"A Study of a Method to Predict Printing Quality of Paper by Means of Smoothness and Elongation Test Results"

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"A STUDY OF A METHOD TO PREDICT PRINTING QUALITY OF PAPER BY MEANS OF SMOOTHNESS AND ELONGATION TEST RESULTS"

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ABSTRACT

The object of this thesis is to investigate the use of smoothness and elongation test results as criterion for evaluating the printing quality of paper. The relationship of smoothness and printing quality has been known for many years and in all previous work it has been shown to be influential to printing quality. The relationship of elongation and printing quqlity has never been investigated. The experimental procedure consisted of testing the paper samples for smoothness and elongation, and determining the printing quality of the different papers with the I. G. T. Printability Tester. The results of the analysis of the experimental data can be used to indicate good or poor printing quality of paper.

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INTRODUCTION

In the past thirty years great technical advancements have been made in the manufacture and printing of paper. However, the development of evaluating techniques to determine paper printability and printing quality have not kept pace with other developments in the industry(1). This is due to the complexity of the printing operation, lack of suitable definition of printability and printing quality, and the lack of instrumentation to measure the printing aspects of paper(2).

The printing of paper involves three systems: (a) paper, (b) ink, and (c) the printing press(3). Each of these three systems is made up of many variables which affect each system and the other systems because they are interrelating during the printing process. The following diagram illustrates the interrelationship of the three systems during the printing operation:

PAPER
paper board films
coated, uncoated
smoothness, compressability
porosity, wettability
etc.

INK
rheology
component properties

PRESS
speed
pressure
temperature
relative humidity
plate surface
etc.

PRINTABILITY
printability measurement mechanism
interrelationship of various factores
of the three systems
control instrumentation

RUNABILITY
transfer
picking
etc.

PRINT QUALITY
color density — solids
gloss — type
uniformity — of lines
tone value — dots
contrast — color

POST PRESS
setting
drying
etc.

The goal of any method of evaluation is to be able to determine before printing how paper will print or the paper's printability and print quality. The evaluation method should be short, simple, and give fast results which can be used to evaluate paper's printing properties in the paper mill and print shop.

Printability and printing quality are two terms which are often confused. Printability means the combination of strength properties, ink receptivity, and runability which enable the paper to withstand the tensions of the printing press and to have high printing quality(6, 7, 8). Printing Quality is the evaluation of the reproduction of the original copy judged by its general appearance, gloss, finish and contrast of printed and unprinted areas, uniformity of solid and halftone areas, tone value and printing fidelity(3, 6, 8, 1, 21).

HISTORY - METHODS OF EVALUATION

Most of the important work done in developing methods of evaluation has been carried on in the last fifteen years. Three schools of thought have developed as to the basis for testing paper to determine its printing quality. The first one believes that any evaluation technique should be based on instrument testing of the paper after it is printed(3, 1); while the other group bases their methods on testing the paper before it is printed(10, 9, 2, 4, 1). The third group believes it should be based on both types of tests.

Methods used in the past to test printed paper for printing quality have seen the wide use of the proof press utilizing letterpress and gravure printing processes(1, 13, 4, 15), ink setting time using the printing gage to obtain a visual value for printing quality(6), drawdown to simulate printing pressures in which paper is characterized as it would appear during the printing operation(17), and actual observation of the printing operation by high speed motion pictures and microscopic analysis of the printed paper(13, 9, (). All these methods have one big drawback which is the lack of an unbiased evaluation of the results of the tests to give a value which can accurately determine the printing quality of the paper. In the use of proof press methods, human evaluation is widely used and much work has been done to alleviate this human factor and give reproducible results(18, 15).

Those who favor testing the paper before printing have investigated all the physical properties of paper which could possibly have any influence on printing quality to determine if they could be used to evaluate paper's printing characteristics. Of all the properties, tests showed that smoothness was the most important factor for paper in printing. Compressibility was found to be influential to printing, but measurement of this property is very difficult. Softness was found to be a factor. Ink receptivity was found, also, to be a factor of printing quality. Press speed is influential. Stiffness has no correlation.

Of all the studies carried out on the physical properties of paper, those directed to investigating the rheology of paper seem to be the most promising for the development of a method evaluating printing quality(23). This work involves the study of tensile and elongation properties of paper. So far paper rheology relative to printing quality has not been investigated, but work done to date has brought to light what actually happens during tensile and elongation tests. This is a significant step toward developing a printing evaluation method because it has revealed that the present tensile instruments and elongation testers are inaccurate and incapable of giving reproducible results, because of the present jaw design which allows slippage of the paper during the test. The paper expands during the test; and the time-load factor is not analogous to that of actual use.

The evaluation methods developed to date have had partial success in evaluating paper printing quality, but they all lack the ability to give results which can correlate papers' physical properties and printed paper characteristics with printing quality to the satisfaction of the papermaker and of the printer. The reason for this is that our present understanding of paper and the printing operation is in its infancy. The answer to the problem lies in the field of paper rheology. Future research in this area will eventually unlock the essential factors that govern printing quality in paper. Once these factors are found, instruments can be designed to evaluate them; and, thus, determine the printing quality of the tested paper.

HISTORY - SMOOTHNESS AND ELONGATION TEST DEVELOPMENT

Whenever smoothness has been investigated to find out whether or not it correlates with printing quality, the results have shown that it is the most influential factor affecting printing quality of paper(21, 22, 23).

Smoothness has been called several names such as: surface configuration and roughness in an attempt to use a more meaningful term(20). This has come about because of the lack of understanding of just what smoothness is and how it affects printing. Smoothness of paper deals primarily with all the deviations in height, depth, and width of surface imperfections; and the frequency and distribution pattern of these variations. The frequency and distribution pattern of the surface variations is very important, because a paper with numerous small deviations prints better than a paper with a few large deviations when both of these papers have the same smoothness.

There are three variations inherent in paper which affect smoothness. These are coating patterns, interfiber voids, felt and wire marks.

Smoothness instruments use five different principles to the surface configuration of paper; they are as follows:

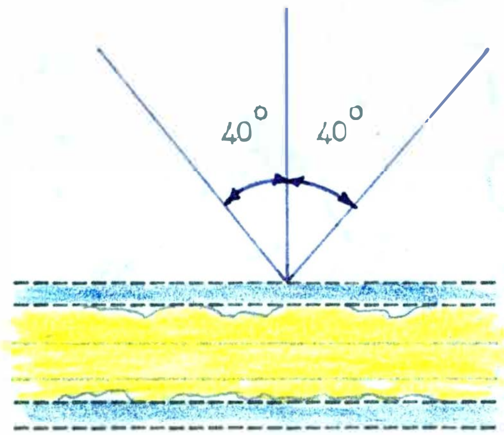
1. air-leak instruments
2. optical contact
3. ink-oil transfer and coverage
4. surface-profile measurement
5. subjective evaluation of magnified surfaces

The air-leakage instruments now in use throughout the paper industry are the Bekk, Burley, and Burley SPS, Scheffield, Bentsen, and the Williams. These instruments are limited by one important factor and that is their inability to duplicate paperpress conditions. In the first place, they all work under a static pressure condition which allows the paper to come to equilibrium with the pressure by compressing. Actually, in printing the pressure in dynamic; and the paper does not have a chance to come to equilibrium. Also, in printing there is an ink film which makes contact with the surface of the paper and printing plate. This is not taken into account in any smoothness tester.

There is only one optical contact area instrument in use in the industry at the present. This is the Chapman Smoothness Tester(10). This instrument comes the closest to simulating actual printing conditions on all the present testers. Here the paper is subjected to considerable pressure which, due to the static conditions, leads to compressiblility of the paper and increases the smoothness results.

The printing smoothness is that fraction of the surface that can be brought into contact with a smooth surface pressed against it under pressures comparable to printing pressures. The amount of contact is measured by the amount of light reflected back from the glass surface which the paper is pressed against. In areas where the paper doesn't make contact with the glass, the light is bent away from the normal and is not recorded by a system utilizing a photoelectric cell.

Therefore, high reflectance along the normal indicates a smooth surface while low reflectance indicates a rough sheet.



(Light reflected back from surface imperfection will not follow the normal; therefore, the instrument records only the light that comes within 40 degrees of either side the normal.)

This instrument suffers from one big disadvantage, which I have explained earlier, static equilibrium under pressure. The inventor noted this and pointed out that to correct the instrument would be to costly.

Ink-oil transfer and coverage techniques have developed to visually evaluate the surface of paper in attempt to determine smoothness. These tests utilize proof press techniques, Hull draw-downs and wipes, and nip-oil separating apparatus; but they have one big drawback which is the inability to give results that can be used to evaluate smoothness or as mentioned earlier, printing quality.

Surface profile instruments have been designed in an attempt to measure the actual surface deviations of paper. Those in use today are the Brush Surface Analyzer and the Proficorder. These types of instruments show great promise because they can investigate the entire surface of sheet, where else other testers measure only a small fraction of the sheet.

Subjective evaluation of the surface of paper with the aid of magnification has seen the use of various photographic techniques to visually examine and evaluate the printed and unprinted paper surface.

The prime value of any smoothness instrument is to predict and rank paper surfaces' effect on printing fidelity. This is essential because printing is affected by the individual imperfections and not instrument averages. Future developments should be designed to create a smoothness tester which will test paper under the conditions found in printing.

The prime object of this thesis is to determine whether a combination of smoothness and elongation test results can give an accurate correlation with printing quality. Research in elongation's influence on printing quality is nonexistant; but within the last twenty years, studies and experiments to investigate paper rheological properties have brought to light many interesting facts about paper which have promise as being the key to the whole evaluation problem(23). By using elongation as a factor in connection with smoothness, this thesis hopes to show that rheology can solve evaluation problems.

Rheological studies have brought out one factor which for many years was suspected but never proved. This is the fact that our present tensile and elongation testing equipment is not adequate to measure these properties because the instruments fail to take into account the fact that paper expands under tension. The present design of the jaws in the tensile tester allow slippage of the paper. The stress, loading, shear, and strain of the paper is not applied uniformily; while the time relationship is not even taken into account. Besides this the testers do not simulate actual printing or other actual conditions of use(Gront, Rancee, Gibbon, Farebrother, Steenberg, Ivarsson) (23).

Future rheological studies into the structure of papers and their relation to the stress, strain, and time factors involved when paper is printed, will give the basic knowledge from which it will be possible to design instruments to evaluate printing quality of paper.

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EXPERIMENTAL DESIGN

Purpose

The literature survey has shown that smoothness has a definite correlation with printing quality and that the influence of elongation has never been evaluated.

Therefore, the purpose of this thesis is to evaluate the use of smoothness and elongation test data in predicting printing quality of paper before printing.

General Design

The general design of the experimental procedure is to test the samples of paper (various coated and uncoated sheets) for smoothness on the Gurley SPS Tester and elongation on the Testing Machines Tensile Tester.

To determine the applicability of the results in predicting printing quality, the I. G. T. Printability Tester was utilized to evaluate the printing quality of the sample papers. This envolved an adaptation of the I. G. T. smoothness test in which a 20mm half-tone screen containing a 10, 50, 70, and 90 per cent etch is used instead of the usual 10mm solid dics. The samples are tested at various printing pressures by means of adjusting the printing apparatus (2.5kg/cm^2, 5.0 kg/cm^2, 10.0 kg/cm^2, 20.0 kg/cm^2, and 40 kg/cm^2). The evaluation is based upon the minimum printing pressure required to reproduce the 10, 50, 70, and 90 per cent etch screens. The minimum printing pressure for each sample is computed. The rating as to good or poor printing quality is based on the sum of the printing pressures. The minimum total is four times the minimum pressure which is 2.5 kg/cm^2 or 10.0 points. The maximum would be four times 40 kg/cm^2 or a total of 160 points. Good printing quality lies from 10-75 points while 76-160 points for poor printing quality.

In actual practice two changes were necessary for efficiency. The first was the change to the Bekk smoothness tester. This was facilitated by the high results caused by an oil spot which appeared on the sample. The second change developed in the determination of printing quality of the paper samples when it was noticed that the 90 per cent etch screen failed to be produde on all of the samples because of filling-in of the screen. This also changed the rating system because there are three total printing pressures instead of four. Thus the good printing quality was between 7.5 and 60 points and the poor printing quality from 61-120 points. For the analysis of the smoothness and elongation test results data of the best of the good printing quality papers and of the worst of the poor printing quality papers was utilized.

Materials and Equipment

The following materials and equipment were used in the experimental investigation of the thesis:

Materials

1. Fifty seven samples of coated and uncoated papers from Allied Paper Corporation.
2. I. P. I. Black Letterpress No. 2 ink.

Equipment

1. Gurley S. P. S. Tester
2. Bekk Smoothness Tester.
3. I. G. T. Inking Apparatus
4. I. G. T. Printing Apparatus
5. I. G. T. Ink Pipette
6. 20mm. Printing disc with half-tone screens of 10, 50, 70, and 90 per cent etch

Experimental Procedure

All of the testing carried out under Tappi standard conditions of constant humidity and temperature.

The samples of paper are first tested for smoothness with the Bekk Smoothness Tester following the procedure set down in T 479sm-48 with the following changes:

1. The sample is not cut into 2 x 2 inch test samples. Instead the 11 x 8½ sheets were used in the test.
2. The smoothness is taken only on the felt side of the sample.
3. The smoothness determinations were made covering the majority of the test sample. The average value is determined and recorded.
4. The 1/10 position was used when the smoothness was over 100 sec. The result is then multiplied by ten to convert it to an "0" position reading. This was done to decrease the time of the test.

The paper samples were then tested for elongation on the Testing Machines Tensile Tester elongation testing apparatus. This apparatus measures elongation and per cent elongation. Elongation is measured in machine and cross direction. The sample size is 10 x ½ inches. Four samples were tested in the machine direction and one sample tested in the cross direction (due to small sample size). The per cent elongation and the tensile results were also recorded.

The I. G. T. Printability tester was used to evaluate the printing quality of the paper samples. The samples were cut into 1 x 10 inch strips in the machine direction. There were five samples cut for each make of paper. The procedure for inking the I. G. T. Inking Apparatus was to apply an initial 0.4cm^3 of No. 2 ink and allow it to distribute for ten minutes (soft rubber roles were used). After five applications to the half-tone disc 0.1cm^3 of ink was added to the inking apparatus and allowed to distribute for two minutes before additional use. The I. G. T. ink pipette was used to measure out the exact quanities of ink.

The procedure to print the samples was as follows:

1. Attach the pendulum drive to the I. G. T. Printing Apparatus if it is not already on the machine.
2. Attach sample with felt side up.
3. Raise the pendulum into test position.
4. Adjust the printing pressure with the printing disc axle in the forward position.
5. Put the printing disc axle in the rearward position.
6. Apply the printing disc to the axle and put it in the forward position
7. Print the sample.
8. Repeat steps 1-7 at the various printing pressures.

The procedure for rating the printing quality of the printed paper samples is as follows:

Each printed sample is evaluated by the use of a magnifing glass to determine the minimum pressure required to reproduce the various etches. The sum of the minimum printing pressures of the three etches is recorded. Since five different printing pressures were used on each of the three etches, the rating of good or poor printing quality of this total is used.

A point system based on the multiplication of the printing pressure by three (the number of etches) was used to rate the good or poor printing quality papers. The range in points lay from 7.5 to 120, so 60 was chosen as the division point between good or poor printing quality.

2.5	x 3--	7.5	
5	x 3--	15	
10	x 3--	30	GOOD
15	x 3--	45	
20	x 3--	60	
40	x 3--	120	POOR

The sum of points for good printing quality is between 7.5 and 60, while poor printing quality is from 61 to 120. (NOTE: Some samples failed to reproduce the 50 and/or 70 per cent etch screens. In this case a poor rating was automatically given. These were then the worst of the poor printing quality papers.

PRESENTATION OF RESULTS

Table I shows the results of the smoothness, elongation, and I. G. T. printing pressure tests on the fifty seven samples of coated and uncoated papers.

Table II presents the analysis of the results of the initial smoothness, elongation, and I. G. T. printing pressure tests. This data was based on the results of Table I for the eleven best of the good printing quality papers and the ten worst of the poor printing quality papers. Thus it is possible to examine both extremes of printing quality to ascertain the the establishment of any trends which could be used to evaluate printing quality of paper.

TABLE I - INITIAL RESULTS

GRADE	SMOOTHNESS	MD-ELONGATION VALUE	%	T	CD-ELONGATION VALUE	%	T	I.G.T. PRINTING PRESSURE 10%	50%	70%	TOTAL
CELLUGLOSS OFFSET ENAMEL BLUE-WHIT 80#	1,329.86	0.033	0.008	18.90	0.117	0.029	10.30	5.0	10.0	20.0	35.0
ONE TIME CARBON 9#	62.02	0.033	0.050	7.85	0.096	0.028	4.30	2.5	20.0	20.0	42.5
ENCYCLOPEDIA BRITANNICA 30#	66.23	0.020	0.005	7.35	0.081	0.020	4.40	40.0	10.0	10.0	60.0
THINPAQUE 20#	102.77	0.011	0.003	8.07	0.000	0.000	3.65	10.0	20.0	20.0	50.0
WET STRENGTH MAP PAPER 61#	55.58	0.199	0.049	28.59	0.218	0.054	12.45	20.0	10.0	20.0	50.0
GLOSSOMER E.F. 35#	88.19	0.028	0.007	6.75	0.150	0.037	4.37	10.0	20.0	20.0	50.0
BUFF NORTHBROOK LEDGER 24#	27.05	0.095	0.023	18.45	0.189	0.047	11.60	----	20.0	20.0	----
WHITE NORTHBROOK LEDGER 32#	26.41	0.119	0.029	20.80	0.212	0.053	12.40	10.0	20.0	20.0	50.0
WHITE NORTHBROOK LEDGER 24#	19.33	0.132	0.033	17.60	0.193	0.048	8.80	40.0	40.0	40.0	120.0
BLUE-WHITE NORTHBROOK DUPLICATOR 20#	104.03	0.040	0.010	9.70	0.052	0.013	5.20	5.0	10.0	10.0	25.0
GOLDENROD NORTHBROOK BOND 16#	74.39	0.016	0.004	13.61	0.088	0.022	6.50	10.0	20.0	40.0	70.0
BLUE-WHITE NORTHBROOK MIMEO 20#	21.68	0.023	0.008	9.02	0.091	0.022	5.00	10.0	40.0	40.0	90.0
BUFF NORTHBROOK BOND 16#	43.66	0.027	0.007	11.31	0.225	0.056	6.34	10.0	20.0	20.0	50.0
GREEN NORTHBROOK BOND 16#	28.70	0.051	0.012	12.02	0.123	0.033	6.65	20.0	40.0	40.0	100.0
CANARY NORTHBROOK BOND 16#	49.85	0.042	0.010	11.45	0.112	0.024	6.18	10.0	40.0	40.0	90.0
PINK NORTHBROOK BOND 16#	32.59	0.016	0.004	11.31	0.008	0.002	6.34	10.0	20.0	40.0	70.0
BLUE-WHITE NORTHBROOK BOND 16#	28.47	0.040	0.010	13.78	0.210	0.052	6.15	10.0	40.0	40.0	90.0
BLUE NORTHBROOK 24#	31.60	0.057	0.014	10.98	0.069	0.017	5.80	10.0	40.0	40.0	90.0
ERITHEHUE TINTS MINT 50#	56.94	0.049	0.012	10.70	0.112	0.028	6.17	10.0	40.0	40.0	90.0
ERITHEHUE TINTS OCHRE 50#	38.46	0.045	0.011	11.45	0.057	0.014	4.96	20.0	40.0	40.0	100.0
ERITHEHUE TINTS BEIGE 50#	38.24	0.030	0.007	10.75	0.067	0.017	5.52	10.0	20.0	20.0	50.0
CELLUFOLD OFFSET ENAMEL C2S 80#	578.21	0.058	0.014	21.06	0.152	0.038	10.70	20.0	20.0	20.0	60.0
CELLUGLOSS OFFSET ENAMEL C2S 70#	530.45	0.041	0.010	15.90	0.080	0.020	5.50	5.0	20.0	20.0	45.0
CELLUPRINT ENAMEL C2S 80#	1,075.93	0.035	0.009	11.70	0.000	0.000	7.20	20.0	20.0	40.0	80.0
IMPERIAL OFFSET ENAMEL C2S 70#	1,034.53	0.071	0.019	18.10	0.087	0.022	6.30	5.0	10.0	20.0	35.0
IMPERIAL ENAMEL C2S 80#	884.01	0.035	0.009	13.16	0.067	0.017	6.60	5.0	20.0	20.0	45.0
VELOUR OFFSET ENAMEL C2S 80#	786.24	0.062	0.015	15.60	0.140	0.035	10.70	5.0	10.0	10.0	25.0
VELOUR ENAMEL C2S 80#	431.71	0.038	0.009	14.10	0.143	0.036	7.90	5.0	20.0	20.0	45.0
CELLUFOLD LITHO C2S 70#	368.41	0.047	0.012	18.50	0.151	0.038	6.20	10.0	20.0	40.0	70.0
MONARCH LITHO C1S 60#	839.24	0.036	0.009	12.70	0.113	0.033	6.90	5.0	10.0	20.0	35.0
CELLUGUARD OFFSET ENAMEL 65#	522.91	0.052	0.012	16.50	0.091	0.022	7.40	10.0	40.0	40.0	90.0
EXCELGLOSS OFFSET ENAMEL C2S 70#	471.36	0.050	0.012	13.71	0.110	0.027	8.90	5.0	20.0	20.0	45.0
EXCELITH LITHO C1S 60#	675.45	0.056	0.014	12.60	0.800	0.200	9.30	20.0	40.0	40.0	100.0
COMET ENAMEL C2SGREEN 70#	657.88	0.055	0.014	13.30	0.048	0.012	7.60	2.5	20.0	20.0	42.5
COMET ENAMEL C2S CANARY 80#	557.18	0.046	0.011	14.57	0.077	0.019	8.30	5.0	20.0	20.0	45.0
COMET ENAMEL C2S GOLDENROD 80#	368.22	0.032	0.008	13.50	0.010	0.002	5.70	10.0	20.0	20.0	50.0
COMET ENAMEL C2S INDIA 70#	573.09	0.059	0.015	13.10	0.075	0.019	8.50	10.0	20.0	40.0	70.0
LITHOBULK OFFSET FOR OFFSET 50#	6.39	0.056	0.014	12.30	0.090	0.022	9.80	20.0	40.0	40.0	100.0
CUSTOM OFFSET 50#	21.04	0.048	0.012	15.70	0.107	0.027	7.70	20.0	----	----	----

TABLE I - INITIAL RESULTS

GRADE	SMOOTHNESS	MD-ELONGATION VALUE	MD-ELONGATION %	T	CD-ELONGATION VALUE	CD-ELONGATION %	T	I.G.T. PRINTING PRESSURE 10%	50%	70%	TOTAL
ALL STAR OFFSET BLUE WHITE 50#	27.23	0.041	0.010	13.24	0.222	0.055	7.06	20.0	40.0	----	-----
SOLAR OFFSET WOVE 50#	38.17	0.039	0.009	10.16	0.087	0.013	6.60	20.0	40.0	40.0	100.0
TYPOBULK EGGSHELL 50#	9.00	0.036	0.009	14.90	0.090	0.022	7.40	40.0	----	----	-----
CLIMAX E.F. 50#	113.74	0.046	0.011	10.82	0.084	0.021	8.00	20.0	40.0	40.0	100.0
CLIMAX EGGSHELL 50#	92.48	0.042	0.010	9.70	0.101	0.025	6.16	40.0	----	----	-----
SOLAR E.F. 50#	180.44	0.031	0.010	8.15	0.045	0.011	5.12	10.0	40.0	40.0	90.0
SOLAR EGGSHELL 50#	8.92	0.033	0.008	8.20	0.093	0.023	4.78	40.0	----	----	-----
THINAQUE 30#	73.11	0.029	0.007	8.74	0.081	0.020	4.52	20.0	----	----	-----
IMPERIAL BIBLE E.F. 30#	165.12	0.001	0.0002	4.58	0.060	0.015	2.56	40.0	40.0	40.0	120.0
BRITISH OPAQUE E.F. 30#	102.59	0.001	0.0002	3.56	0.033	0.008	2.91	10.0	40.0	40.0	90.0
ERITHEHUE TINTS SKY BLUE 50#	41.13	0.033	0.008	12.73	0.080	0.020	6.03	40.0	40.0	40.0	120.0
ERITHEHUE TINTS CORAL 50#	36.00	0.021	0.005	13.46	0.117	0.029	6.50	40.0	----	----	-----
ERITHEHUE TINTS FORSYTHIA 50#	47.82	0.041	0.010	12.03	0.086	0.021	5.80	40.0	40.0	40.0	120.0

TABLE II - ANALYSIS OF INITIAL RESULTS

GRADE	SM X MDE	SM X CDE	MDE X CDE	SM X MDE X CDE	SM X MDE / PP	SM X CDE / PP	MDE X CDE / PP	SM X MDE X CDE / PP
GOOD PRINTING QUALITY PAPERS:			(X 10^{-3})				(X 10^{-4})	(X 10^{-2})
ONE TIME CARBON	2.04	5.95	3.168	1.97	0.04800	0.140	0.745	4.64
CELLUGLOSS OFFSET ENAMEL C2S	21.75	42.44	3.280	1.39	0.48300	0.943	0.716	3.90
IMPERIAL OFFSET ENAMEL C2S	73.34	89.56	6.180	6.40	2.09540	2.559	1.770	18.30
IMPERIAL ENAMEL C2S	29.54	59.24	2.350	2.80	0.65600	1.316	0.522	4.54
VELOUR OFFSET ENAMEL C2S	41.87	110.07	8.680	6.64	1.67500	4.403	3.360	26.60
VELOUR ENAMEL C2S	16.37	61.60	5.430	2.35	0.36400	1.367	1.200	5.22
MONARCH LITHO C1S	30.20	94.80	4.070	3.41	0.86290	2.709	1.620	9.74
EXCELGLOSS OFFSET ENAMEL C2S	23.57	51.80	5.500	2.59	0.52400	1.151	1.220	5.76
COMET ENAMEL C2S GREEN	36.20	31.60	2.640	1.74	0.85200	0.744	0.621	4.09
COMET ENAMEL C2S CANARY	25.63	42.90	3.540	1.97	0.57000	0.953	0.787	4.38
CELLUGLESS OFFSET ENAMEL B-W	43.88	115.40	3.860	5.13	0.97500	4.616	1.103	14.70
POOR PRINTING QUALITY PAPERS:			(X 10^{-3})				(X 10^{-4})	(X 10^{-2})
BUFF NORTHBROOK LEDGER	2.57	5.12	18.000	0.470	0.02140	0.0427	1.500	3.917
CUSTOM OFFSET	0.91	2.25	5.130	0.108	0.00758	0.0188	9.000	0.090
ALL STAR OFFSET BLUE-WHITE	1.12	6.05	9.100	0.248	0.00933	0.0504	0.760	2.070
TYPOBULK EGGSHELL	0.32	0.81	3.240	0.029	0.00270	0.0068	0.270	0.242
CLIMAX EGGSHELL	3.88	9.34	4.240	0.392	0.03230	0.0786	0.350	3.270
SOLAR EGGSHELL	0.30	0.83	30.100	0.027	0.00247	0.0069	0.250	0.233
THINAQUE	2.42	5.92	2.350	0.172	0.00201	0.0441	0.200	1.430
IMPERIAL BIBLE E.F.	0.17	9.91	0.006	0.010	0.00138	8.2583	0.000	0.083
ERITHEHUE TINTS CORAL	0.76	4.22	2.660	0.096	0.00630	0.0352	0.220	0.789
ERITHEHUE TINTS SKY BLUE	1.35	3.28	2.640	0.109	0.01120	0.0273	0.220	0.908

TABLE II - ANALYSIS OF INITIAL RESULTS (CONTINUED)

GRADE	PP / SM X MDE	PP / SM X CDE	PP / MDE X CDE	PP / SM X MDE X CDE	P P / MDE	P P / CDE	PP / SM	MDE / P P	CDE / P P	SM / PP
GOOD PRINTING QUALITY PAPERS:								(X 10^{-4})	(X 10^{-4})	
ONE TIME CARBON	20.830	7.142	1,341.5	21.57	1,287.9	856.9	0.0685	7.76	2.26	1.471
CELLUGLOSS OFFSET ENAMEL C2S	2.069	1.060	13,719.5	32.37	1,097.6	562.6	0.0085	9.11	1.78	11.790
IMPERIAL OFFSET ENAMEL C2S	0.477	0.359	5,663.4	5.47	492.9	402.3	0.0034	20.30	4.90	29.560
IMPERIAL ENAMEL C2S	1.523	0.760	19,148.9	21.63	1,285.7	671.6	0.0051	7.78	14.90	19.640
VELOUR OFFSET ENAMEL C2S	0.597	0.226	2,880.2	3.77	403.2	1.8	0.0318	24.80	56.00	31.450
VELOUR ENAMEL C2S	2.749	0.733	8,287.3	19.15	1,184.2	314.7	0.1040	8.44	31.60	9.590
MONARCH LITHO C1S	1.159	0.369	8,599.5	10.26	972.2	309.7	0.0417	10.30	32.30	23.980
EXCELGLOSS OFFSET ENAMEL C2S	1.909	0.869	8,181.8	17.37	900.0	4.9	0.0955	11.10	24.40	10.480
COMET ENAMEL C2S GREEN	1.174	1.344	16,098.5	24.43	772.7	885.4	0.0646	12.90	11.30	15.480
COMET ENAMEL C2S CANARY	1.755	1.049	12,711.9	22.84	978.3	584.4	0.0808	10.12	17.10	12.380
CELLUGLOSS OFFSET ENAMEL B-W	0.798	0.225	9,067.4	6.82	1,060.6	299.2	0.2630	9.43	32.80	37.400
POOR PRINTING QUALITY PAPERS:								(X 10^{-4})	(X 10^{-4})	
BUFF NORTHBROOK LEDGER	46.690	23.430	6,666.7	2,533.19	1,263.2	634.9	4.440	7.92	15.80	0.225
CUSTOM OFFSET	131.870	53.330	2,339.2	1,111.11	2,500.0	1,121.5	5.700	4.00	8.92	0.175
ALL STAR OFFSET BLUE-WHITE	107.140	24.750	1,318.6	483.87	2,926.8	540.5	4.410	3.42	18.50	0.227
TYPOBULK EGGSHELL	370.370	749.380	3,703.7	4,137.93	3,333.3	1,333.3	13.040	3.00	7.50	0.088
CLIMAX EGGSHELL	30.930	12.840	2,830.2	306.12	2,852.1	1,188.2	1.298	3.50	8.42	0.771
SOLAR EGGSHELL	140.540	114.750	3,986.7	4,477.61	36,036.0	1,129.0	13.450	2.75	7.75	0.074
THINAQUE	49.580	20.270	5,106.4	679.67	4,137.9	1,481.5	1.641	2.42	6.67	0.609
IMPERIAL BIBLE E.F.	127.370	12.110	200,000.0	1,212.21	120,000.0	2,000.0	0.727	0.08	5.00	1.376
ERITHEHUE TINTS CORAL	158.730	28.430	4,511.3	1,252.61	5,714.3	1,025.6	3.330	1.75	19.80	0.300
ERITHEHUE TINTS SKY BLUE	88.890	36.590	4,545.5	1,100.92	3,636.4	1,500.0	2.920	2.75	6.67	0.343

DISCUSSION OF RESULTS

The results of the analysis of the initial results of Table II show that in four cases the printing quality can be evaluated by the use of smoothness, elongation, and I. G. T. printing pressure tests results.

The first and most significant correlation of printing quality and the data in Table II is the calculation of smoothness x machine direction elongation x cross direction elongation. Papers with good printing quality gave results which were always larger than 1.0 while papers of poor printing quality gave figures which were always smaller than 1.0. This is significant because a control test utilizing three simple and fast tests may be possible after further work to insure that the before mentioned calculation holds true for all typed of paper.

Three more apparent correlations are also brought to light by Table II. The difference between these three calculations and the first calculation is that I. G. T. printing pressure test results is utilized in the calculation. These three calculations are:

(a) $\frac{PP}{SM \times MDE}$ (b) $\frac{PP}{SM \times CDE}$ (c) $\frac{PP}{SM \times MDE \times CDE}$

With (a) good printing quality papers give a figure which is always below 30.0, and poor printing quality papers give a figure which is always larger than 30.0.

With (b) good printing papers give a figure which lies below 10.0, and poor printing quality papers give a result which always above 10.0.

With (c) good printing quality papers give a figure which is always below 50.0, and poor printing quality papers give a figure which is larger than 50.0.

The previous four cases of correlation have occured under the experimental conditions of this thesis and cover the samples listed on Table I.

Future work in the use of the four calculations to evaluate printing quality of paper should cover an extremely wide selection of samples to insure their applicability to all papers.

In the literature survey the deficiences of the elongation test and the inability of present smoothness testing instruments to simulate printing conditions was thoroughly discussed. These deficiences should be overcome in the design of new testing equipment. With the aid of new instruments, a better understanding of paper and printing will be possible, and thus printing quality will be further understood.

CONCLUSIONS

Under the conditions of this experiment, the following conclusions can be made concerning the experimental work resulting from the investigation of smoothness and elongation test results.

In four cases smoothness and elongation test results definitely correlate with printing quality.

The experimental work of this thesis supports all previous work which found that smoothness was influential to printing quality.

This thesis has found that elongation definitely contributes to printing quality of paper. This presents the question of the influence of other rheological properties of paper on printing quality. Further studies into the rheological properties of paper hold the key to the understanding of paper and printing. With this knowledge it will be possible to understand and evaluate printing quality of paper.

William R. Castle

June 10, 1961 William R. Castle

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