499	0.740	0.163	0.586	0.775	0.832	0.746	1.0

TABLE III: Brown linerboards: Selected multi-linear regressions: Halftone image

	Halftone rating vs. Print Surf	Halftone rating vs. 1. PPS 2. contact angle	Halftone rating vs. Emveco	Halftone rating vs 1. Talyscan 2. L*	Halftone rating vs. 1. PPS 2. PD 50% halftone area
Standard error	0.969	0.904	0.871	0.731	0.959
Intercept	156; $p < 0.001$	21.6; $p < 0.001$	8.77; $p < 0.001$	4.51	-0.711; $p < 0.001$
Coefficient 1	-1.18; $p < 0.001$	-1.13; $p < 0.001$	-0.0273; $p < 0.001$	-1.430; $p < 0.01$	-0.559; $p < 0.001$
Coefficient 2	----	-0.0645; $p = 0.039$	----	0.147; $p = 0.02$	34.6; $p < 0.001$
R^2 adjusted	0.795	0.817	0.759	0.886	0.919

TABLE III: Brown linerboards : Selected multi-linear regressions: Solid print

	Solid rating vs. PPS	Solid rating vs. 1. PPS 2. Contact angle	Solid rating vs. Emveco	Solid rating vs. 1. Emveco 2. Contact angle	Solid rating vs. 1. PPS 2. Standard deviation of the solid PD	Solid rating vs. 1. PPS 2. Standard deviation of the solid PD 3. Solid coverage
Standard error	1.93	1.79	1.61	1.49	1.53	1.39
Intercept	13.0; $p < 0.001$	28.7; $p < 0.001$	9.43; $p < 0.001$	23.1; $p < 0.001$	15.7; $p < 0.001$	67.9; $p < 0.001$
Coefficient 1	-0.840; $p < 0.001$	-0.712; $p < 0.001$	-0.0254; $p < 0.001$	-0.0227; $p < 0.001$	-0.676; $p < 0.001$	-1.08; $p < 0.001$
Coefficient 2	----	-0.155; $p = 0.012$	----	-0.129; $p = 0.079$	244; $p < 0.001$	246; $p < 0.001$
Coefficient 3	----	----	----	------	----	-0.503; $p = 0.005$
R^2 adjusted	0.331	0.407	0.536	0.589	0.569	0.644

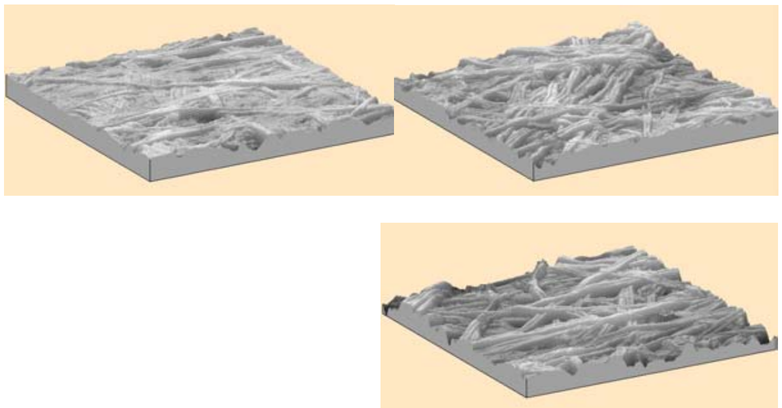

Figure 3. Topographical images. Top left: sample 1 inside; top right: sample 10 outside; bottom right: sample 13 outside. (See Table A-1 for details)

Also of interest is the correlation with Sheffield roughness (R^2 = 0.516). Since many mills still use the Sheffield, this poor correlation is of concern. The New Parker Print Surf [7] (NPPS) gave a correlation R^2 = 0.805, which was approximately the same as that obtained with the existing Print Surf.

Halftone image, roughness, and contact angle

The contact angle has a *small* influence, when combined with Print Surf roughness (Table III). The p coefficient is 0.039; significant at the 95% confidence level. Contact angle makes a difference of only about 1 unit of subjective rating: a small improvement compared to the far greater influence of topography. Such secondary influences must be used with care, especially since previous work [3] showed *no* correlation with contact angle.

Halftone image and print properties

The correlation between rating of the image and the halftone print density is excellent (R^2 = 0.855, Table I). The correlation between the rating of the halftone image and a combination of Print Surf roughness and the print density of the 50% halftone region is R^2 = 0.919 (Table III). However, this presents the problem of needing both unprinted and printed properties.

Solid Print — Web Press — Brown Linerboards

Solid print and roughness measurements

As shown in Table I, Print Surf correlated with the rating of the solid print with R^2 = 0.331: statistically significant, but far too poor to have any predictive power. The correlation with the Sheffield roughness is even poorer: R^2 = 0.269. As shown in Table III, contact angle with water improves the Print Surf correlation somewhat (R^2 = 0.407; p = 0.012). As with the contribution of contact angle to halftone rating, the contribution of contact angle to the solid print rating is still secondary to the contribution of roughness, and as before, weak correlations with secondary factors should be taken cautiously.

The Emveco micro-deviation correlated with rating of the solid with $R^2 = 0.536$. While this correlation is better than the Print Surf correlation, it is still not good enough to be predictive. The Talyscan roughness correlated with the solid rating with $R^2 = 0.589$: again, highly significant but still not enough to be predictive.

Solid print rating and print properties

Several print-related factors (Table II) gave better correlations with the visual ranking of the solid than did the unprinted tests. For example, $R^2 = 0.619$ between the solid rating and the print density of the 50% halftone area. As with the halftone image, while these correlations are useful, it is preferable to have simple tests that can be done *without* printing.

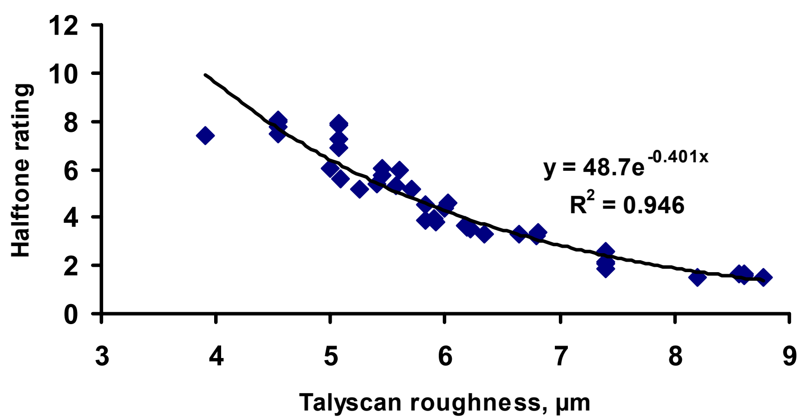

Figure 4. Rating of halftone image from web trial as a function of Talyscan roughness. Note non-linear (exponential) fit ($R^2 = 0.946$).

In Figure 5, solid print density is plotted on the x-axis, the standard deviation in the print density of the solid is plotted on the y-axis, and the subjective rating of the solid is plotted on the z-axis. The best samples had a high print density with a low standard deviation. Samples with high PD/high standard deviation or low PD/low standard deviation received an intermediate rating. Finally, the poorest prints combined a low print density with a high standard deviation.

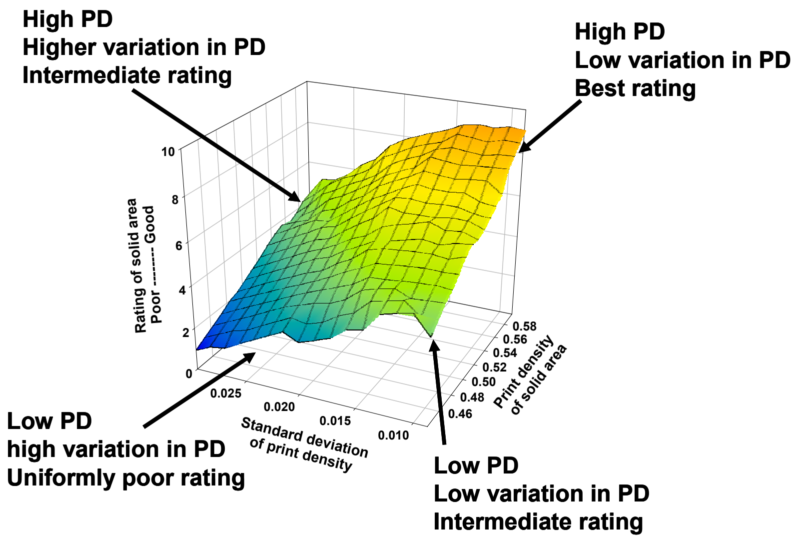

Figure 5. Solid band rating vs. standard deviation in the PD and the PD of the solid area.

Image quality and speckle

Figure 6 shows the correlation between the halftone rating and the amount of speckle in the solid area of the print The correlation is improved once the

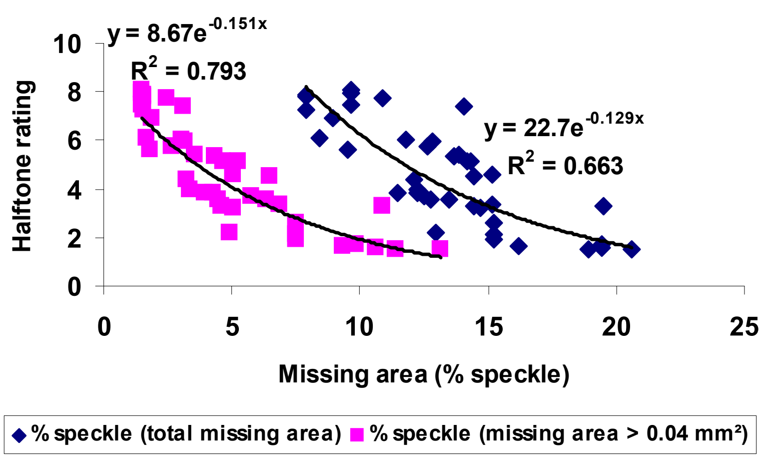

Figure 6. Correlation between rating of the halftone image and the measured speckle in the solid print. Note the non-linear (exponential) fit.

speckle has been filtered to remove the smaller features (< 0.04 mm^2). All of the prints showed fine speckle, and the response of the human eye is much greater to larger scale defects. Figure 7 shows that the Talyscan roughness is especially predictive ($R^2 = 0.778$) of the larger-scale speckle.

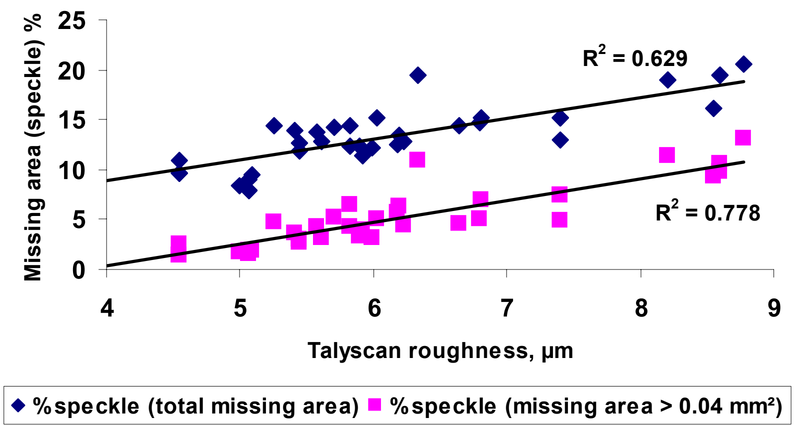

Figure 7. Correlation between Talyscan roughness and the measured speckle in the solid print.

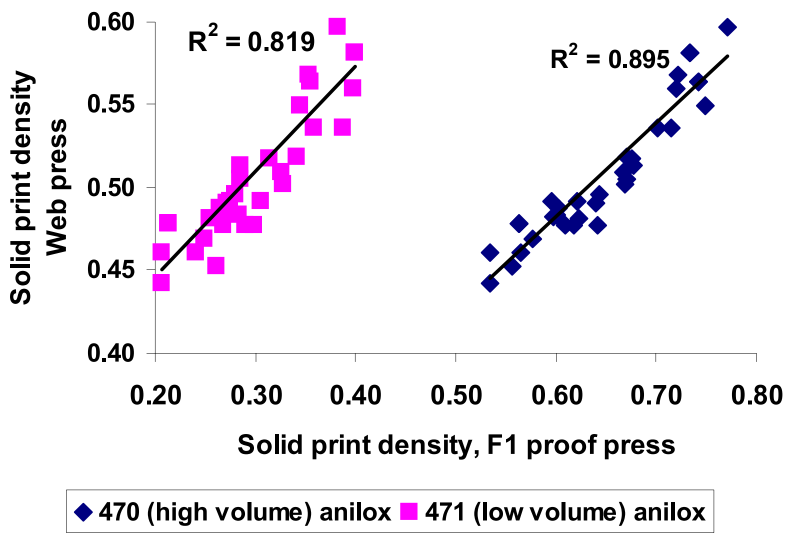

Figure 8. Solid print density of web press band no. 3 as a function of the F1 proof press print density, measured with the 470 (high volume) and 471 (low volume) anilox rolls.

Properties of F-1 Proof Prints

Figure 8 shows the print densities of the web solid vs. the proof press solid. The correlations between web print density and proof press print density are excellent ($R^2 = 0.819$ with the low volume anilox and $R^2 = 0.895$ with the high volume anilox). The details of the correlations are shown in Table II. The correlations between proof print properties and subjective ratings, and between the web print properties and subjective ratings are comparable. Visually, the F1 proof prints and commercial prints were also very similar.

The F1 prints also correlated with the subjective ratings of the web prints. Table II shows the correlation between the rating of the web halftone image and the print density measurement on the 50% halftone on the F1 press is $R^2 = 0.739$. The halftone image rating correlated with the print density measurement on the 50% web halftone with $R^2 = 0.855$.

RESULTS AND DISCUSSION: WHITE-TOP AND SOLID BLEACHED

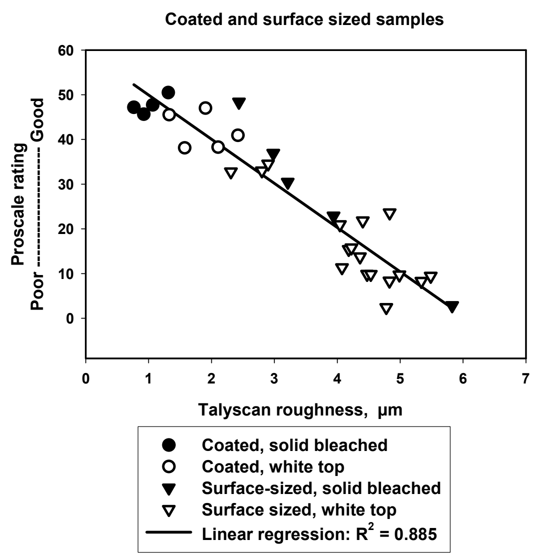

Figure 9. Rating of coated/surface sized samples vs. Talyscan roughness.

Subjective Print Quality

Two separate subjective ratings were carried out on the solid test prints. Surface sized and coated samples were judged together, and the dry finish/surface sized samples were judged together. In their exit interviews, the judges commented that favourable ratings had been influenced by: absence of speckle and mottle; high gloss; and high print density.

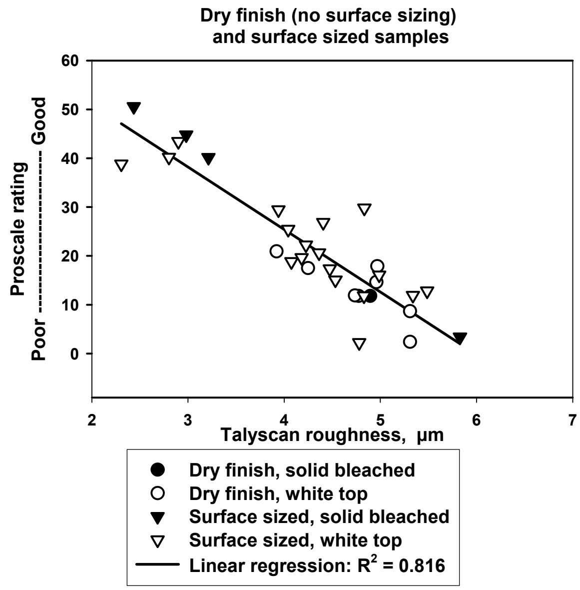

Figure 10. Rating of dry finish/surface sized samples vs. Talyscan roughness.

Tables IV and V give the correlations between subjective judgements and physical and print properties. Figures 9 and 10 show that there is a good correlation between the ratings and the Talyscan RMS roughness. There is also a good correlation with the Emveco roughness and a fair correlation with the Print Surf roughness. In the previous brown board study, the correlation with the Sheffield roughness was extremely poor. With these samples, the correlation with the Sheffield roughness was comparable to the Print Surf case. This may have been due to the fact that this range of samples was smoother.

For the coated/surface sized group, it is not surprising that the most favoured samples were coated samples on solid bleached board, followed by the coated samples on the white-top board. Nevertheless, the results also showed that the best of the surface sized substrates could compete closely with the coated board. Similarly, in the dry finish/surface sized group, while several of the surface sized samples were rated the highest, there was considerable overlap between the poorer surface sized samples and the better dry finish samples. One factor, that is certainly an artefact, is the positive correlation between the sample rating and the standard deviation in the print gloss, since samples with higher gloss also have a higher standard deviation in the gloss.

TABLE IV: White linerboards: Regressions for coated and surface sized ratings: unprinted and proof press properties

	Rating – Solid print	Sheffield	PPS	Emveco	Talyscan	Unprinted gloss	Solid PD	COV PD	Printed gloss
Rating – proof press solid	1.0								
Sheffield	0.778	1.0							
PPS	0.849	0.681	1.0						
Emveco	0.901	0.739	0.794	1.0					
Talyscan	0.885	0.718	0.914	0.868	1.0				
Unprinted gloss	0.665†	0.351	0.778	0.517	0.698	1.0			
Solid PD	0.740	0.479	0.864	0.656	0.815	0.862	1.0		
COV PD	0.790†	0.493	0.466	0.596	0.577	0.215	0.367	1.0	
Printed gloss	0.682†	0.341	0.714	0.465	0.668	0.956	0.853	0.187	1.0

†Non-linear exponential fit. See text for details.

TABLE V: White linerboards: Regressions for dry finish and surface sized samples: unprinted and proof press properties

	Rating – proof press	Sheffield	PPS	Emveco	Talyscan	L*	Unprinted gloss	Solid PD	COV in solid PD	Printed gloss
Rating – proof press	1.0									
Sheffield	0.692	1.0								
PPS	0.685	0.714	1.0							
Emveco	0.827	0.694	0.661	1.0						
Talyscan	0.816	0.641	0.754	0.841	1.0					
L*	0.000	0.090	0.010	0.010	0.000	1.0				
Unprinted gloss	0.610†	0.417	0701	0.436	0.547	0.016	1.0			
Solid print density	0.645	0.369	0.573	0.604	0.626	0.024	0.333	1.0		
COV solid PD	0.685†	0.339	0.407	0.404	0.490	0.053	0.171	0.336	1.0	
Printed gloss	0.480†	0.481	0.667	0.559	0.656	0.000	0.846	0.436	0.195	1.0

†Non-linear exponential fit. See text for details

Evaluation of Print Quality

Figure 11A shows the print density and Figure 11B shows the coefficient of variation (COV) in the print density using the intermediate volume anilox 472, as a function of Talyscan roughness. The COV in the print density is greater for rougher surfaces. This is expected, but a critical exception could occur with substrates with poor formation, where excessive calendering will lead to a higher print density, but with *more* print mottle [e.g, 11].

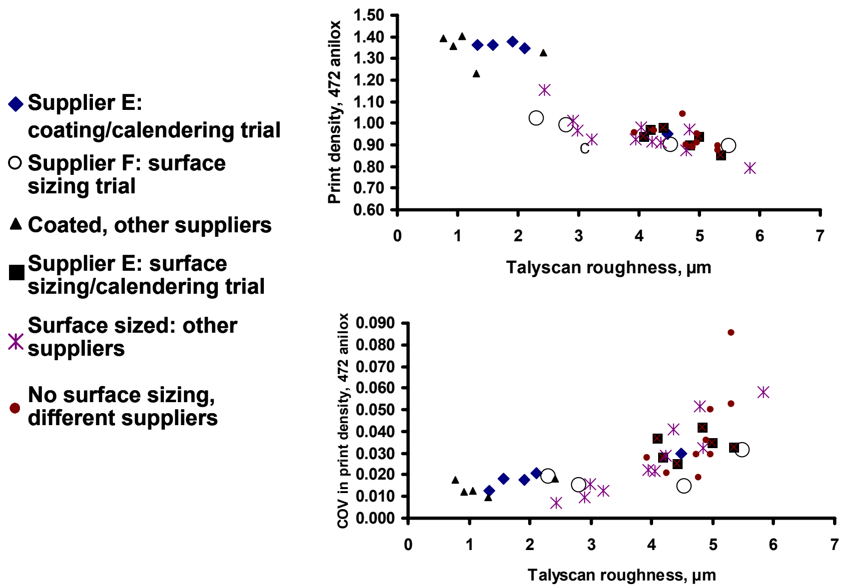

Figure 11. (a) Print density (472 anilox) as a function of Talyscan roughness. (b) Coefficient of variation in print density as a function of Talyscan roughness.

Figure 12 shows the "snap" (the difference between the printed and unprinted gloss) as a function of Talyscan roughness. For all the surface sized and dry finish samples, snap is very low or negative. That is, the printed gloss may be lower than the unprinted gloss, due to water penetration into the sheet, leading to fibre rising and sheet roughening. Fibre rising is well-known with uncoated and lightly coated or surface sized papers. While most familiar in mechanical printing grades, fibre rising also occurs with woodfree grades as well [12,13].

Unprinted Tests

Unlike the brown linerboards where a weak contribution from surface chemistry (contact angle) was found, *no* correlations were found between surface chemistry and other physical or print quality properties for the white linerboards. *However, water absorbency beyond the commercial norm — either greater or less — may produce problems*. This explains Jensen's results

[14] showing that excessively hydrophobic coating binders gave print mottle, due to poor wetting by the ink. Similarly, Johnson [15] showed that in simulated multi-colour flexo printing, printing a wax emulsion first and overprinting with a flexo ink also led to more mottle. Finally, Bassemir and Krishnan [16] showed that inks with a high surface energy did not properly wet the coating surface, and so gave mottle. Our ongoing work shows that for surface-sized linerboards, linerboard surface chemistry *may* be important, depending on the ink [11].

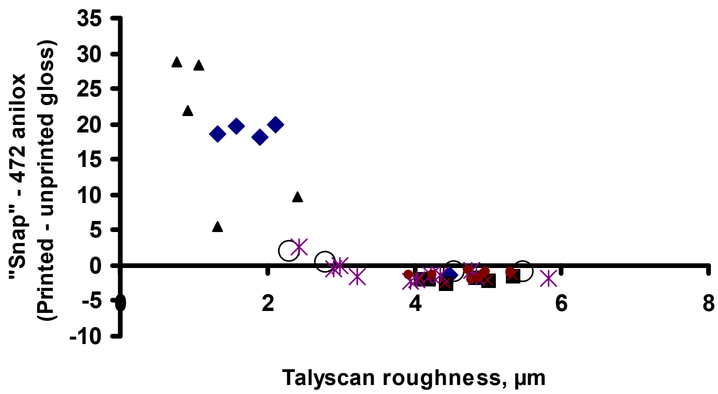

Figure 12. Difference between printed and unprinted gloss (“snap”). Gloss values were measured at an angle of 60°. See Figure 11 for Legend.

SUMMARY AND CONCLUSIONS

A range of brown linerboards were printed on a commercial web flexo press and on the IGT F1 flexo proof press. The results from the web press and the proof press were well-correlated, showing that the F1 press can predict web press performance. Profilometric roughness provided the best predictions of print quality. The correlation between visual assessment of brown linerboards and the common Sheffield roughness was very poor. This is of concern, considering the number of mills that still use the Sheffield test. A wide range of white top and solid bleached linerboards were printed on the F1 proof press only, and the print results were also well-correlated with profilometric roughness.

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APPENDIX: SUPPLEMENTARY DATA

This appendix contains raw data on the printed and unprinted samples

TABLE A-I: Brown linerboards: Physical properties, top side (outside)

Code	L*	Emveco	Sheffield	Talyscan	PPS	Contact angle
1	62.8	106.9	272	5.45	7.48	111
2	58.3	195.0	385	6.64	8.83	109
3	59.9	373.2	404	8.55	11.2	107
4	64.3	128.2	388	5.41	7.47	117
5	61.3	282.2	390	8.20	9.93	114
6	58.6	118.3	360	5.71	8.07	110
7	60.1	123.2	399	5.82	8.54	112
8	61.5	201.2	370	6.79	9.25	116
9	64.5	112.4	331	5.61	7.02	104
10	60.5	159.6	368	5.90	8.26	104
11	58.5	124.8	381	6.81	8.85	106
12	59.9	169.0	379	6.34	9.53	107
13	58.4	269.2	411	8.60	11.4	110
14	59.7	161.1	370	6.03	9.14	111
Bottom side (Inside)						
1	61.8	77.6	233	4.55	6.53	98
2	56.5	170.8	380	6.23	9.03	107
3	57.8	196.0	393	8.78	10.1	117
4	61.9	159.3	401	5.92	9.26	115
5	58.2	175.8	382	6.18	9.63	113
6	57.1	128.3	370	5.25	8.47	114
7	61.7	88.1	377	5.07	7.96	108
8	58.2	132.5	336	5.09	7.86	116
9	63.5	81.1	276	4.99	7.27	103
10	58.6	59.3	322	3.91	6.30	115
11	56.5	173.1	371	5.57	8.22	113
12	59.0	148.1	381	6.20	9.62	107
13	56.0	206.1	413	7.40	11.8	107
14	59.3	124.3	363	5.99	8.71	111

TABLE A-II: Brown linerboards: Properties of prints, top side (outside)							
Code	Rating halftone	Rating solid	Web solid PD	% speckle	Proof press PD	Web PD halftone	Proof press PD halftone
1	6.03	4.75	0.549	11.8	0.749	0.307	0.158
2	3.28	2.47	0.452	14.5	0.556	0.272	0.123
3	1.64	2.39	0.469	16.2	0.576	0.265	0.117
4	5.41	2.80	0.518	13.9	0.671	0.306	0.151
5	1.52	2.77	0.487	18.9	0.603	0.264	0.119
6	5.17	5.28	0.492	14.2	0.595	0.282	0.140
7	4.54	4.51	0.517	14.5	0.675	0.295	0.156
8	3.24	2.47	0.491	14.7	0.621	0.276	0.149
9	5.97	4.27	0.568	12.9	0.721	0.313	0.171
10	3.95	4.44	0.495	12.3	0.643	0.285	0.149
11	3.38	4.92	0.481	15.2	0.623	0.250	0.134
12	3.31	4.65	0.490	19.5	0.640	0.263	0.142
13	1.56	1.83	0.442	19.5	0.534	0.249	0.121
14	4.60	4.62	0.477	15.2	0.610	0.267	0.154
Print properties – bottom (inside)							
1	7.84	9.06	0.581	9.68	0.733	0.348	0.179
2	3.54	5.26	0.477	12.78	0.618	0.282	0.148
3	1.52	2.08	0.461	20.59	0.564	0.228	0.109
4	3.83	5.07	0.513	11.46	0.677	0.307	0.126
5	3.70	4.24	0.483	12.53	0.597	0.289	0.125
6	5.17	5.41	0.483	14.33	0.601	0.292	0.137
7	7.65	8.49	0.563	7.88	0.742	0.351	0.168
8	5.60	6.79	0.510	9.54	0.666	0.296	0.155
9	6.07	7.92	0.597	8.45	0.771	0.355	0.201
10	7.43	9.78	0.536	14.05	0.715	0.359	0.204
11	5.31	8.03	0.477	13.69	0.641	0.286	0.138
12	3.56	7.54	0.505	13.49	0.670	0.291	0.158
13	2.20	5.33	0.479	15.22	0.563	0.259	0.123
14	4.37	7.49	0.502	12.12	0.668	0.291	0.157

TABLE A-III: Coated samples: Basic physical, optical and surface properties								
Mill	Code	Basesheet	L*	Unprinted gloss	Print Surf	Emveco	Talyscan	Contact angle
Coating and calendering trial								
E	17 – basesheet	White-top	88.9	6.7	6.28	82	4.47	116
E	13	White-top	92.6	48.4	1.25	9	1.33	105
E	14	White-top	92.5	47.3	1.13	8	1.90	105
E	15	White-top	94.5	58.9	1.87	15	2.10	94
E	16	White-top	93.9	59.4	1.33	12	1.57	92
Other coated samples								
B	2	Solid white	93.9	49.8	0.82	3	1.07	107
B	3	Solid white	93.3	18.2	1.49	5	1.31	111
B	4	Solid white	94.0	59.5	0.64	3	0.77	106
H	34	Solid white	94.7	57.6	0.97	3	0.92	91
I	36	White-top	92.1	36.6	2.19	22	2.42	95

TABLE A-IV: Uncoated (dry finish) samples: Physical, optical, surface properties								
Mill	Code	Basesheet	L*	Unprinted gloss	Print Surf	Emveco	Talyscan	Contact angle
A	1	White-top	87.4	7.1	6.17	79	4.97	120
C	7	White-top	89.5	8.5	5.44	90	4.77	109
C	8	Solid	92.3	8.7	5.17	90	4.89	113
D	10	Solid	95.2	7.3	7.23	97	5.31	90
D	12	White-top	93.3	8.0	6.98	105	5.31	96
F	30	White-top	88.1	7.0	6.58	82	4.74	116
F	31	White-top	88.0	6.3	6.72	91	4.96	115
G	32	White-top	89.1	12.1	4.94	55	3.92	115
F	40	White-top	88.0	8.9	5.20	67	4.25	115

TABLE A-V: Surface sized samples: Basic physical, optical, and surface properties							
Supplier	Code	Basesheet	Unprinted gloss, 75º	Print Surf	Emveco	Talyscan	Contact angle
Surface sizing and calendering trial							
E	23 – basesheet	White-top	6.1	6.79	118	5.34	114
E	18	White-top	15.8	4.44	56	4.41	108
E	19	White-top	12.9	4.90	78	4.18	110
E	20	White-top	11.6	5.27	80	4.08	110
E	21	White-top	10.1	5.66	102	4.99	113
E	22	White-top	9.4	5.92	122	4.83	115
Surface sizing and calendering trial							
F	30 – basesheet	White-top	7.0	6.58	82	4.74	116
F	26	White-top	6.1	6.84	94	4.53	97
F	27	White-top	21.5	3.23	25	2.80	93
F	28	White-top	26.7	2.83	21	2.31	86
F	29	White-top	5.9	6.74	104	5.49	116
F	31	White-top	6.3	6.72	91	4.96	115
Other surface sized samples							
B	5	Solid	12.6	2.93	5	2.44	105
B	6	Solid	11.5	4.40	31	3.21	90
D	9	Solid	8.2	5.23	23	2.98	96
D	11	White-top	7.5	6.01	57	4.83	95
E	24	White-top	7.1	5.53	68	4.04	108
E	25	White-top	7.6	6.69	117	5.83	104
H	33	Solid	11.5	7.04	78	4.78	90
I	35	White-top	11.0	5.51	55	4.23	109
I	37	White-top	12.0	5.19	61	4.36	109
H	38	Solid	16.9	3.80	54	3.94	116
F	39	White-top	14	3.90	36	2.90	113

TABLE A-VI: Coated samples: Print properties				
Code	Solid print Anilox 472 (Medium ink level)			
Coating & calendering	Ink transfer, g/m^2	Print density	COV in print density	Printed gloss, %
17	2.81	0.95	0.030	3.06
13	2.77	1.37	0.013	33.6
14	2.63	1.38	0.018	32.3
15	2.49	1.35	0.021	38.3
16	2.52	1.37	0.018	39.6
Other coated samples				
2	2.54	1.40	0.013	43.1
3	2.71	1.23	0.010	10.8
4	2.46	1.39	0.018	49.3
34	2.45	1.36	0.012	40.6
36	3.09	1.33	0.018	20.0

TABLE A-VII: Dry finish samples: Print properties				
Code	Solid print Anilox 470 (highest ink level)			
	Ink transfer, g/m^2	Print density	COV in print density	Printed gloss, %
1	4.45	1.10	0.013	3.62
7	4.09	1.05	0.015	3.71
8	4.18	1.04	0.025	4.04
10	4.54	1.09	0.014	3.81
12	4.37	1.07	0.035	3.68
30	4.60	1.04	0.019	3.17
31	4.44	1.08	0.015	3.09
32	4.28	1.05	0.022	4.31
40	4.73	1.11	0.011	3.34

TABLE A-VIII: Surface sized samples: Print properties				
Sample Code	Solid print Anilox 472 (Medium ink level)			
Surface sizing and calendering trial	Ink transfer. g/m^2	Print density	COV in print density	Printed gloss, %
23 – basesheet	3.02	0.85	0.033	3.22
18	2.95	0.98	0.025	5.51
19	3.04	0.97	0.029	4.97
20	2.79	0.94	0.037	4.44
21	3.17	0.94	0.035	4.16
22	3.04	0.90	0.042	3.85
Surface sizing and calendering trial				
30 – basesheet	2.76	0.89	0.085	3.42
26	2.99	0.90	0.015	3.14
27	3.18	0.99	0.015	8.04
28	3.18	1.02	0.019	10.18
29	2.69	0.89	0.031	3.14
31	3.08	0.91	0.029	2.95
Other surface-sized samples				
5 (reverse of 4)	2.64	1.15	0.007	6.98
6	2.77	0.93	0.012	5.19
33	2.91	0.96	0.016	6.40
35	2.86	0.97	0.032	4.68
37	2.89	0.98	0.022	4.64
9	2.69	0.79	0.058	3.77
11	2.65	0.88	0.051	3.50
24	2.87	0.92	0.029	3.52
25	3.09	0.91	0.041	3.41
38	2.67	0.92	0.022	4.75
39	3.07	1.01	0.010	5.16