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A Study of the relationship of Sheffield & IGT methods for determining paper smoothness and their ability to predict gravure printability

Austin Sung

A STUDY OF THE RELATIONSHIP OF THE SHEFFIELD & IGT METHODS FOR DETERMINING PAPER SMOOTHNESS AND THEIR ABILITY TO PREDICT GRAVURE PRINTABILITY

by

Austin H. Sung

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology.

November, 1984

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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with a major in Printing Technology has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of

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ABSTRACT

A variety of methods have been devised for the measurement of the smoothness of paper. These are reviewed and summarized in this work. Of the available methods, two of the most widely used have been selected for study. The air-leak method exemplified by the Sheffield instrument, and the nip-spreading method of the IGT printability tester are specifically presented and performed. The data obtained in empirical experiments are statistically analyzed and plotted, so as to determine if there is a functional relationship between the responses of these two methods. A linear relationship between the two is shown to be an appropriate model. This paper also indicates the predictability of gravure printing quality on the basis of paper smoothness/roughness. The percentage of missing cells of the gravure prints are shown to be related to both forms of smoothness/roughness measurement. 78% of the gravure cell skipping data variation as printed by the IGT printability tester is attributable to smoothness/roughness measurement. The remaining amount of variation is associated with error or untested factors. Compressibility and oil

absorbency of paper should be further studied and incorporated into similar studies. It is expected that the addition of these variables would improve laboratory prediction of gravure printability as defined by cell skipping.

Abstract approved: Chester Daniels, thesis advisor
Senior Technologist T&E Center, title & dept.
November 9, 1984, date

CHAPTER I

INTRODUCTION

The most universally accepted substrate for printing is paper. Much of the knowledge of the world is recorded on paper. It is paradoxical that the material on which so much information is recorded is difficult to characterize for a positive prediction of printing quality. From the standpoint of printing quality, smoothness is generally recognized as one of the most important properties of paper.[1] Smoothness has an influence on both the functional and the appearance properties of paper.[2] There are many paper characteristics thought to affect printing quality. These properties include paper dusting, linting, hardness, smoothness, absorptivity, etc. Each is determined on an independent basis.

Among the properties that are measurable, the degree of surface smoothness is of first rank importance. It is generally recognized that good smoothness is required for letterpress and gravure printing. Smoothness is desired because the depressions in rough sheets are difficult to fill with ink, resulting in speckle, or non-printing areas where printing is expected in solid printed areas or a lack

of definition in halftones. Although a number of other attributes of print quality are important, these other features are likely to be ignored if a reproduction print has poor ink coverage.

Definition

Smoothness is defined as the property of a surface determined by the degree to which it is free of irregularities,[3] while roughness may be defined as the deviation of a surface from an ideal plane or cylindrical reference surface (compare with smoothness).[4] Both definitions refer to the same characteristics, i.e., the degree of smoothness.

For practical and scientific purposes, a description of any form of measurement should include: how the position of the reference surface is to be determined; by what parameter the deviation is to be measured; and the range of wavelengths to be considered. For smoothness/roughness measurement, the magnitude and mode of application of any force on the paper surface must be specified because paper is deformed by pressure. Due to the application of the pressure the hardness of the backing material is quite critical. On the print side of the paper, the pressure could be concentrated on the relatively small-scale surface projections. However, if the material backing

the paper being measured is soft enough, the pressure on the back of the paper is uniformly distributed despite thickness variations.

One object of measuring roughness is to predict the thickness of ink required to fill the deepest pits in the paper surface. If the paper surface is non-absorbent and the ink can flow readily over it, then the arithmetic mean gap between plate and paper would equal the volume of ink needed per unit area to fill all surface voids. However, if the paper is absorbent, allowing ink to penetrate its surface without any cross-flow, the thickness of ink required to achieve complete coverage would equal the maximum gap between paper and plate within the area to be printed.[5]

During printing processes, mechanical forces are exerted on the paper, causing deformation of the surface structure. It is important, therefore, to measure the paper under pressure. Paper is compressible and its smoothness increases under pressure. In other words, the property of interest is smoothness under compression, preferable under circumstances closely related to printing conditions.

A second feature of the printing process is that the ink film may be able to reach into the surface, and in effect, level out the inequalities. The ink film

itself has an effect on what is seen. This is true for Letterpress or Lithographic printing, but not for Gravure in which the paper surface must be able to contact a cell containing ink which is actually slightly below the surface of the gravure roll.

There are many approaches used for the evaluation factors that govern the print quality. One such approach includes the evaluation of the faithfulness of reproduction sharpness, contrast, and unevenness of the printed product. The former three out of the four evaluation factors, i.e., faithfulness, sharpness, and contrast, have been objectively defined in many studies. The unevenness in the highlight in a gravure print consists of missing dots called skips or speckles. In the overall evaluation, each missing dot holds its independent significance so that the sum total of missing dots per unit area could be the expression of visual evaluation.[6]

One more important variable to cope with during any printing process is printing speed. Fortunately, printing speed can be reproducibly adjusted on a press.

This paper describes in detail the experimental work carried out for the purpose of comparing the response of the Sheffield instrument and IGT printability tester for the measurement of the smoothness of the paper.

Thesis Objectives

The objectives of the study are:

(1) to establish a functional relationship, if any between the results obtained by the Sheffield, and the IGT methods.

(2) to determine if gravure printing quality can be predicted on the basis of the smoothness and/or roughness of paper.

The results obtained in this experiment will be presented in tabular and graphic form, and a statistical interpretation of the data will be given.

FOOTNOTES FOR CHAPTER ONE

[1] Roehr, Walter H., Tappi 38, No. 11: 660-664 (Nov. 1955)

[2] Bureau, William H., "What the Printer Should Know About Paper," Graphic Arts Technical Foundation, p. 91

[3] "The Dictionary of Paper," Third Edition, American Paper and Pulp Association, 1965, p. 408.

[4] "Technical Information," Paper Technology, TMI 58-32, p. 126

[5] Ibid.

[6] Akio Yanagawa, "Study on Print Quality-Unevenness of Gravure Prints," p. 21

CHAPTER II

LITERATURE REVIEW ON METHODS FOR MEASURING SMOOTHNESS

It is well known that the surface characteristics of paper have a significant effect on the final quality of the printing product. Some papermakers try to evaluate the printing characteristics of paper by defining a printability index resulting from the development of smoothness measuring instruments. Research on smoothness measurement continues with apparently increased intensity, giving witness to the importance of this property of paper. Instruments and methods for the quantitive or qualitative evaluation of smoothness have been devised by which one can get an impression of paper smoothness. Some common useful methods are based on the following principles.[1]

Principles of Several Measuring Methods

(1) optical averaging using oblique illumination, including visual inspection (unaided eye, hand lens, binocular microscope, photomacrography,) and photocell methods (glossmeter, surface fuzz);

(2) friction, such as feel or the frictional force between metal and paper or two paper surfaces;

(3a) profile amplification, by means of a rider with optical or electrical magnification of the rider movement, (brush profilometer), by using a micrometer focusing adjustment, or by using a photometer over the microscope and oblique illumination of the paper;

(3b) profile integration, using rider and electrical or mechanical magnification, but with single valued output rather than a profile curve (Brush Surface Analyzer);

(4) electrical capacitance, in which the capacitance of a condenser consisting of the test specimen between two brass plates is compared with the capacitance with mercury (or graphite) replacing the upper plate;

(5) optical contact area between a paper surface and a glass prism or plate which is pressed against the paper surface (Prior, Davis, Chapman);

(6) ink contact area by means of a proof press the drawdown technique, or a roller;

(7) air flow through capillaries or channels formed between the paper surface and an optically flat surface pressed against the paper surface (Bekk, Sheffield, Williams, Gurley, Bendtsen).

In addition to the above mentioned methods, there are others listed in the literature:

1. The Bruderhaus smoothness meter[2]

It is a new, optical type, smoothness measuring instrument which makes it possible to determine web smoothness in the laboratory. This instrument is marketed by Bruderhaus (on line, and as a laboratory instrument also being sold by Paul Lippke KG, Nevwied, West Germany) and can be used for continuous on-line measurements in the mill, with the aid of a modified measuring head.[3] Incident on the paper surface at a definite angle is a parallel beam of monochromatic light, and the width of the cone of

reflected scattered light is used as a measure of the smoothness of the paper surface.[4]

2. MAN Test (also known as customer's printing test)[5]

The MAN print test is a controlled letterpress printing method and is designed essentially for the assessment of printing smoothness.[6] The principle of this test is to simulate a commercial printing operation as closely as possible and predict the printability of the paper.[7]

3. IGT Printability Tester: Nip-spreading and other filling-in methods.[8] (Discussion of this method is given in the later pages.)

Lashof and Mandel presented an article[9] and stated as follows:

> ". . . Fetsko reported that using the ink-transfer parameter at low ink-film thicknesses for comparison, none of the smoothness test studied ranked all of the stoc s in the proper order. She included the following methods: Bekk, Gurley, Sheffield, Bendtsen, Brush surface analyzer, Chapman, Scheid, Hull drawdowns, and surface photomicrographs. Hyvarimen, et al. obtained a relationship between minimum compressibility and smoothness required for satisfactory photo-gravure printing. Prince used multiple regression analysis to show that the total variance in the printability of newsprint is determined by smoothness more than by any other physical property. Luey, studying printability of cylinder machine boxboard, has related the extrapolated value of ink-film thickness at an impression of 0.001 in. to visual smoothness as measured by the Scheid smoothness tester.

> Maynard and Newman compared the Bendtsen, Bekk, and Talysurf instruments with subjective assessment of smoothness and found that the Bendtsen correlated best when using nine different papers, but that all three instruments correlated equally well with subjective smoothness when five slightly different sheets of the same paper were evaluated. This is similar to the conclusion of Tetsko that several tests may be useful for quality control purposes but that no available empirical test for evaluating smoothness is applicable to all types of papers. For white patent-coated paperboard in letterpress printing of solids, the Sheffield and Bendtsen methods appear to offer the best compromises between the several requirements of routine control testing.
>
> . . . Troger investigated the effect of relative humidity variations on smoothness of stored paper, and the dependence of smoothness on temperature of 65% R.H.
>
> Bott provided a theoretical explanation of Troger's observation that the smoothness of paper increased with increasing temperature."

The air-flow methods have been the most popular among the various methods for determining paper smoothness. The Bekk method, in particular, had been widely used as the standard in government and in industry specifications for decades until the Sheffield method was developed and put in use in the industry.

In the same paper Lashof and Mandel made a comparative study on the Bekk and Sheffield smoothness testers. A relationship between these two methods was found. The two instruments have approximately equal performance as judged by the sensitivity criteria, but

the Sheffield instrument is preferable because it is five to ten times as fast.[10]

A comparative study of the Sheffield method and IGT method of measuring paper smoothness/roughness will be accomplished in this paper. Both methods are popular, and no such study has ever been made comparing these two popular methods.

Preliminary Studies--Sheffield Method

The preliminary work with the Sheffield paper smoothness gauge includes the examination of the manufacturer's recommended operating conditions, the sensitivity of the gauge to adjustments, and the effect of the relative humidity of the compressed air.[11]

Unlike other smoothness testers, the Sheffield tester requires adjustment and calibration each time it is put into service. Three adjustments must be made for each scale of the Sheffield tester: pressure, amplification, and position.

> Since each of these affects the others, readjustment of any one requires that the others be checked and, if necessary, adjusted. Furthermore, the amplification and position settings are quite sensitive to small adjustments and even to slight sideways pressure on the valves. Thus, the calibration and adjustment of the Sheffield tester can be a tedious and annoying operation, but as discussed below, this calibration and adjustment procedure can be greatly simplified when the tester is in daily use.

After the initial adjustment the test may drift out of calibration. In order to correct for this drift, the manufacturer recommends that first the pressure valve be adjusted so that the mercury gauge indicates a pressure of 1.50 p.s.i., and that after this adjustment the valves that control amplification and position be adjusted. If this procedure is followed, the latter two valves will usually require considerable adjustment--a tedious operation as previously stated. This operation can usually be eliminated or reduced to a minimum--after the first calibration--by adjusting the pressure valve not to obtain the correct pressure but to obtain the correct position. It will then be found that the amplification needs little or no adjustment and that the pressure is very nearly correct.

. . . It was observed that the initial Sheffield smoothness valve changed with time, more or less rapidly, depending on the material. Since, in general, the rate of change decreased with time, it was thought that some particular waiting time before reading might give more reproducible results than other times. . . .

In order to determine whether the difference between the 16% R.H. of the compressed air and the 50% R.H. of the conditioning atmosphre could account for the change in Sheffield reading with time, tests were made at several relative humidities by allowing the compressed air to bubble through saturated solutions of various salts. The results are shown as expected, the least change in the Sheffield reading with time occurred when the relative humidity of the compressed air was near 50%. . . .
There is no evidence that the use of the humidifier improved the precision of the observations. . . . Without further evidence, it appears that the most convenient procedure, avoiding the necessity of constructing a humidifier, is to read the float position at the earliest practical moment--but always at the same time after lowering the smoothness head.

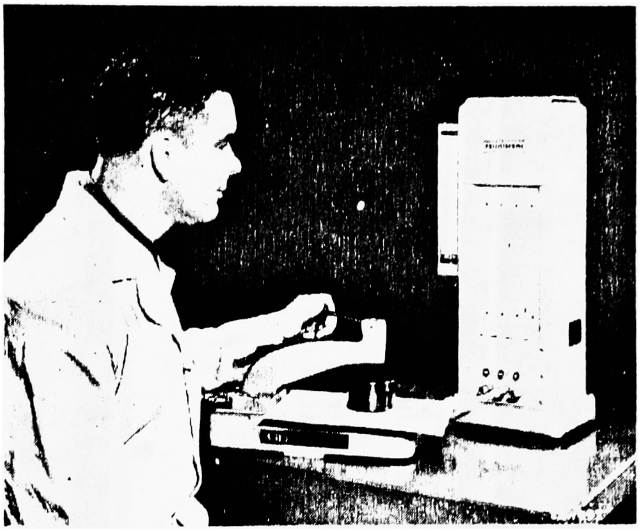


Fig. 1 Sheffield paper smoothness tester, standard three-column instrument.

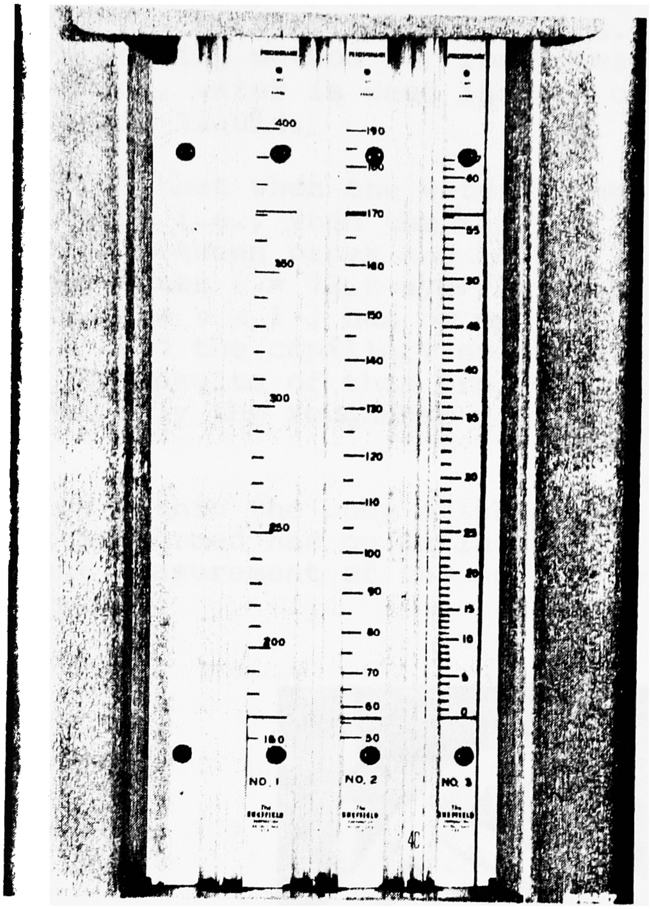


Fig. 2 The Sheffield paper smoothness tester scale with range of zero to 400 air flow units, equivalent to from 10,000 to less than 1 sec. by the air leak method.

Preliminary Studies-IGT Method[12]

The determination of the roughness by the IGT method is based on the fact that if the duration of the contact between water and paper is kept very short, water, will not be absorbed by the pores of the paper surface, this in contrast to oil. So if a drop of water is rolled out at high speed between two identical strips of paper, a blot will be formed the size of which will be determined by the roughness, and of course, by the volume of the water drop as well.

In the application of this method, with the aid of the IGT printability tester, a small, accurately determined, quantity of water is

spread over the paper, forming an oval spot by filling the surface irregularities. With the nip-spreading method for roughness determination, water is used instead of the usual organic liquid.

It was found that when the water is applied very quickly, i.e., when the time of interaction between paper and liquid was short, the water (= 72.8 dyne/cm at 20 C, = 1 c poise, cos θ < 1) has no opportunity to penetrate into the capillary spaces of the paper. The results of this procedure is a measure of only the roughness of the paper surface.

Absorption within the body of the paper after the spot is formed has no influence on the subsequent measurement of the surface of the spot.

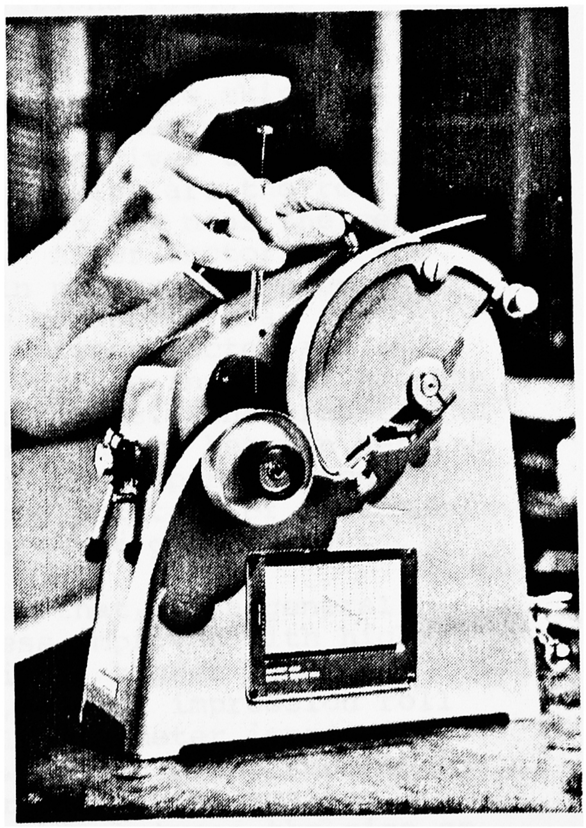


Fig. 3 Testing the roughness of a paper with the IGT printability tester.

George, Oppenheimer, and Marrara[13] of Gravure Research Institute stated in the article "Gravure Print Smoothness Scanner" as follows:

> One of the major requirements for a gravure stock is good print smoothness. Print smoothness is characterized by the absence of missing or defective cells in midtones and highlights. On certain coated papers, only a few skipped dots in tens of thousands of dots can greatly detract from the visual appearance of the printed product. It should be noted that print smoothness is not identical with the average mechanical surface smoothness of the paper or paper bulk compressibility. The only reliable way to determine the gravure print smoothness of a paper experimentally is by printing it under controlled conditions resembling as closely as possible the conditions found on production presses.
>
> As to the factors that produce skipping, the displacement of a fiber after printing on uncoated paper sometimes gives the appearance of a skip. Normally, skips are the result of poor contact between wet ink near the cell edges and the paper. After doctoring, the gravure cells contain premeasured amounts of liquid ink. Because of doctor drag and solvent evaporation between doctor and impression, the ink surface in a cell has the shape of a concave meniscus. Ink transfer is initiated by physical contact between wet ink at the cell edges and the paper. Hence we find a doughnut-shaped printout of midtones and highlights in hard-dot gravure. . . .
>
> An early study showed that, as a general rule, print smoothness improved with higher pressure per area, i.e., higher linear impression pressure, harder impression roll coverings, and smaller diameter impression rolls. It also showed that print smoothness deteriorated on engravings with smaller cells. The relationship between the size or surface depressions and the incidence of skipping on board was established. It was found that depressions which under pressure

> were smaller than a cell unit did not greatly contribute to visual skipping. The often poor correlation between air leak smoothness and printing smoothness was attributed to the contribution of small surface defects to air leakage. The reasons for skipping on coated papers were explained by Miller and Plante. Most skips were associated with "troughs" (long wave depressions) and small sharp "pits" and "logs" (fiber bundles, shives, etc.) protruding above the paper surface.

The occurrence of "speckle" in highlight and mid-tone areas is one of the major paper quality problems in gravure printing. These white spots in the print can be caused by roughness in the paper surface, which prevents complete paper contact with the gravure printing cylinder.[14] Therefore, ink transfer from gravure cells will not be made to the non-contact areas of the paper. In order to minimize the occurrence of cell skipping, paper used for gravure printing should be very smooth. For the purposes of quality control and product development, it is important to characterize the paper smoothness for gravure print. This is most frequently done with the aid of air-leak roughness testers such as the Bekk, Sheffield methods, or the nip-spreading method such as that allowed by the IGT printability tester.

FOOTNOTES FOR CHAPTER TWO

[1] Lashof, T. W., Mandel, J., Worthington, V., "Use of the Sensitivity Criterion for the Comparison of the Bekk and Sheffield Smoothness Testers," Tappi, Vol. 39, No. 7, July 1956, p. 532.

[2] Dipl.-Ing. R. Kirbis and Dipl.-Ing. P. Svenka, "Measurement and Control with a New Optical Smoothness Meter," Paper 18, Feb., 1980, p. 17.

[3] Ibid.

[4] Ibid.

[5] Kapoor, S. G., Wu, S. M., "A New Method for Evaluating the Smoothnesss of Coated Papers," Tappi, Vol. 61, No. 6, June 1978, p. 71.

[6] Ibid.

[7] Ibid.

[8] IGT Information Leaflet W 28, Publication of the Research Institute for the Printing and Allied Industries TNO.

[9] Lashof, T. W., Mandel, J., "Measurement of the Smoothness of Paper," Tappi, Vol. 43, No. 5, May 1960, p. 385.

[10] Lashof, T. W., Mandel, J., Worthington, V., Tappi, Vol. 39, No. 7, July 1956, p. 542.

[11] Ibid. pp. 533-535.

[12] Jansen, F. B., "Applications of the IGT-Printability Testers," IGT Monograph 12, 6th Revised Edition, 1977.

[13] George, H. F., Oppenheimer, R. H., Marrara, C. G., "Gravure Print Smoothness Scanner," Tappi, Vol. 59, No. 9, Sep. 1976, pp. 110-111.

[14] Heintze, H. U., Gordon, R. W., "Reliability of Video Scanner Measurement of Gravure Speckle on Coated Board," Tappi, Vol. 63, No. 9, Sept. 1980, p. 125.

CHAPTER III

HYPOTHESIS (RESEARCH QUESTIONS AND DESIGN OF EXPERIMENT)

Research Questions

A. The basic initial research question is the following: "Is there a relationship between the responses of the Sheffield method and the IGT method for measurement of paper smoothness/roughness?" If the answer is positive, then the first hypothesis states that there is a simple linear relationship between the Sheffield response and the IGT response.

Since the Sheffield instrument and the IGT printability tester are both used for measuring paper smoothness/roughness, and both are widely used in the industry, the author suspects correlation between the response of these two methods.

Hypothesis 1:

There is a simple linear (straight line) relationship between the Sheffield response and the IGT response for smoothness/roughness measurement. It is assumed that the relationship between the two methods of measuring paper surface irregularity can be expressed mathematically. If the y values are linearly related to the x values, this researcher hypothesizes a "true" line of regression according to

$y = a + b\,x$, where

y = IGT response

x = Sheffield response

a = the value of y at the intercept, i.e., at the point where $x = 0$

b = the constant value for the slope of the line

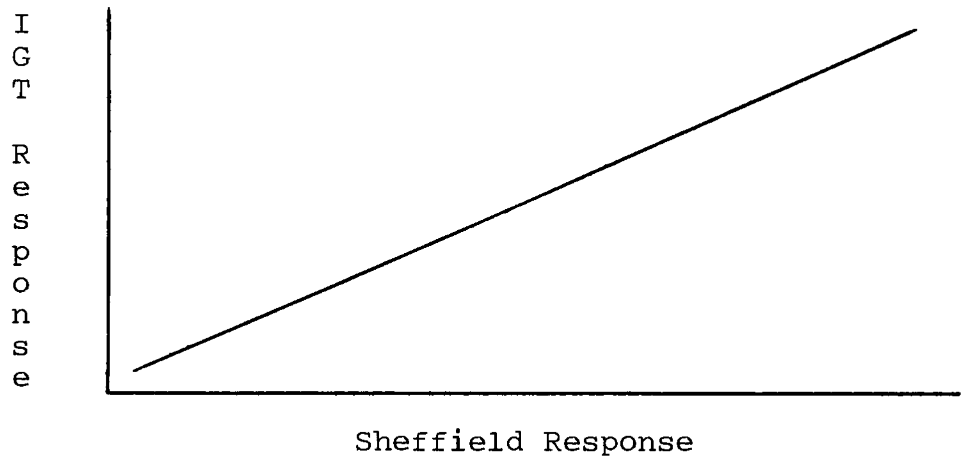


Figure 4. Expected relationship between the functional response of these two methods.

If the relationship between the two measured variables is not linear, the initial hypothesis is rejected and the relationship of the two variables will be estimated on the basis of the experimental data.

B. The second research question is the following: "Can gravure printing quality be predicted on the basis of paper smoothness/roughness?"

To deal with this question, a short discussion about missing or defective cells on various paper samples is appropriate. The total number of skips can

be determined precisely and agrees with subjective visual assessment of speckle severity.[1] Gravure printing quality on coated paper is expected to be better than that on uncoated paper due to the smoothness of coated paper.

For gravure printing, there can be no ink transfer from gravure cells to paper in non-contact areas. Therefore, speckle in gravure prints, which is often referred to as cell skipping, can be used as a response for gravure print quality. This print quality attribute is thought to be associated with the smoothness of the paper surface.

Hypothesis 2:

If the paper surface is smooth, then the result will be a better expected quality of the Gravure print; if the paper surface is rough, then a poorer printed quality will result.

Design of Experiment

A. Two different methods for measuring the smoothness/roughness of the paper are applied. These are the Sheffield instrument and the IGT method as previously described.

The data obtained generated by measurement of paper with a wide apparent degree of smoothness/roughness plotting the IGT response against the Sheffield response shall be used to determine the

functional relationship of these two measuring methods. The line of best fit for the experimental data will be estimated.

B. The paper measured for smoothness/roughness will be printed by IGT A_2 printability tester. The printed paper coated and uncoated, will be inspected with a Graphic Arts Inspector, on which, the quantitative and qualitative effect of the missing cells can be viewed. The Graphic Arts Inspector is a projection magnifier providing a magnified view of 23X. It is expected that a smoother paper will always result in a better printing quality on the basis of the missing or defective cells.

FOOTNOTE FOR CHAPTER THREE

[1]Heintze, H. U., Gordon, R. W., "Reliability of Video Scanner Measurement of Gravure Speckle on Coated Board," Tappi, Vol. 63, No. 9, Sept. 1980, p. 125.

CHAPTER IV

METHODOLOGY

A. A Sheffield paper smoothness gauge[1] and an IGT printability tester are used to measure paper smoothness/roughness respectively. Results obtained in this experiment are presented in tabular and graphic form. The data on the x axis is the Sheffield response and the y axis is the result of IGT measurement.

Coefficient of determination, regression analysis, and correlation coefficient were calculated to help determine the degree of association of the experimental data.

All coated and uncoated paper were measured in the machine and cross direction of the paper. Various kinds of paper were required to generate the full range of smoothness characteristics.

With the Sheffield method, we simply read the float position of the bubble at the earliest practical moment.

As for the IGT method,[2] the following experiment was performed:

Using the IGT printability tester two strips of paper were placed in the clamp with the identical sides facing each other.

One strip was mounted over the 2 cm. wide aluminum disc, the other over the rubber blanket on the sector.

In order to prevent the water from penetrating into the paper in the time interval between applying the water drop and nip spreading, a drop of lacquer was placed on the strip first mentioned.

Using a micro-syringe, a known amount of distilled water stained with trypane blue (1 g/100 ml) is placed on the (dry) lacquer. The volume of water used depends on the smoothness of the paper, the normal amount ranges from 1.00 - 3.00 ul. By having the printing force adjusted to 40 kg and the spring drive in position B (high speed), the water drop is spread over the paper, producing an oval spot. The surface area of the spot is determined. IGT claims that the surface area of this spot is well approximated by using the following formula:

$$\text{surface area} = 0.85 \times l \times b$$

l = spot length

b = spot width halfway down the length

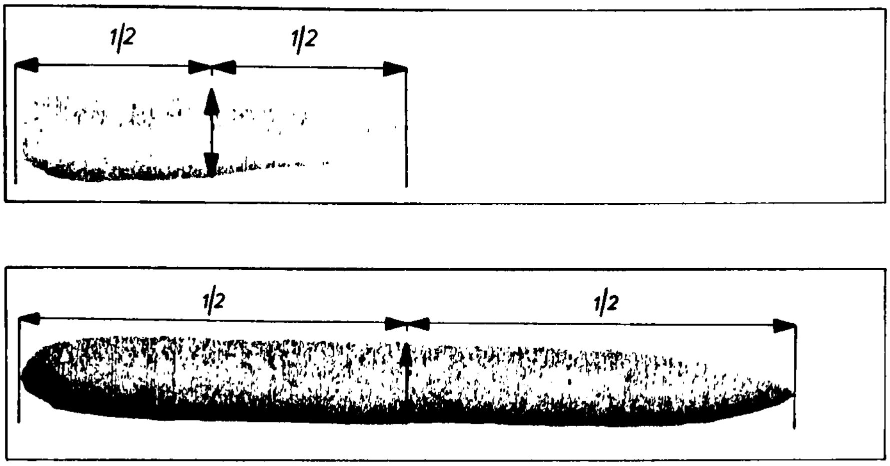


Fig. 5   Length and breadth of a blot

The roughness of the paper can be calculated by using the following equation:

$$R = \frac{ul}{0.85 \times l \times b \times 2} \times 1000 = cm^3/m^2$$

where R = Roughness

ul = Volume of water stained with trypane blue placed on the (dry) lacquer

B. IGT printability tester A_2 was used with the IGT gravure attachment in place for printing the smoothness/roughness measured paper samples. Both coated and uncoated were printed using this apparatus. On the basis of the printed paper samples, we shall determine the quantity and quality of the missing cells. The evaluation of the printing quality will be viewed and determined on the basis of missing dots.

Principle of the Gravure Printing Attachment[3]

A gravure form is fitted on the sector of the printability tester. After a drop of ik has been placed on the gravure form, the ink is distributed and wiped with a doctor blade, and a print is made, all in one revolution. The paper is attached to a coated rubber disc, also serving as the impression cylinder. The pressure between form and cylinder is adjustable. The doctor-blade support keeps the pressure of the doctor blade constant. The ink is distributed by a nylon distributor blade. The advantage of this method is the short interval between application of the ink and printing, thus practically eliminating evaporation, and keeping the composition of the ink constant.

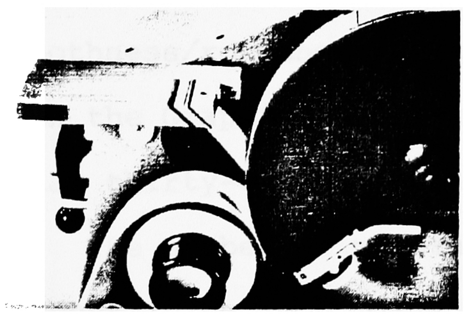


Fig. 6 The IGT gravure printing attachment.

Procedure

- Mounting the gravure printing attachment

  Insert and tighten the gravure printing strip in the packing clamp on the printing sector. Mount the doctor-blade support (with blades). Turn the doctor-blade support until the doctor blade rests on the gravure strip.

- Inking and Printing

  Adjust the printing impression to the optimum pressure.

Apply a drop of gravure ink in the nip between the distributor blade and gravure strip.
Turn the printing sector by hand at a uniform speed immediately after applying the ink.

- Evaluation of the Printed Result

  By the use of Graphic Arts Inspector, the quantitative and qualitative effect of the missing cells can be determined.
  This device allows determination of the number of missing cells within an area where the number of cells is known.
  This is by a visual count of the cells that are missing.
  The result can be visually inspected with ease.

A sampling of the printed paper strips was accomplished to include a full range of the previously determined smoothness/roughness values for visual inspection with the Graphic Arts Inspector. Twenty-one out of the total thirty-one different printed strips were selected. The number of missing cells, within a fixed area of containing 1600 cells were counted. A missing cell percentage for each strip was obtained and listed in a data table.

In order to illustrate the quantitative and qualitative effect of the missing cells, representative samples were photographed and were shown in Figure 10 for reader's reference.

Serial No. _______

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
				Mean	Value

Grain Direction Measured:

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

FOOTNOTES FOR CHAPTER FOUR

[1] Sheffield Paper Smoothness Gauge, Application Data, The Sheffield Corporation.

[2] The IGT Method for Determination of the Roughness of Paper, Research Institute for the Printing and Allied Industries TNO, Publication 25.

[3] IGT Information Leaflet W 34, Publication of the Research Institute for Printing & Allied Industries TNO, April 1970.

CHAPTER V

RESULTS

In order to insure the accuracy of the smoothness/roughness results, these measurements were repeated several times for each type of paper. The average of these data was used as the response for each data point. The data generated by the two different methods for measuring the smoothness/roughness of the various kinds of paper used in this study are tabulated in Appendix A. The average values are listed in Table 2 and are plotted to show the IGT response vs. Sheffield response for measuring the smoothness/roughness of the paper in Figure 7.

To measure the fitness of the regression line for the data, the square of the Pearson[1] product-moment correlation coefficient (R^2) is used to interpret the relationship of the two methods for measuring the paper smoothness. R^2 measures the percentage variation in the data explained by the regression line $y = a + bx$. When $R^2 = 1$, the regression explains 100% of the total variation, when $R^2 = 0$, the regression is independent of the data. In other words, if R^2 is closer to one, a higher degree of linear association between x and y is indicated. The Sheffield and IGT responses, are then said to be significantly associated at levels of sufficiently higher R. If the relationship between the

two measured responses is not linear, a more complex regression curve should be considered.

Serial No.	IGT Response	Sheffield Response
0101	.4491	31.72
0102	4.7946	214.98
0103	.407	33.38
0104	4.714	211.99
0201	.4058	3.63
0202	6.4886	215.66
0203	.4043	4.69
0204	6.799	216.08
0301	5.4261	159.92
0302	5.4406	164.38
0401	.3708	3.60
0402	7.1333	215.15
0403	.3922	3.35
0404	6.6175	212.49
0501	6.813	265.29
0502	7.357	262.08
0601	1.4276	97.81
0602	1.5351	96.56
0701	10.2195	364.06
0702	10.3380	364.72
0800	6.3125	181.66
0901	3.3978	84.03
0902	3.7838	125.10
1000	.9404	61.35
1100	.9353	71.62
1200	3.1322	80.89
1300	1.0796	68.95
1400	6.5716	276.91
1500	8.5608	390.58
1600	9.0805	409.75
1700	6.3850	152.39

Table 2: Average smoothness/roughness measured by IGT printability tester and Sheffield instrument.

Computation with the aid of a computer indicates that the Pearson product-moment correlation coefficient (R) is 0.94815. On the basis of regression analysis, calculation of R and R^2, a more complex regression

model than the simple linear one is not necessary. The first hypothesis is therefore accepted, that is, a simple linear relationship exists between the Sheffield response and the IGT response. This confirms the first hypothesis presented in Chapter Three.

The computer output of the regression line is given as

$y = a + bx$ where a = coefficient of the intercept of the line

b = coefficient of the slope of the line

$$y = 0.29064 + 0.02551\ x$$

where y = IGT response

x = Sheffield response

On the basis of this equation the response of the IGT instrument can be predicted from the Sheffield response. For example, the smoothness of one kind of paper, which is 215.66 on Sheffield instrument, will be $y = 0.29064 + 0.02551\ (215.6) = 5.7905$ on IGT response.

The coefficient of determination, R^2, is 0.89899. This indicates that 89.9% of all the variation in the data is attributable to a relationship between the responses of the Sheffield and IGT methods. The remaining variation is associated with experimental error or other untested factors.

The computer output is shown in Appendix B.

The 95% confidence limits for the true mean value of IGT for a given Sheffield value is given by $y \pm t\,(n-2,\ 0.975)\,(Se)$ where $t\,(n-2,\ 0.975)$ is the 97.5% point of a student t-distribution, with (n-2) degree of freedom for n observation. Se is the estimated standard error of y at a specific value x. The value Se is calculated by the following formula:[2]

$$Se = S \left[\frac{1}{n} + \frac{(x - \bar{x})^2}{(x - \bar{x})^2} \right]^{\frac{1}{2}}$$

where $\bar{x} = \frac{\Sigma x}{n}$

$$S = \left[\Sigma y - \frac{(\Sigma y)^2}{n} \right] / (n - 2)$$

The confidence limits (the loci are shown on Fig. 7) for the regression line is listed as follows:

SHEFFIELD	EST.IGT	LOWER LIMIT	UPPER LIMIT
3.3500	0.3770	0.0000	1.0205
3.6000	0.3833	0.0000	1.0262
3.6300	0.3841	0.0000	1.0269
4.6900	0.4111	0.0000	1.0512
31.7200	1.1008	0.5283	1.6728
33.3800	1.1431	0.5751	1.7111
61.3500	1.8567	1.3522	2.3612
68.9500	2.0506	1.5619	2.5394
71.6200	2.1187	1.6353	2.6022
80.8900	2.3552	1.8896	2.8208
84.0300	2.4353	1.9755	2.8952
96.5600	2.7550	2.3165	3.1936
97.8100	2.7865	2.3504	3.2235
125.1000	3.4032	3.0219	3.7845
152.3900	4.1794	3.7957	4.5631
159.9200	4.3715	3.9892	4.7539
164.3800	4.4853	4.1030	4.8676
181.6600	4.9262	4.5390	5.3134
211.9900	5.7000	5.2855	6.1144
212.4900	5.7128	5.2977	6.1278
214.9800	5.7763	5.3581	6.1945
215.1500	5.7806	5.3622	6.1991
215.6600	5.7936	5.3745	6.2128
216.0800	5.8043	5.3847	6.2240
262.0800	6.9779	6.4777	7.4782
265.2900	7.0598	6.5523	7.5669
276.9100	7.3563	6.8237	7.8889
364.0600	9.5798	8.8223	10.3372
364.7200	9.5966	8.8373	10.3559
390.5600	10.2564	9.4234	11.0893
409.7500	10.7455	9.8569	11.6342

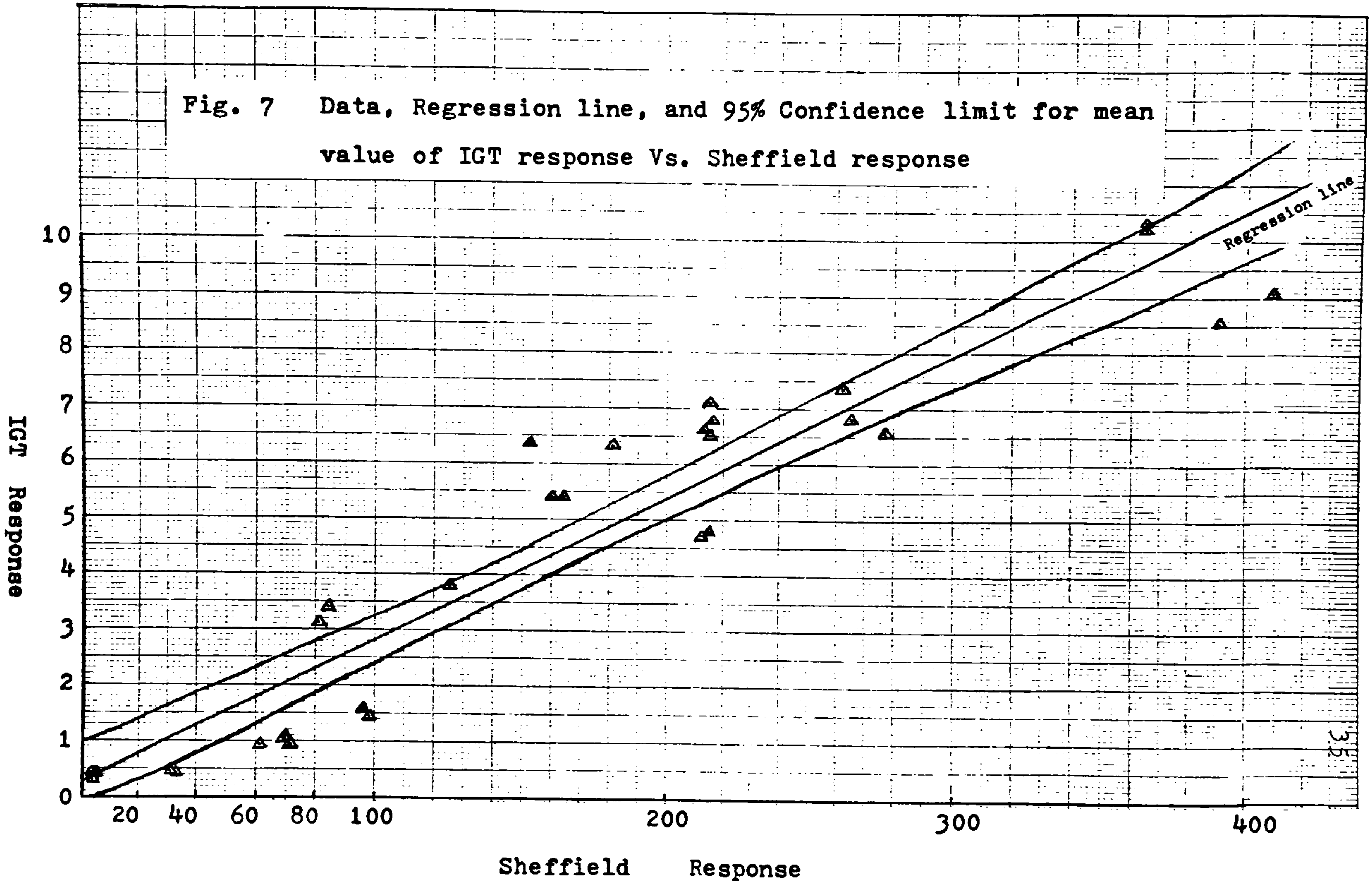


Fig. 7 Data, Regression line, and 95% Confidence limit for mean value of IGT response Vs. Sheffield response

B. Using the paper samples measured for smoothness/roughness gravure printing was accomplished using the IGT printability tester and the IGT gravure attachment. A sampling of these printed strips was selected to curve the full range of smoothness/roughness for evaluation using the Graphic Arts Inspector. The number of missing cells on each sample were counted in fixed fields of 1600 gravure cells each and the percentage of missing cells was calculated. These results are shown in Table 3. The percentage of missing cells versus IGT roughness measurement and Sheffield smoothness response are plotted on Figure 8 and 9 respectively.

The regression theory of this part is about the same as Part A. No more interpretation is needed.

On the basis of Table 3, we can easily see the if the smoothness/roughness of the IGT measurement is below 0.5 and below 50 on the Sheffield, the missing cell percentage is 0. At the other end of the scale the printed cells on some of the roughest paper are difficult to count due to the increase of missing cells caused by paper surface roughness. Therefore, we can say that the smoother the paper, the better printing quality of the gravure print; the rougher the paper, the poorer the printed result. Micro-photographs of some of the samples are shown in Figure 10. These

pictures indicate that the smaller the smoothness value, the more solid the printed cell, resulting in more distinct dots.

Regression analysis as shown in Appendix C indicates the simple linear equation does not fit the data well. Several other models were tried and a second order polynomial equation appears to be the best choice producing an acceptable R^2 with the line of regression fitting the data reasonably well.

The computer output of the regression curves are given by

$$y = 0.059 + 0.3173\ x + 0.574\ x^2$$

where x = IGT response

y = percent of missing cells

$R^2 = 0.7825$

and

$$y = 0.0638 + 9.204\text{-}03\ x + 3.743\text{-}05\ x^2$$

where x = Sheffield response

y = Missing cell percentage

$R^2 = 0.7778$

The confidence limits for the regression curves are listed as follows:

IGT	EST.CELLS	LOWER LIMIT	UPPER LIMIT
0.3708	0.0652	0.0000	1.1366
0.3922	0.0728	0.0000	1.1406
0.4043	0.0771	0.0000	1.1429
0.4058	0.0776	0.0000	1.1432
0.4070	0.0781	0.0000	1.1435
0.4491	0.0932	0.0000	1.1516
1.4276	0.5031	0.0000	1.4084
1.5351	0.5546	0.0000	1.4447
3.3978	1.6611	0.9652	2.3571
4.7140	2.6826	2.0035	3.3617
4.7946	2.7516	2.0607	3.4335
5.4261	3.3180	2.5999	4.0361
5.4406	3.3316	2.6123	4.0508
6.4886	4.3741	3.5467	5.2015
6.6175	4.5111	3.6671	5.3550
6.7990	4.7071	3.8389	5.5753
6.8130	4.7224	3.8523	5.5924
7.1333	5.0780	4.1625	5.9935
7.3570	5.3334	4.3844	6.2823
8.5606	6.8060	5.6590	7.9531
10.2195	9.1073	7.6553	10.5592

SHEFFIELD	EST.CELLS	LOWER LIMIT	UPPER LIMIT
3.3500	0.0927	0.0000	1.2109
3.6000	0.0950	0.0000	1.2120
3.6300	0.0953	0.0000	1.2122
4.6900	0.1052	0.0000	1.2171
31.7200	0.3664	0.0000	1.3769
33.3800	0.4054	0.0000	1.3897
84.0300	1.0859	0.2922	1.8797
96.5600	1.2839	0.5262	2.0417
97.8100	1.3043	0.5499	2.0539
159.9200	2.4652	1.7989	3.1417
164.3800	2.5597	1.8816	3.2379
211.9900	3.6612	2.9064	4.4160
212.4900	3.6736	2.9175	4.4297
214.9800	3.7360	2.9732	4.4988
215.1500	3.7403	2.9770	4.5035
215.6600	3.7531	2.9885	4.5178
216.0800	3.7637	2.9979	4.5295
262.0800	5.0032	4.0738	5.9277
265.2900	5.0957	4.1582	6.0331
364.0600	8.3164	6.9125	9.7204
390.5800	9.3057	7.7632	10.8481

The loci of these limits are shown on Figure 8 and 9 respectively.

Serial No.	IGT Response	Sheffield Response	Missing Cells Counted	Missing Percentage
0101	0.4491	31.72	0	0
0102	4.7946	214.98	194	1.35
0103	0.4070	33.38	0	0
0104	4.7140	211.99	288	2.00
0201	0.4058	3.63	0	0
0202	6.4886	215.66	241	1.68
0203	0.4043	4.69	0	0
0204	6.7990	216.08	450	3.13
0301	5.4261	159.92	711	4.94
0302	5.4406	164.38	779	5.41
0401	0.3708	3.60	0	0
0402	7.1333	215.15	509	3.54
0403	0.3922	3.35	0	0
0404	6.6175	212.49	456	3.17
0501	6.8130	265.29	792	5.50
0502	7.3570	262.08	1055	7.33
0601	1.4276	97.81	86	0.60
0602	1.5351	96.56	87	0.60
0701	10.2195	364.06	1208	8.39
0901	3.3978	84.03	474	3.29
1500	8.5608	390.58	1376	9.56

Total cells counted in the fixed areas: 14400

Table 3: Average percentage of missing gravure cells in the fixed areas. (Chemical paper)

Serial No.	IGT Response	Sheffield Response	Missing Cells Counted	Missing Percentage
1200 (Newsprint)	3.1322	80.89	10	0.07
1300 (Gravure)	1.0796	68.95	8	0.06

Total cells counted in the fixed areas: 14400

Table 3a: Average percentage of missing gravure cells in the fixed areas. (Groundwood paper)

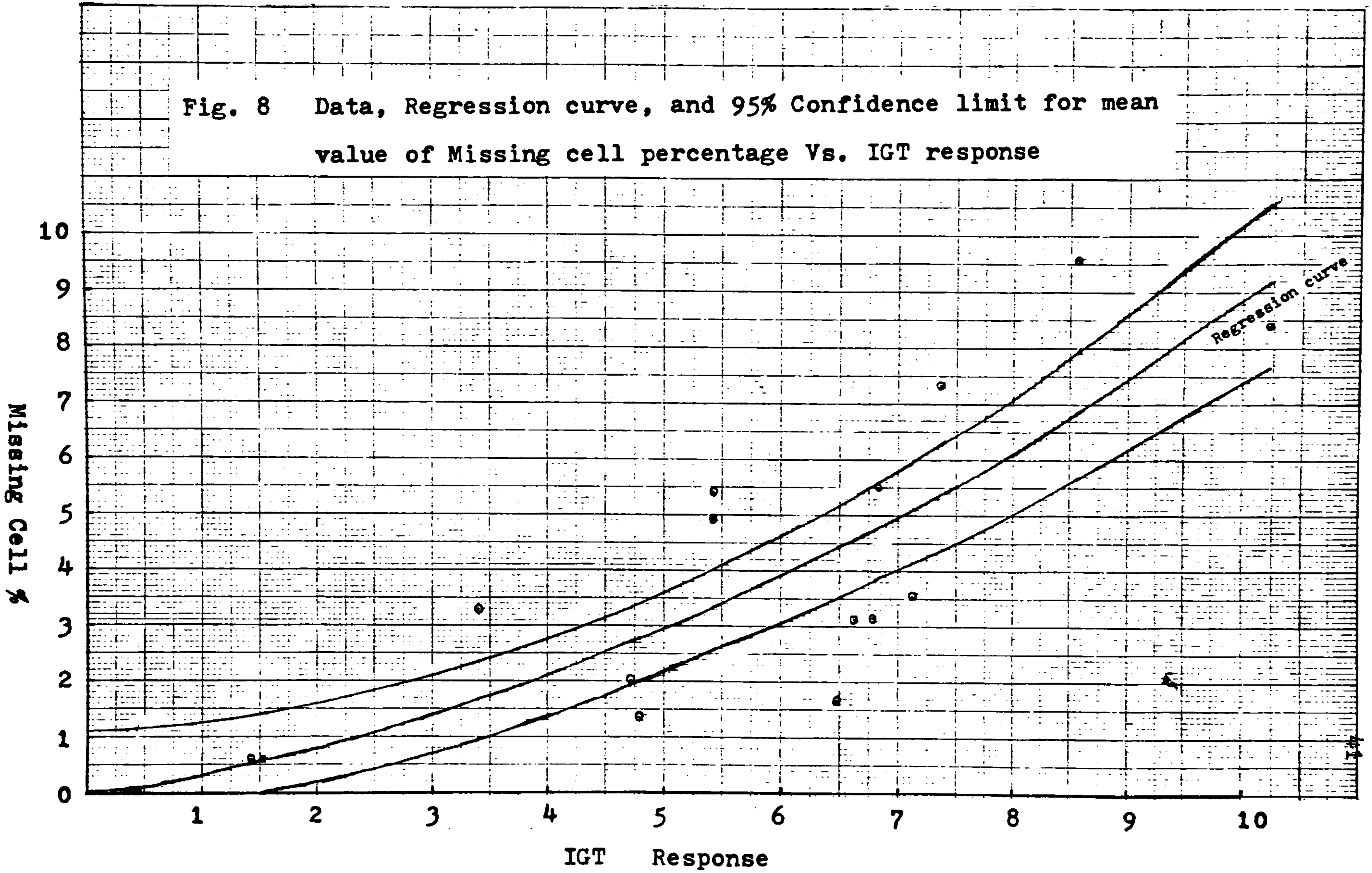


Fig. 8 Data, Regression curve, and 95% Confidence limit for mean value of Missing cell percentage Vs. IGT response

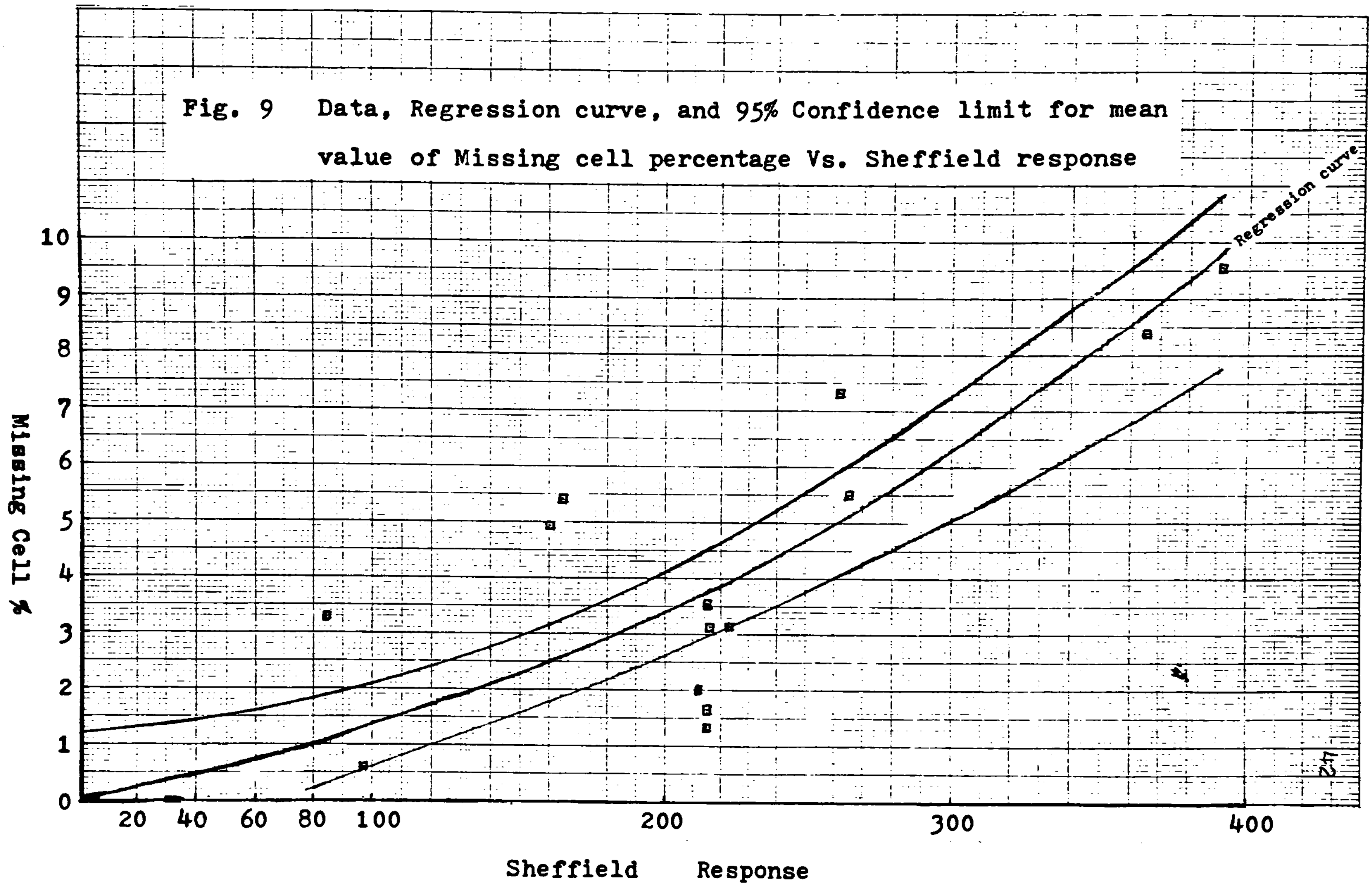
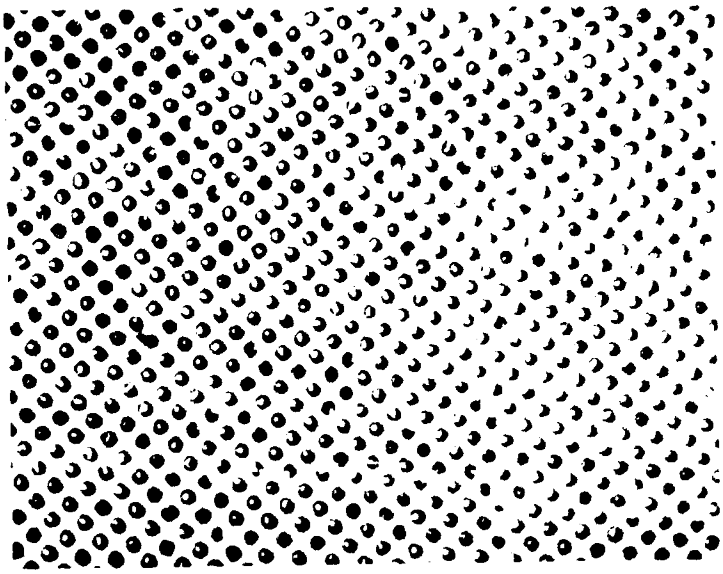


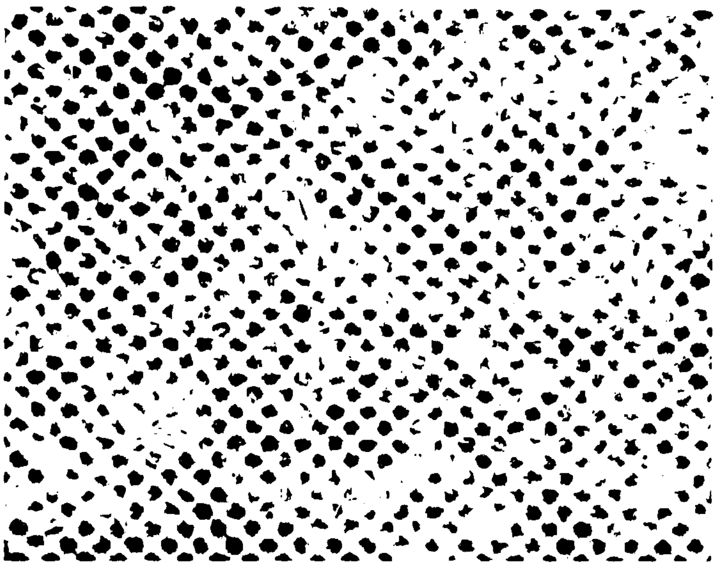
Fig. 9 Data, Regression curve, and 95% Confidence limit for mean value of Missing cell percentage Vs. Sheffield response

Figure 10 A



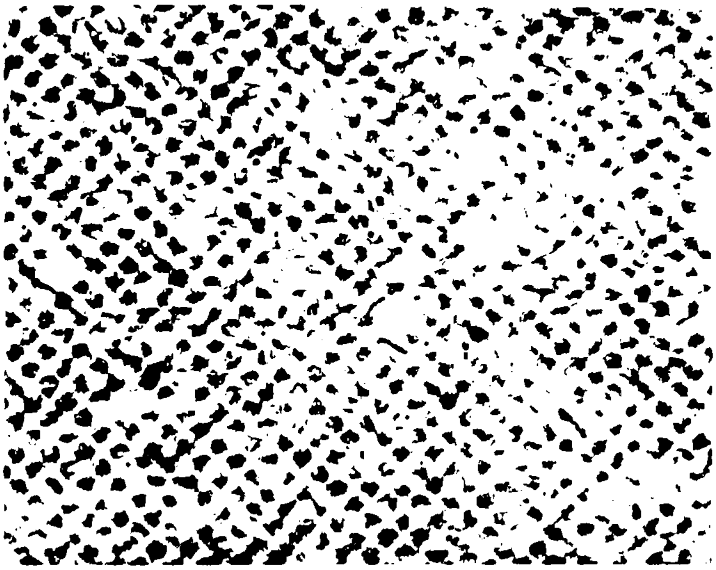
Serial No.:	0101
IGT Response:	0.4491
Sheffield Response:	31.72
Missing Cells:	0.0%

Figure 10 B



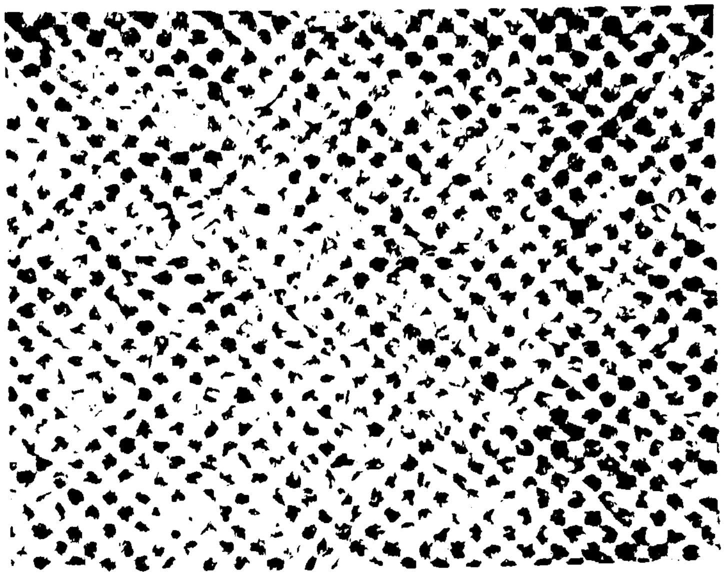
Serial No.:	0104
IGT Response:	4.7140
Sheffield Response:	211.99
Missing Cells:	2.0%

Figure 10 C



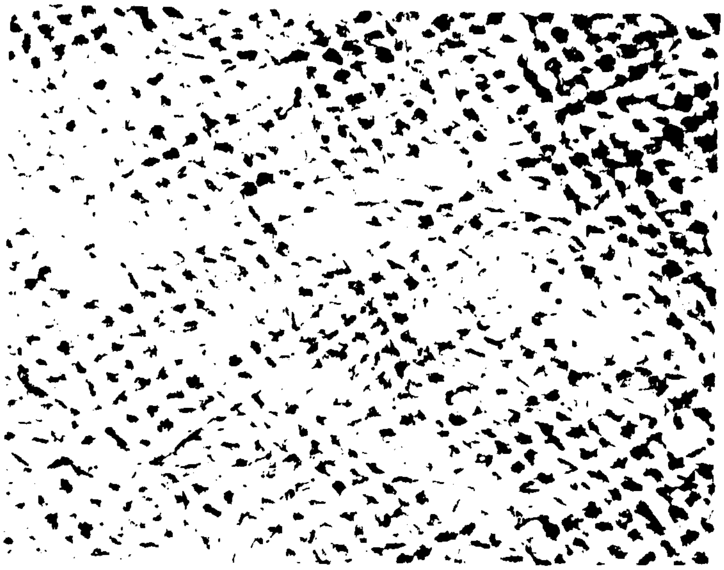
Serial No.:	0301
IGT Response:	5.4261
Sheffield Response:	159.92
Missing Cells:	4.94%

Figure 10 D



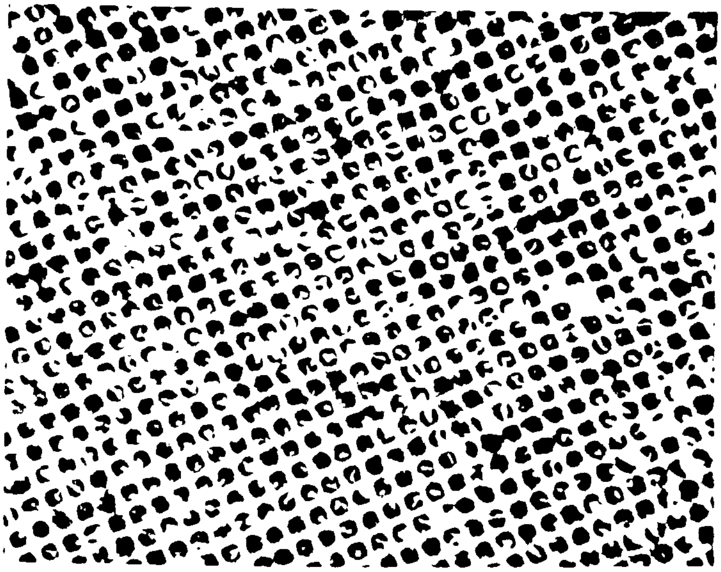
Serial No.:	0404
IGT Response:	6.6175
Sheffield Response:	212.49
Missing Cells:	3.17%

Figure 10 E



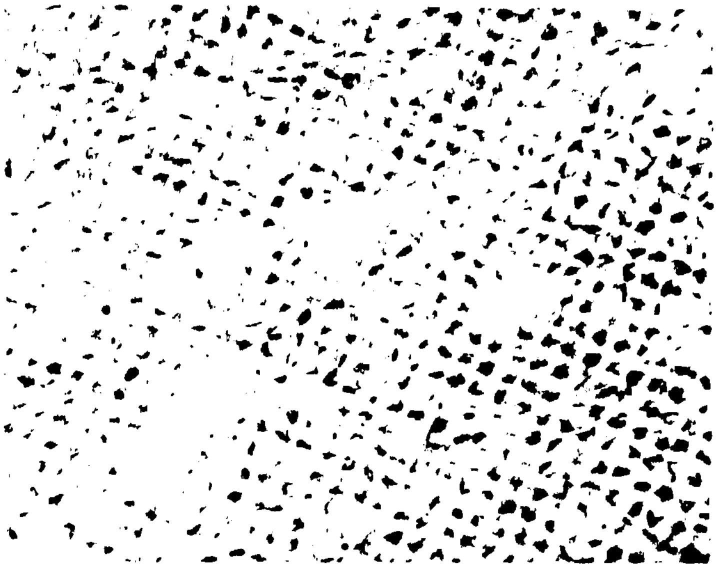
Serial No.:	0501
IGT Response:	6.813
Sheffield Response:	265.29
Missing Cells:	5.50%

Figure 10 F



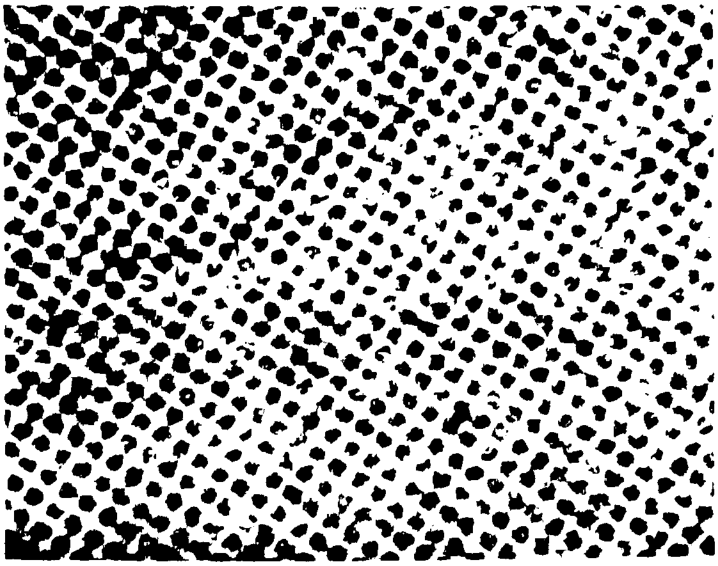
Serial No.:	0601
IGT Response:	1.4276
Sheffield Response:	97.81
Missing Cells:	0.60%

Figure 10 G



Serial No.:	1500
IGT Response:	8.5608
Sheffield Response:	390.58
Missing Cells:	9.56%

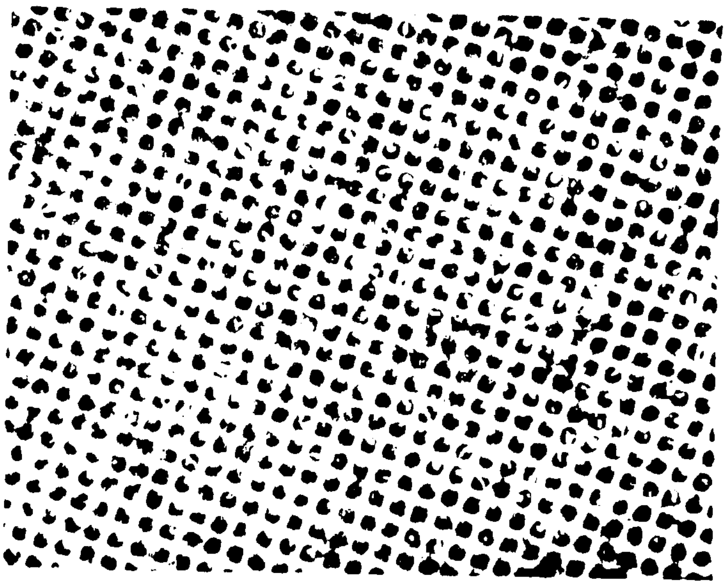
Figure 10 H



Serial No.:	1200
IGT Response:	3.1322
Sheffield Response:	80.89
Missing Cells:	0.07%

(Groundwood Newsprint)

Figure 10 I



Serial No.: 1300

IGT Response: 1.0796

Sheffield Response: 68.95

Missing Cells: 0.06%

(Groundwood Gravure)

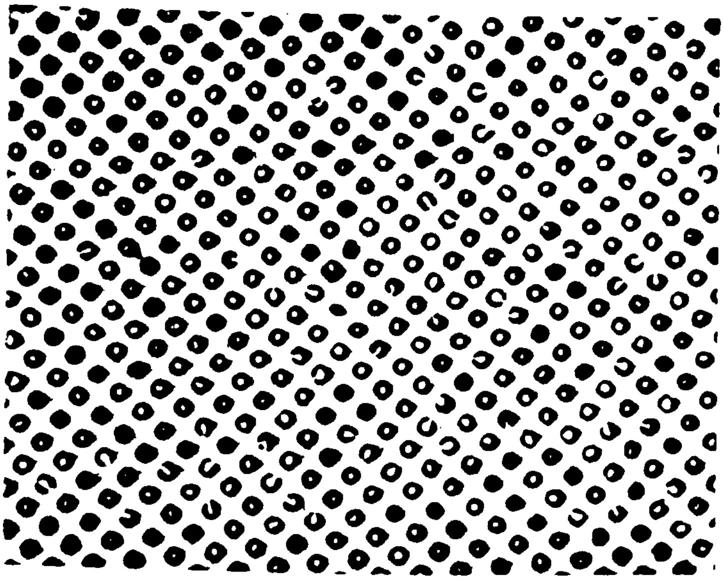


Figure 10 J Gravure Print with ESA

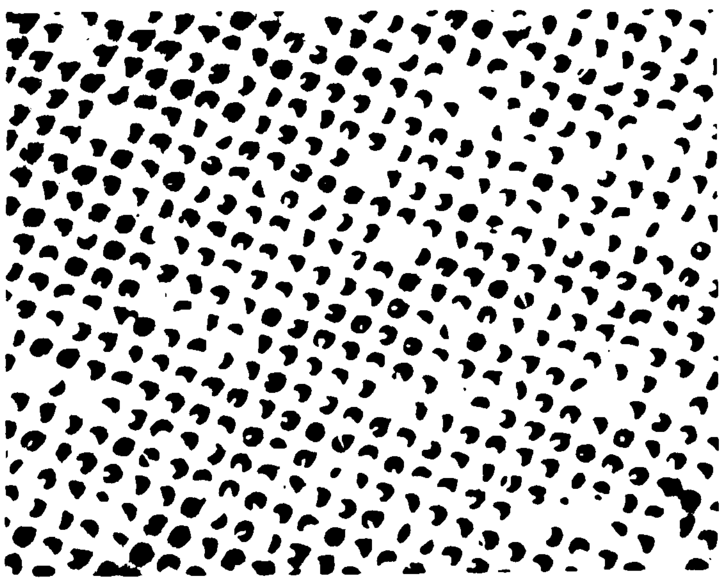


Figure 10 K Gravure Print Without ESA

FOOTNOTES FOR CHAPTER FIVE

[1]Rickmers, A. D., Todd, H. J., "Statistics (An Introduction)," p. 266.

[2]Draper, N. R., Smith, H., "Applied Regression Analysis," Second Edition, Chapter I.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

Conclusion

Data shown in Appendix A indicate that there is little difference in the values obtained for smoothness/roughness between the measurement of machine direction and cross direction of the paper grain. Therefore, only by measuring the machine direction of the paper grain can we obtain the accurate data we need.

From the data plotted in Figure 7 and the R value obtained by computer output, it indicates that there is a linear relationship between response of the Sheffield instrument and IGT Printability Tester for the measurement of smoothness of the paper. In other words, these two methods to measure the paper smoothness are associated with each other as

$y = a + bx$, $y = 0.29064 + 0.02551\,x$

a = coefficient of the intercept of the line

b = coefficient of the slope of the line

where y = IGT Response

x = Sheffield Response

Data shown in Table 3 and 3a tell us that paper with smoothness measured and used for prediction of the gravure printing quality by a count of missing gravure

cells is limited to chemical pulp only. Groundwood paper is excluded, because printing with groundwood paper will generate less skipping cells presumably due to its compressibility. This response was not considered in this work, but the effect is shown by two groundwood sheets which were included in this paper. Groundwood paper seems to generate better gravure print quality at rougher levels than the chemical pulp.

Having visually inspected and counted with the aid of using the Graphic Arts Inspector, this researcher found that too-rough paper could not be used for the counting of the missing cells because of the increased number of complete or partial missing cells making it difficult to count.

The microphotographs of some of the samples shown in Figure 10 indicate that the lower the smoothness value, the more solid the printed cell, resulting in more distinct dots.

Figure 8 and 9 show the regression curves and 95% confidence limits for mean value of missing cells percentage vs. IGT response and Sheffield response respectively.

Regression analysis indicates the simple linear equation does not fit the data well. Several other models were tried and a second degree polynomial equation appears to be the best choice producing an

acceptable R^2 with the line of regression fitting the data reasonably well.

Recommendation

1. As we know, the humidity seriously affects the Sheffield responses while measuring the smoothness of the paper. It is suggested that an air-conditioned and humidity controlled laboratory be provided.
2. 78% of the gravure cell skipping data variation as printed by the IGT printability tester is attributable to roughness measurement. The remaining amount of variation is associated with error or untested factors. It is recommended that compressibility and oil absorbency of paper be further studied and incorporated into similar studies. It is expected that the addition of these variables would improve laboratory prediction of gravure printability as defined by cell skipping.

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Draper, N. R., Smith, H., "Applied Regression Analysis," Second Edition, Chapter I.

APPENDIX A

Serial No. 0101

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	162	18	0.6050	33.26
	3	175	18	0.5602	
2	3	192	18	0.5106	35.40
	2	179	15	0.4381	
	2	192	14	0.4376	
3	2	143	14	0.5876	35.42
	1.5	125	14	0.5042	
	1.5	134	15	0.4389	
4	1	123	14.5	0.3298	30.42
	1	123	12.5	0.3825	
	1	91	13	0.4972	
5	1	100	12.5	0.4705	36.58
	1	95	13	0.4763	
	1	132	13	0.3427	
				Mean	Value

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0101

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
6	1	127	12.5	0.3705	27.5
	1	137	12	0.3578	
	1	129	12	0.3799	
7	1	147	12	0.3334	35
	1	122	12	0.4018	
	1	104	12.5	0.4524	
	1	146	13	0.3079	
	1	109	12.5	0.4317	
8	1	102	12	0.4805	25.5
	1	110.5	12	0.4436	
	1	101.5	13	0.4458	
	1	112.5	12	0.4357	
	1	110	12	0.4456	
9	1	114	11.5	0.4486	27.42
	1	123	11	0.4347	
	1	116.5	11.5	0.4390	
	1	117	11	0.4570	
10	1	106	12	0.4624	30.75
	1	115	12	0.4262	
	1	103	13	0.4393	
	1	113	11.5	0.4526	
	1	105.5	11.5	0.4848	
				Mean	**Value**
				0.4491	31.72

Grain Direction Measured: MD

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0102

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	39	10	4.5248	198.33
	3	36	11	4.4563	
	3	40	11	4.0106	
2	3	46	9	4.2625	220.94
	3	38	11	4.2217	
	3	41	10	4.3041	
3	3	34	8.5	6.1062	221.43
	3	39	10	4.5248	
	3	53	7	4.7566	
4	3	44	8	5.0133	214.58
	3	42	9	4.6685	
	3	53	7	4.7566	
5	3	38	9.5	4.8883	222.50
	3	46	7	5.4804	
	3	48	8	4.5955	
6	3	45	9	4.3572	214.16
	3	46	10	3.8363	
	3	44	8.5	4.7184	
				Mean	Value

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0102

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
7	3	51	7	4.9431	213.33
	3	44	8.5	4.7184	
	3	43	9	4.5599	
	3	51	7.5	4.6136	
	3	46	8	4.7953	
8	3	42.5	8.5	4.8849	216.25
	3	45	7.5	5.2287	
	3	40	9	4.9019	
	3	47	7	5.3638	
	3	47	8	4.6933	
9	3	48	7	5.2521	211.67
	3	42	8.5	4.9431	
	3	51	8.5	4.0708	
	3	54	6	5.4466	
10	3	49	7	5.1449	216.67
	3	49	7	5.1449	
	3	49	7.5	4.8019	
	3	42	8	5.2521	
	3	32	12	4.5955	
				Mean	Value
				4.7946	214.98

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0103

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	186	18	0.5270	40.19
2	2	174	17	0.3977	38.62
3	1.5	151	15	0.3895	34.17
	1.5	154	15.5	0.3696	
	1.5	148	15	0.3974	
4	1	105	13	0.4309	34.75
	1	111	13	0.4076	
	1	144	13	0.3142	
5	1	137	14.5	0.2961	40.5
	1	120	13	0.3770	
	1	120	13.5	0.3631	
6	1	130	13.5	0.3351	32.25
	1	135	14	0.3112	
	1	136	13.5	0.3203	
7	1	112	13	0.4040	31
	1	111	12	0.4416	
	1	92	12	0.5328	
	1	108.5	12.5	0.4337	
	1	107	12	0.4581	
				Mean	Value

Grain Direction Measured: C D

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0103

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
8	1	118	12.5	0.4357	27.66
	1	110	12	0.4456	
	1	113	12	0.4338	
	1	111	12	0.4416	
	1	121.5	11	0.4401	
9	1	121	12	0.4051	25.25
	1	124	12	0.3953	
	1	118	12.5	0.3988	
	1	122	12.5	0.3857	
	1	119	12.5	0.3954	
10	1	113	12	0.4338	27.42
	1	114	13	0.3969	
	1	115	12	0.4262	
	1	113	12.5	0.4164	
				Mean	Value
				0.4070	33.38

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0104

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	39	10	4.5248	209.05
	3	54	8	4.0849	
	3	38	11	4.2217	
2	3	39	10	4.5248	215.83
	3	37	10	4.7694	
3	3	64	6	4.5955	207.14
	3	68	5	5.1903	
	3	54	7	4.6685	
4	3	47	8	4.6933	217.08
	3	56	8	3.9390	
	3	51	7.5	4.6136	
5	3	49	8	4.5018	206.67
	3	52	8	4.2420	
	3	50	6	5.8823	
6	3	53	7.5	4.4395	198.75
	3	53	8	4.1620	
	3	53	8	4.1620	
				Mean	Value

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0104

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
7	3	61	5.5	5.2599	217.5
	3	55	6.5	4.9362	
	3	56	5.5	5.7295	
	3	51	7	4.9431	
	3	48	7	5.2521	
8	3	53	7	4.7566	205.83
	3	47.5	8	4.6439	
	3	52	6.5	5.2210	
	3	53	6	5.5493	
	3	55	6.5	4.9362	
9	3	48	8	4.5955	217.08
	3	47	8	4.6933	
	3	53	7	4.7121	
	3	52	6.5	5 2210	
	3	52	6	5.6561	
10	3	46	8	4.7953	225
	3	51	6.5	5.3233	
	3	51	7.5	4.6136	
	3	46.5	10	3.7950	
				Mean	**Value**
				4.7140	211.99

Grain Direction Measured: C D

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0201

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	1	120	12.5	0.3921	3
	1	115	12.5	0.4092	
	1	123	11.5	0.4158	
2	1	124	12	0.3953	4.08
	1	121	12	0.4051	
	1	136	11.5	0.3761	
3	1	127	11.5	0.4027	4.08
	1	138	12	0.3552	
	1	130	11.5	0.3934	
	1	128	11.5	0.3996	
4	1	100	12	0.4901	5.08
	1	135	11	0.3961	
	1	114	11	0.4690	
	1	107	12.5	0.4398	
5	1	133	11.5	0.3845	4.91
	1	126	12	0.3890	
	1	130	11	0.4113	
				Mean	Value
				0.4058	3.63

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0202

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	37	7	6.8135	223.33
	3	38	6	7.7399	
	3	32	8	6.8933	
2	3	36	7	7.0028	220.83
	3	40	6	7.3529	
	3	37	7	6.8135	
	3	36	7	7.0028	
3	3	36	8	6.1274	212.91
	3	37	6	7.9491	
	3	40	6	7.3529	
	3	30	9	6.5359	
4	3	31	8.5	6.6971	215.00
	3	32	9	6.1274	
	3	36	7.5	6.5359	
	3	37	7	6.8135	
5	3	38	6.5	7.1445	206.25
	3	36	7	7.0028	
	3	42	6	7.0028	
				Mean	Value
				6.4886	215.66

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0203

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	1	134	12	0.3658	3.08
	1	120	11.5	0.4262	
	1	122	12	0.4018	
	1	112	12.5	0.4201	
2	1	127	11.5	0.4027	3.50
	1	121	12.5	0.3889	
	1	129	11	0.4145	
3	1	138	10.5	0.4059	4.50
	1	143	11	0.3739	
	1	131.5	11.5	0.3889	
	1	123	12	0.3985	
	1	116	12	0.4225	
4	1	138	11	0.3875	5.58
	1	125	11.5	0.4092	
	1	122.5	11.5	0.4175	
	1	118	12	0 4154	
5	1	135	11	0.3961	6.83
	1	122	11.5	0.4192	
	1	116.5	12	0.4207	
	1	117	13	0.3867	
	1	118	11.5	0.4334	
				Mean	Value
				0.4043	4.69

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0204

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	33	9	5.9417	219.16
	3	34	8	6.4878	
	3	30	9	6.5359	
	3	38	7	6.6342	
2	3	36	7	7.0028	209.16
	3	37	7	6.8135	
	3	37	7	6.8135	
3	3	35	8	6.3025	213.75
	3	35	8	6.3025	
	3	36	7.5	6.5359	
	3	36	7.5	6.5359	
	3	39	6.5	6.9613	
4	3	32	8	6.8933	223.75
	3	42	5	8.4033	
	3	28	9	7.0028	
	3	37	7	6.8135	
5	3	37	7	6.8135	214.58
	3	33	8	6.6844	
	3	31	8	7.1157	
	3	34	7	7.4147	
	3	36	7.5	6.5359	
				Mean	**Value**
				6.7990	216.08

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0301

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	59	5	5.9820	142.85
	3	68	5	5.1903	
	3	65.5	5	5.3884	
2	3	52	6.5	5.2210	167.57
	3	39	7.5	4.7630	
	3	44	8	5.0133	
3	3	48	7	5.2521	162.57
	3	50	7	5.0420	
	3	57	7	4.8480	
4	3	64	5	5.5147	166.71
	3	58	4.5	6.7613	
				Mean	Value
				5.4261	159.92

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0302

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	50	6 5	5.4298	152.28
	3	50	6	5.8823	
	3	47	7	5.3638	
2	3	46	6	6.3938	167.71
	3	46	7	5.4804	
	3	46	8	4.7953	
3	3	36.5	10.5	4.6045	169.14
	3	47	6.5	5.7764	
	3	48	6	6.1274	
4	3	49	7	5.1449	168.42
				Mean	Value
				5.4406	164.38

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0401

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	1	120	12.5	0.3721	3.68
	1	115	13.75	0.3720	
	1	117	13.5	0.3724	
	1	122.5	13	0.3693	
2	1	125	13	0.3619	3.50
	1	123	13	0.3678	
	1	123	13	0.3678	
3	1	130	12.5	0.3617	3.56
	1	128	12.5	0.3676	
	1	123	13	0.3678	
	1	127	12.5	0.3705	
4	1	129	13	0.3507	3.68
	1	121	13	0.3737	
	1	121	12	0.4051	
	1	123	13	0.3678	
				Mean	Value
				0.3708	3.60

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0402

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	32	9	6.1274	208.12
	3	31	8	7.1157	
	3	44	5	8.0213	
	3	41.5	4.5	9.4495	
2	3	38.5	7	6.5480	218.12
	3	35	8	6.3025	
	3	41	6	7.1736	
3	3	35	7	7.2028	216.25
	3	40	6	7.3529	
	3	38	7	6.6342	
	3	37	7	6.8135	
4	3	38	6.5	7.1445	218.12
	3	42	5	8.4033	
	3	38	7	6.6342	
	3	36	7.5	6.5359	
				Mean	**Value**
				7.1333	215.15

Grain Direction Measured: MD

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0403

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	1	126	12	0.3870	3.62
	1	117.5	12.5	0.4005	
	1	126	11.5	0.4059	
	1	114	12	0.4299	
2	1	118	12.5	0.3788	3.06
	1	121	12.5	0.3889	
	1	121	13	0.3739	
	1	130	12	0.3770	
3	1	123	12.5	0.3825	3.31
	1	121	12	0.4051	
	1	119	12.5	0.3954	
	1	122	12.5	0.3857	
4	1	122	12.5	0.3857	3.43
	1	124	12	0.3953	
	1	119.5	12.75	0.3860	
	1	125	12.5	0.3764	
			Mean Value	0.3922	3.35

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0404

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	30	9	6.5359	223.75
	3	33	8	6.6844	
	3	40	6	7.3529	
	3	28	9.5	6.6342	
2	3	33	8	6.6844	205.62
	3	35	7.5	6.7226	
	3	31.5	9.5	5.8970	
	3	36	7.5	6.5359	
3	3	33	8	6.6844	210.62
	3	34	7.5	6.9204	
	3	34	8	6.4878	
	3	33	8.5	6.2912	
4	3	34	8	6.4878	210
	3	38	7	6.6342	
	3	36	7	7.0028	
	3	31	9	6.3251	
				Mean	Value
				6.6175	212.49

Grain Direction Measured: C D

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0501

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	32	8	6.8933	263.75
	3	36	6.5	7.5414	
	3	35	7	7.2028	
	3	36	7	7.0028	
2	3	28	9.5	6.6342	266.66
	3	34	8	6.4878	
	3	35	8	6.3025	
	3	30	9	6.5359	
3	3	39	7	6.4641	268.75
	3	36	8	6.1274	
	3	36	8	6.1274	
	3	34	7.5	6.9204	
4	3	37	7	6.8135	257.5
	3	34	8	6.4878	
	3	35	7	7.2028	
	3	36	7	7.0028	
	3	43	5	8.2079	
				Mean	Value
				6.813	265.29

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0502

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	33	7	7.6394	256.25
	3	33	7.5	7.1301	
	3	37	7	6.8135	
2	3	34	7	7.4147	272.08
	3	35	6.5	7.7569	
	3	33	7.5	7.1301	
	3	37	6.5	7.3376	
	3	37	6.5	7.3376	
3	3	36	7	7.0028	262.5
	3	30.5	8.5	6.8069	
	3	40	5	8.8235	
	3	37	6	7.7491	
	3	42.5	5	8.3044	
4	3	30	8	7.3529	251.66
	3	41	5.5	7.8257	
	3	37	7.5	6.3593	
	3	39	6.5	6.9613	
	3	30.5	8.5	6.8069	
				Mean	**Value**
				7.357	262.08

Grain Direction Measured: C D

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0601

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	106.5	12	1.3808	100.41
	3	100	12.5	1.4117	
	3	107	12	1.3743	
	3	101	12	1.4560	
	3	115	10.5	1.4614	
2	3	102	12.5	1.6477	97.00
	3	104	12	1.4140	
	3	108	11	1.4854	
	3	104	11.5	1.4755	
	3	105	12	1.4005	
3	3	102	12.5	1.3840	99.58
	3	111	11	1.4452	
	3	108	12	1.3616	
	3	110	10.5	1.5278	
	3	108	12.5	1.3071	
4	3	108	11.5	1.4208	94.25
	3	106	12	1.3873	
	3	102	12	1.4417	
	3	117	11.5	1.3115	
	3	110	11	1.4584	
				Mean	Value
				1.4276	97.81

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0602

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	95	12.5	1.4860	97.00
	3	100	11.5	1.5345	
	3	102	10.5	1.6477	
	3	98	12	1.5006	
	3	106	10	1.6648	
2	3	108	10.5	1.5561	99.75
	3	107	11	1.4993	
	3	107	10.5	1.5707	
	3	103	10.5	1.6317	
	3	100.5	11	1.5962	
3	3	113	10.5	1.4873	94.58
	3	102	11	1.5728	
	3	111	10.5	1.5141	
	3	117	10.5	1.4364	
	3	108	11	1.4854	
4	3	103	12	1.4277	94.91
	3	117	10	1.5082	
	3	102	11.5	1.5044	
	3	110	10	1.6042	
	3	92	13	1.4755	
				Mean	Value
				1.5351	96.56

Grain Direction Measured: CD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0701

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	5	37	9	8.8323	363.33
	5	36	7	11.6713	
	5	41	7.5	9.5648	
	5	35	9	9.3370	
2	5	43	7	9.7713	362.66
	5	44	5	13.3689	
	5	46	6.5	9.8367	
	5	34	9.5	9.1058	
	5	51	4	14.4175	
3	5	32	10	9.1911	367.75
	5	48	6	10.2124	
	5	44	7	9.5492	
	5	30.5	10.5	9.1840	
4	5	35	8.25	10.1858	362.50
	5	36	8.5	9.6116	
	5	39	7.5	10.0553	
	5	42	7	10.0040	
	5	38	7	11.0570	
				Mean	Value
				10.2195	364.06

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0702

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	5	31	10	9.4876	367.33
	5	44.5	7.5	8.8125	
	5	36	9	9.0777	
	5	36	9.5	8.5799	
	5	31	10.5	9.0358	
2	5	49.5	5.5	10.8032	363.25
	5	39.5	8	9.3075	
	5	40	8	9.1911	
	5	34	7.5	11.5340	
	5	33	10	8.9126	
3	5	39	8	9.4268	367.50
	5	48	5.5	11.1408	
	5	55	4	13.3689	
	5	50	5.5	10.6951	
	5	50	5	11.7647	
4	5	43.5	6	11.2688	360.83
	5	39	7	10.7735	
	5	43	5.5	12.4362	
	5	35.5	8.5	9.7470	
	5	47	5.5	11.3778	
				Mean	Value
				10.3380	364.72

Grain Direction Measured: C.D

IGT Conditions:

1. Printing force: 40 kg (Pressure)
2. Spring drive: Position B (High Speed) (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0800

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	41	6.75	6.3765	169.16
	3	47	5.2	7.2205	
	3	42	6.5	6.4641	
	3	48	5.25	7.0028	
2	3	48	4.5	8.1679	179.16
	3	48	5	7.3529	
	3	45	5.5	7.1301	
	3	43	6	6.8399	
3	3	44	8	5.0133	195
	3	51	7	4.9431	
	3	56	5.5	5.7295	
	3	56	5.6	5.6272	
4	3	57	5	6.1919	183.33
	3	49	7	5.1449	
	3	49.5	6.25	5.7040	
	3	61	4.75	6.0904	
				Mean	Value
				6.3125	181.66

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0901

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	2	60	6.5	3.0165	89.33
	3	67	7	3.7626	
	3	66	8.1	3.3009	
	3	73	8.25	2.9301	
	3	70	7.5	3.3613	
2	3	66	8	3.3422	96.66
	3	61	8	3.6162	
	3	77	7	3.2740	
	3	66	7.75	3.4500	
	3	67	7.5	3.5118	
3	3	68.5	7.5	3.4349	75.25
	3	67	8	3.2923	
	3	62	9.5	2.9961	
	3	66	7.5	3.5650	
	3	63	8	3.5014	
4	3	69	7	3.6536	74.91
	3	64	7.5	3.6764	
	3	68	7.8	3.3271	
	3	63	8.5	3.2954	
	3	77	7	3.2740	
				Mean	Value
				3.3978	84.03

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)

2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 0902

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	75	6	3.9215	133.25
	3	69	6.75	3.7889	
	3	71	6.8	3.6551	
	3	81	6.25	3.4858	
	3	72	6	4.0849	
2	3	69	6	4.2625	141.33
	3	70	6	4.2016	
	3	65	7	3.8784	
	3	64	7.25	3.8032	
	3	65	7	3.8784	
3	3	69	6.5	3.9346	113.08
	3	64	8	3.4466	
	3	65	8.2	3.3108	
	3	77.5	6.5	3.5031	
	3	64	8	3.4466	
4	3	82	6	3.5868	112.75
	3	82	6	3.5868	
	3	82	5.8	3.7104	
	3	75	5.5	4.2780	
	3	75	6	3.9215	
				Mean	Value
				3.7838	125.10

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1000

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	145	13.5	0.9015	64.58
	3	144	14	0.8753	
	3	138.5	13	0.9801	
	3	144	14	0.8753	
	3	131	14	0.9622	
2	3	133.5	14	0.9441	60.83
	3	142	13	0.9559	
	3	143	13	0.9492	
	3	134	14.5	0.9082	
	3	139	14	0.9068	
3	3	144	12.75	0.9611	57.08
	3	136.5	13.5	0.9576	
	3	128	14.9	0.9252	
	3	141	13.5	0.9270	
	3	135.5	13.5	0.9647	
4	3	129	13.5	1.0133	62.91
	3	142	13	0.9559	
	3	136.5	13.8	0.9368	
	3	134	14	0.9406	
	3	135	13.5	0.9682	
				Mean	Value
				0.9404	61.35

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1100

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	2	103.5	11.75	0.9673	64.91
	2	99	12.5	0.9506	
	2	98.5	13	0.9187	
	2	110	11	0.9722	
	2	106.5	12	0.9205	
2	2	94.5	12	1.0374	68.25
	2	114.5	11.25	0.9133	
	2	109	11.5	0.9385	
	2	97	11	1.1025	
	2	109.5	11	0.9767	
3	2	117	11.5	0.8743	75.58
	2	102	13.5	0.8543	
	2	111.75	12.5	0.8422	
	2	103	11.5	0.9932	
	2	103.75	11.5	0.9860	
4	2	112	11.5	0.9134	77.75
	2	115	12	0.8525	
	2	115	11.5	0.8895	
	2	116.5	11.5	0.8781	
	2	110.5	11.5	0.9258	
				Mean	Value
				0.9353	71.62

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1200

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	2	51	7.5	3.0757	79.33
	2	51.5	8	2.8555	
	2	52	6	3.7707	
	2	56	6.5	3.2320	
	2	60.5	5.25	3.7039	
2	2	48.5	8.25	2.7402	87.25
	2	52	7	3.2320	
	2	58	6	3.3806	
	2	51	6.5	3.5489	
	2	44	7.5	3.5650	
3	2	57	7	2.9485	83.16
	2	64	6	3.0637	
	2	59	6	3.3233	
	2	72	6	2.7233	
	2	61	6.5	2.9671	
4	2	68	6.5	2.6616	73.83
	2	63	6	3.1123	
	2	60.5	6.5	2.9916	
	2	66	6	2.9708	
	2	57	8	2.5799	
				Mean	Value
				3.1322	80.89

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1300

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	2	91.5	11.5	1.1180	67.12
	2	92	11	1.1625	
	2	93	11.5	1.1000	
2	2	97	12	1.0107	69.37
	2	96	11.5	1.0656	
	2	100	11	1.0695	
3	2	107	10	1.0975	70.37
	2	101	11	1.0589	
	2	97	11.75	1.0322	
				Mean	**Value**
				1.0796	68.75

Grain Direction Measured: CD

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1400

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
	3	56	4.5	7.0028	278
	3	57	4.5	6.8799	280
	3	54	4.8	6.8082	270
	3	43.5	7.25	5.5955	266
					276
					288
					285
					290
					282
					282
					274
					252
				Mean	Value
				6.5716	276.91

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1500

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
	3	33	8	6.6844	382
	3	55	3	10.6951	393
	3	46	5	7.6726	388
	3	48	4	9.1911	390
					390
					388
					390
					389
					397
					396
					396
					388
				Mean	**Value**
				8.5608	390.58

Grain Direction Measured: MD

IGT Conditions:

1. **Printing force:** 40 kg
   (Pressure)
2. **Spring drive:** Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1600

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
	3	35	5	10.0840	409
	3	27.5	8	8.0213	410
	3	35	5.5	9.1673	408
	3	30	6.5	9.0497	410
					410
					412
					411
					411
					407
					408
					412
					409
				Mean	Value
				9.0805	409.75

Grain Direction Measured: MD

IGT Conditions:

1. Printing force: 40 kg
   (Pressure)
2. Spring drive: Position B (High Speed)
   (Velocity)

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

Serial No. 1700

Paper Strip Measured (Sample No.)	Volume (ul) Placed on Microsyringe	Length of Blot	Width of Blot	IGT Roughness X in cm3/m2	Sheffield Smoothness
1	3	57	5	6.1919	168.16
	3	60	3.75	7.8431	
2	3	58	5.25	5.7954	152.83
	3	58	5	6.0851	
	3	45	7.5	5.2287	
3	3	70.5	4	6.2578	146.16
	3	47.25	5.75	6.2315	
	3	59	5	5.9820	
	3	59	4.8	6.2313	
4	3	54	5	6.5359	142.41
	3	70.3	4	6.2756	
	3	58	4.5	6.7613	
	3	63	4	7.0028	
				Mean	**Value**
				6.3850	152.39

Grain Direction Measured: MD

IGT Conditions:

1. **Printing force: 40 kg (Pressure)**
2. **Spring drive: Position B (High Speed) (Velocity)**

Table 1 Data Table for IGT Roughness vs. Sheffield Smoothness

APPENDIX B

DATA FILE = B:SUNG01
VARIABLES = 2 OBSERVATIONS = 31 PAGE 1

	1 IGT	2 SHEF
1	.4491	31.72
2	4.7946	214.98
3	.407	33.38
4	4.714	211.99
5	.4058	3.63
6	6.4886	215.66
7	.4043	4.69
8	6.799	216.08
9	5.4261	159.92
10	5.4406	164.38
11	.3708	3.6
12	7.1333	215.15
13	.3922	3.35
14	6.6175	212.49
15	6.813	265.29
16	7.357001	262.08
17	1.4276	97.81
18	1.5351	96.56
19	10.2195	364.06
20	10.338	364.72
21	6.3125	181.66
22	3.3978	84.03
23	3.7838	125.1
24	.9404	61.35
25	.9353	71.62
26	3.1322	80.89
27	1.0796	68.95
28	6.5716	276.91
29	8.560799	390.58
30	9.080849	409.75
31	6.385	152.39

FILE: B:SUNG01

VAR:	IGT	SHEF
0 1 :	.4491	31.72
0 2 :	4.7946	214.98
0 3 :	.407	33.38
0 4 :	4.714	211.99
0 5 :	.4058	3.63
0 6 :	6.4886	215.66
0 7 :	.4043	4.69
0 8 :	6.799	216.08
0 9 :	5.4261	159.92
0 10 :	5.4406	164.38
0 11 :	.3708	3.6
0 12 :	7.1333	215.15
0 13 :	.3922	3.35
0 14 :	6.6175	212.49
0 15 :	6.813	265.29
0 16 :	7.357001	262.08
0 17 :	1.4276	97.81
0 18 :	1.5351	96.56
0 19 :	10.2195	364.06
0 20 :	10.338	364.72

FILE: B:SUNG01

VAR:	IGT	SHEF
0 21 :	6.3125	181.66
0 22 :	3.3978	84.03
0 23 :	3.7838	125.1
0 24 :	.9404	61.35
0 25 :	.9353	71.62
0 26 :	3.1322	80.89
0 27 :	1.0796	68.95
0 28 :	6.5716	276.91
0 29 :	8.560799	390.58
0 30 :	9.080849	409.75
0 31 :	6.385	152.39

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= IGT
.376	.016		
.382	-.012		
.383	.023		
.41	-.006		
1.1	-.651		
1.142	-.735		
1.856	-.915		
2.05	-.97		
2.118	-1.183		
2.354	.778		
2.434	.963		
2.754	-1.219		
2.786	-1.358		
3.482	.302		
4.178	2.207		
4.371	1.056		
4.484	.956		
4.925	1.387		
5.699	-.985		
5.712	.906		
5.775	-.981		
5.78	1.354		
5.793	.696		
5.803	.996		
6.977	.38		
7.059	-.246		
7.355	-.784		
9.579001	.641		
9.595	.743		
10.255	-1.694		
10.744	-1.663		

SUM OF RESIDUALS = 0

LOG MODEL FOR FILE - B:SUNG01
VARIABLES = SHEF (IND.) AND IGT (DEP.)

INTERCEPT = -3.935457
SLOPE = 1.843469
R-SQUARE = .6620755
PEARSON'S R = .8136803

STANDARD ERROR OF ESTIMATE = 1.903274
SIGNIFICANCE OF EQUATION: F = 56.81799 WITH 1, 29 D.F.
STANDARD ERROR OF SLOPE = .2445642

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 29 D.F.
1.843-T(.245) < B < 1.843+T(.245)

SUMMARY STATISTICS SHEF (IND.), IGT (DEP.)

SUMX = 140.8823 SUMY = 137.7129 N = 31

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 60.564 SUMY^2= 310.871 SUMXY= 111.648

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	205.8203	1	205.8203
ERROR	105.0511	29	3.62245
TOTAL	310.8714	30	********

SIMPLE LINEAR MODEL FOR FILE - B:SUNG01
VARIABLES = SHEF (IND.) AND IGT (DEP.)

INTERCEPT = .2906428
SLOPE = 2.551217E-02
R-SQUARE = .898995
PEARSON'S R = .9481534

STANDARD ERROR OF ESTIMATE = 1.04055
SIGNIFICANCE OF EQUATION: F = 258.1145 WITH 1, 29 D.F.
STANDARD ERROR OF SLOPE = 1.587966E-03

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 29 D.F.
.026-T(.002) < B < .026+T(.002)

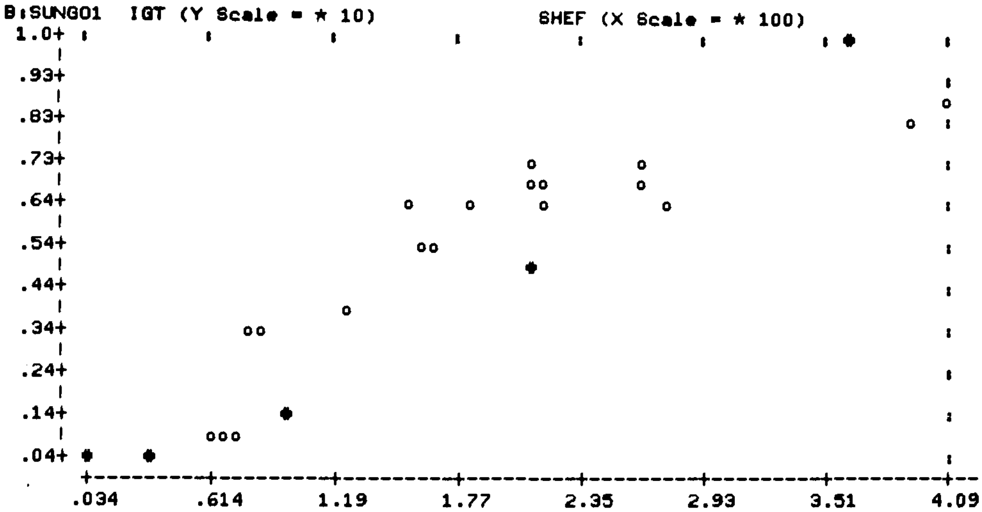
SUMMARY STATISTICS SHEF (IND.), IGT (DEP.)

SUMX = 5044.77 SUMY = 137.7129 N = 31

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 429381.5 SUMY^2= 310.871 SUMXY= 10954.45

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	279.4718	1	279.4718
ERROR	31.39957	29	1.082744
TOTAL	310.8714	30	*********


B:SUNG01 IGT (Y Scale = * 10)
SHEF (X Scale = * 100)
1.0+
.93+
.83+
.73+
.64+
.54+
.44+
.34+
.24+
.14+
.04+
.034
.614
1.19
1.77
2.35
2.93
3.51
4.09

POWER MODEL FOR FILE - B:SUNG01
VARIABLES = SHEF (IND.) AND IGT (DEP.)

INTERCEPT = 9.196898E-02
SLOPE = .7497075
R-SQUARE = .8281486
PEARSON'S R = .9100267

STANDARD ERROR OF ESTIMATE = .4935415
SIGNIFICANCE OF EQUATION: F = 139.7504 WITH 1, 29 D.F.
STANDARD ERROR OF SLOPE = 6.341841E-02

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 29 D.F.
.75-T(.063) < B < .75+T(.063)

SUMMARY STATISTICS SHEF (IND.), IGT (DEP.)

SUMX = 140.8823 SUMY = 31.64508 N = 31

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 60.564 SUMY^2= 41.105 SUMXY= 45.405

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	34.04084	1	34.04084
ERROR	7.063912	29	.2435832
TOTAL	41.10475	30	********

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= IGT
-1.707	2.099		
-1.574	1.945		
-1.559	1.965		
-1.086	1.491		
2.437	-1.988		
2.531	-2.124		
3.653	-2.713		
3.869	-2.789		
3.939	-3.003		
4.163	-1.031		
4.233	-.835		
4.49	-2.954		
4.513	-3.086		
4.967	-1.183		
5.331	1.054		
5.42	.007		
5.47	-.03		
5.655	.658		
5.939	-1.225		
5.944	.674		
5.965	-1.17		
5.966	1.167		
5.971	.518		
5.974	.825		
6.33	1.027		
6.353	.46		
6.432	.14		
6.936	3.283		
6.939	3.399		
7.066	1.495		
7.154	1.927		

SUM OF RESIDUALS = 0

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= IGT
.707	-.315		
.709	-.338		
.709	-.303		
.716	-.311		
.902	-.453		
.915	-.508		
1.163	-.223		
1.242	-.162		
1.27	-.335		
1.375	1.757		
1.413	1.985		
1.573	-.038		
1.59	-.163		
2.01	1.774		
2.54	3.845		
2.709	2.717		
2.815	2.626		
3.265	3.048		
4.235	.479		
4.253	2.365		
4.345	.45		
4.351	2.782		
4.37	2.119		
4.386	2.413		
6.507	.85		
6.689	.124		
7.39	-.818		
15.605	-5.386		
15.694	-5.356		
19.591	-11.03		
23.092	-14.011		

SUM OF RESIDUALS = -10.4179

EXPONENTIAL MODEL FOR FILE - B:SUNG01
VARIABLES = SHEF (IND.) AND IGT (DEP.)

INTERCEPT = .6872959
SLOPE = 8.577158E-03
R-SQUARE = .7684896
PEARSON'S R = .8766354

STANDARD ERROR OF ESTIMATE = .5728386
SIGNIFICANCE OF EQUATION: F = 96.26432 WITH 1, 29 D.F.
STANDARD ERROR OF SLOPE = 8.741998E-04

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 29 D.F.
8.999999E-03-T(.001) < B < 8.999999E-03+T(.001)

SUMMARY STATISTICS SHEF (IND.), IGT (DEP.)

SUMX = 5044.769 SUMY = 31.64508 N = 31

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 429381.4 SUMY^2= 41.105 SUMXY= 3682.872

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	31.58857	1	31.58857
ERROR	9.516178	29	.3281441
TOTAL	41.10475	30	********

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= IGT
.228	.165		
.24	.131		
.242	.164		
.293	.111		
1.228	-.779		
1.276	-.869		
2.014	-1.073		
2.198	-1.118		
2.261	-1.326		
2.477	.655		
2.549	.849		
2.829	-1.294		
2.857	-1.429		
3.435	.348		
3.983	2.402		
4.13	1.296		
4.216	1.225		
4.544	1.769		
5.101	-.387		
5.111	1.507		
5.155	-.361		
5.158	1.975		
5.168	1.321		
5.175	1.624		
5.981	1.376		
6.036	.777		
6.233	.339		
7.652	2.568		
7.662	2.676		
8.066	.495		
8.361	.72		

SUM OF RESIDUALS = 15.8541

APPENDIX C

21 SAMPLES

LINEAR: Y=A+BX
A= -0.5683
B= 0.8123
R-SQ= 0.7571

X= 0.4491
Y-CALC= -0.2034
Y-OBS= 0.0000

X= 4.7946
Y-CALC= 3.3266
Y-OBS= 1.3500

X= 0.4070
Y-CALC= -0.2376
Y-OBS= 0.0000

X= 4.7140
Y-CALC= 3.2611
Y-OBS= 2.0000

X= 0.4058
Y-CALC= -0.2386
Y-OBS= 0 0000

X= 6.4886
Y-CALC= 4.7027
Y-OBS= 1 6800

X= 0.4043
Y-CALC= -0.2398
Y-OBS= 0.0000

X= 6.7990
Y-CALC= 4.9549
Y-OBS= 3.1900

X= 5.4261
Y-CALC= 3.8396
Y-OBS= 4.9400

X= 5.4406
Y-CALC= 3.8514
Y-OBS= 5.4100

X= 0.3708
Y-CALC= -0.2679
Y-OBS= 0.0000

X= 7.1333
Y-CALC= 5.2264
Y-OBS= 3.5400

X= 0.3922
Y-CALC= -0.2497
Y-OBS= 0.0000

X= 6.6175
Y-CALC= 4.8074
Y-OBS= 3.1700

X= 6.8130
Y-CALC= 4.9662
Y-OBS= 5.5000

X= 7.3570
Y-CALC= 5.4082
Y-OBS= 7.3300

X= 1.4276
Y-CALC= 0.5914
Y-OBS= 0.6000

X= 1.5351
Y-CALC= 0.6788
Y-OBS= 0.6000

X= 10.2195
Y-CALC= 7.7335
Y-OBS= 8.3900

X= 3.3978
Y-CALC= 2.1919
Y-OBS= 3.2900

X= 8.5608
Y-CALC= 6.3861
Y-OBS= 9.5600

STD ERR 1.5074

```
Y=A+BX+CX*X
A=          -0.0590
B=           0.3173
C=           0.0574
R-SQ=        0.7825
STD ERR      1.4654

X=           0.4491
Y-CALC=      0.0951
Y-OBS=       0.0000

X=           4.7946
Y-CALC=      2.7821
Y-OBS=       1.3500

X=           0.4070
Y-CALC=      0.0796
Y-OBS=       0.0000

X=           4.7140
Y-CALC=      2.7125
Y-OBS=       2.0000

X=           0.4058
Y-CALC=      0.0792
Y-OBS=       0.0000

X=           6.4896
Y-CALC=      4.4170
Y-OBS=       1.6800

X=           0.4043
Y-CALC=      0.0787
Y-OBS=       0.0000

X=           6.7990
Y-CALC=      4.7523
Y-OBS=       3.1300

X=           5.4261
Y-CALC=      3.3531
Y-OBS=       4.9400

X=           5.4406
Y-CALC=      3.3667
Y-OBS=       5.4100

X=           0.3708
Y-CALC=      0.0665
Y-OBS=       0.0000

X=           7.1333
Y-CALC=      5.1258
Y-OBS=       3.5400

X=           0.3922
Y-CALC=      0.0743
Y-OBS=       0.0000

X=           6.6175
Y-CALC=      4.5549
Y-OBS=       3.1700

X=           6.8130
Y-CALC=      4.7677
Y-OBS=       5.5000

X=           7.3570
Y-CALC=      5.3829
Y-OBS=       7.3300

X=           1.4276
Y-CALC=      0.5110
Y-OBS=       0.6000

X=           1.5351
Y-CALC=      0.5633
Y-OBS=       0.6060

X=          10.2195
Y-CALC=      9.1800
Y-OBS=       8.3900

X=           3.3978
Y-CALC=      1.6819
Y-OBS=       3.2900

X=           8.5608
Y-CALC=      6.8651
Y-OBS=       9.5600
```

```
21.0000 SAMPLES

DEGREE           1

A=          -0.5683
B=           0.8123

X-OBS        0.4491
Y-CALC      -0.2034
Y-OBS        0.0000

X-OBS        4.7946
Y-CALC       3.3266
Y-OBS        1.3500

X-OBS        0.4070
Y-CALC      -0.2376
Y-OBS        0.0000

X-OBS        4.7140
Y-CALC       3.2611
Y-OBS        2.0000

X-OBS        0.4058
Y-CALC      -0.2386
Y-OBS        0.0000

X-OBS        6.4836
Y-CALC       4.7027
Y-OBS        1.6800

X-OBS        0.4043
Y-CALC      -0.2398
Y-OBS        0.0000

X-OBS        6.7990
Y-CALC       4.9549
Y-OBS        3.1300

X-OBS        5.4261
Y-CALC       3.8396
Y-OBS        4.9400

X-OBS        5.4406
Y-CALC       3.8514
Y-OBS        5.4100

X-OBS        0.3708
Y-CALC      -0.2670
Y-OBS        0.0000

X-OBS        7.1333
Y-CALC       5.2264
Y-OBS        3.5400

X-OBS        0.3922
Y-CALC      -0.2497
Y-OBS        0.0000

X-OBS        6.6175
Y-CALC       4.8074
Y-OBS        3.1700

X-OBS        6.8130
Y-CALC       4.9662
Y-OBS        5.5000

X-OBS        7.3570
Y-CALC       5.4082
Y-OBS        7.3300

X-OBS        1.4276
Y-CALC       0.5914
Y-OBS        0.6000

X-OBS        1.5351
Y-CALC       0.6788
Y-OBS        0.6000

X-OBS       10.2195
Y-CALC       7.7335
Y-OBS        8.3900

X-OBS        3.3978
Y-CALC       2.1919
Y-OBS        3.2900

X-OBS        8.5608
Y-CALC       6.3861
Y-OBS        9.5600

R-SQ=        0.7571
STD ERR=     1.5074
```

POLYNOMIAL REGRESSIONS

DEGREE	2
A=	-0.0590
B=	0.3173
C=	0.0574

X-OBS	0.4491
Y-CALC	0.0951
Y-OBS	0.0000
X-OBS	4.7946
Y-CALC	2.7821
Y-OBS	1.3500
X-OBS	0.4070
Y-CALC	0.0796
Y-OBS	0.0000
X-OBS	4.7140
Y-CALC	2.7125
Y-OBS	2.0000
X-OBS	0.4058
Y-CALC	0.0792
Y-OBS	0.0000
X-OBS	6.4886
Y-CALC	4.4170
Y-OBS	1.6800
X-OBS	0.4043
Y-CALC	0.0787
Y-OBS	0.0000
X-OBS	6.7990
Y-CALC	4.7523
Y-OBS	3.1300
X-OBS	5.4261
Y-CALC	3.3531
Y-OBS	4.9400
X-OBS	5.4406
Y-CALC	3.3667
Y-OBS	5.4100
X-OBS	0.3708
Y-CALC	0.0665
Y-OBS	0.0000
X-OBS	7.1333
Y-CALC	5.1258
Y-OBS	3.5400
X-OBS	0.3922
Y-CALC	0.0743
Y-OBS	0.0000
X-OBS	6.6175
Y-CALC	4.5549
Y-OBS	3.1700
X-OBS	6.8130
Y-CALC	4.7677
Y-OBS	5.5000
X-OBS	7.3570
Y-CALC	5.3829
Y-OBS	7.3300
X-OBS	1.4276
Y-CALC	0.5110
Y-OBS	0.6000
X-OBS	1.5351
Y-CALC	0.5633
Y-OBS	0.6000
X-OBS	10.2195
Y-CALC	9.1800
Y-OBS	8.3900
X-OBS	3.3978
Y-CALC	1.6819
Y-OBS	3.2900
X-OBS	8.5608
Y-CALC	6.8651
Y-OBS	9.5600

R-SQ=	0.7825
STD ERR=	1.4654

```
21.0000 SAMPLES

DEGREE            1

A=          -0.5054
B=           0.0219

X-OBS       31.7200
Y-CALC       0.1882
Y-OBS        0.0000

X-OBS      214.9600
Y-CALC       4.1959
Y-OBS        1.3500

X-OBS       33.3800
Y-CALC       0.2245
Y-OBS        0.0000

X-OBS      211.9900
Y-CALC       4.1305
Y-OBS        2.0000

X-OBS        3.6300
Y-CALC      -0.4261
Y-OBS        0.0000

X-OBS      215.6600
Y-CALC       4.2107
Y-OBS        1.6800

X-OBS        4.6900
Y-CALC      -0.4029
Y-OBS        0.0000

X-OBS      216.0800
Y-CALC       4.2199
Y-OBS        3.1300

X-OBS      159.9200
Y-CALC       2.9913
Y-OBS        4.9400

X-OBS      164.3800
Y-CALC       3.0893
Y-OBS        5.4100

X-OBS        3.6000
Y-CALC      -0.4267
Y-OBS        0.0000

X-OBS      215.1500
Y-CALC       4.1996
Y-OBS        3.5400

X-OBS        3.3500
Y-CALC      -0.4322
Y-OBS        0.0000

X-OBS      212.4900
Y-CALC       4.1414
Y-OBS        3.1700

X-OBS      265.2900
Y-CALC       5.2961
Y-OBS        5.5000

X-OBS      262.0800
Y-CALC       5.2259
Y-OBS        7.3300

X-OBS       97.8100
Y-CALC       1.6335
Y-OBS        0.6000

X-OBS       96.5600
Y-CALC       1.6062
Y-OBS        0.6000

X-OBS      364.0600
Y-CALC       7.4560
Y-OBS        8.3900

X-OBS       84.0300
Y-CALC       1.3322
Y-OBS        3.2900

X-OBS      390.5800
Y-CALC       8.0360
Y-OBS        9.5600

R-SQ=        0.7459
STD ERR=     1.5418
```

POLYNOMIAL
REGRESSIONS

DEGREE	2
A=	0.0638
B=	9.204 -03
C=	3.743 -05
X-OBS	31.7200
Y-CALC	0.3934
Y-OBS	0.0000
X-OBS	214.9800
Y-CALC	3.7726
Y-OBS	1.3500
X-OBS	33.3800
Y-CALC	0.4127
Y-OBS	0.0000
X-OBS	211.9900
Y-CALC	3.6972
Y-OBS	2.0000
X-OBS	3.6300
Y-CALC	0.0977
Y-OBS	0.0000
X-OBS	215.6600
Y-CALC	3.7898
Y-OBS	1.6800
X-OBS	4.6900
Y-CALC	0.1078
Y-OBS	0.0000
X-OBS	216.0800
Y-CALC	3.8004
Y-OBS	3.1300
X-OBS	159.9200
Y-CALC	2.4931
Y-OBS	4.9400
X-OBS	164.3800
Y-CALC	2.5882
Y-OBS	5.4100
X-OBS	3.6000
Y-CALC	0.0974
Y-OBS	0.0000
X-OBS	215.1500
Y-CALC	3.7769
Y-OBS	3.5400
X-OBS	3.3500
Y-CALC	0.0950
Y-OBS	0.0000
X-OBS	212.4900
Y-CALC	3.7098
Y-OBS	3.1700
X-OBS	265.2900
Y-CALC	5.1401
Y-OBS	5.5000
X-OBS	262.0800
Y-CALC	5.0472
Y-OBS	7.3300
X-OBS	97.8100
Y-CALC	1.3222
Y-OBS	0.6000
X-OBS	96.5600
Y-CALC	1.3016
Y-OBS	0.6000
X-OBS	364.0600
Y-CALC	8.3762
Y-OBS	8.3900
X-OBS	84.0300
Y-CALC	1.1015
Y-OBS	3.2900
X-OBS	390.5800
Y-CALC	9.3694
Y-OBS	9.5600
R-SQ=	0.7778
STD ERR=	1.4812

FILE: B:SUNG1

VAR:	IGT	SHEF	CELL
0 1 :	.4491	31.72	.000001
0 2 :	4.7946	214.98	1.35
0 3 :	.407	33.38	.000001
0 4 :	4.714	211.99	2
0 5 :	.4058	3.63	.000001
0 6 :	6.4886	215.66	1.68
0 7 :	.4043	4.69	.000001
0 8 :	6.799	216.08	3.13
0 9 :	5.4261	159.92	4.94
0 10 :	5.4406	164.38	5.41
0 11 :	.3708	3.6	.000001
0 12 :	7.1333	215.15	3.54
0 13 :	.3922	3.35	.000001
0 14 :	6.6175	212.49	3.17
0 15 :	6.813	265.29	5.5
0 16 :	7.357001	262.08	7.33
0 17 :	1.4276	97.81	.6
0 18 :	1.5351	96.56	.6
0 19 :	10.2195	364.06	8.389999
0 20 :	3.3978	84.03	3.29

FILE: B:SUNG1

VAR:	IGT	SHEF	CELL
0 21 :	8.560799	390.58	9.560001

SIMPLE LINEAR MODEL FOR FILE - B:SUNG1
VARIABLES = IGT (IND.) AND CELL (DEP.)

INTERCEPT = -.5682635
SLOPE = .8123449
R-SQUARE = .7571419
PEARSON'S R = .8701389

STANDARD ERROR OF ESTIMATE = 1.50737
SIGNIFICANCE OF EQUATION: F = 59.23498 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = .1055483

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
.812-T(.106) < B < .812+T(.106)

SUMMARY STATISTICS IGT (IND.), CELL (DEP.)

SUMX = 89.15369 SUMY = 60.49001 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 203.956 SUMY^2= 177.763 SUMXY= 165.683

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	134.5916	1	134.5916
ERROR	43.17111	19	2.272164
TOTAL	177.7627	20	********

YHAT VALUES	RESIDUALS	IND= IGT	DEP= CELL
-.267	.267		
-.25	.25		
-.24	.24		
-.239	.239		
-.238	.238		
-.203	.203		
.591	8.999999E-03		
.679	-.079		
2.192	1.098		
3.261	-1.261		
3.327	-1.977		
3.84	1.1		
3.851	1.559		
4.703	-3.023		
4.807	-1.637		
4.955	-1.825		
4.966	.534		
5.226	-1.686		
5.408	1.922		
6.386	3.174		
7.733	.657		

SUM OF RESIDUALS = 0

LOG MODEL FOR FILE - B:SUNG1
VARIABLES = SHEF (IND.) AND CELL (DEP.)

INTERCEPT = -2.624047
SLOPE = 1.266493
R-SQUARE = .4823152
PEARSON'S R = .6944891

STANDARD ERROR OF ESTIMATE = 2.200778
SIGNIFICANCE OF EQUATION: F = 17.70187 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = .3010184

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
1.266-T(.301) < B < 1.266+T(.301)

SUMMARY STATISTICS SHEF (IND.), CELL (DEP.)

SUMX = 91.27177 SUMY = 60.49001 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 53.452 SUMY^2= 177.763 SUMXY= 67.697

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	85.73763	1	85.73763
ERROR	92.02503	19	4.843423
TOTAL	177.7627	20	********

YHAT VALUES	RESIDUALS	IND= IGT	DEP= CELL
-.629	.629		
-.526	.526		
-.47	.47		
-.463	.463		
-.457	.457		
-.276	.276		
1.859	-1.259		
1.993	-1.393		
3.459	-.169		
4.063	-2.063		
4.094	-2.744		
4.323	.617		
4.328	1.082		
4.653	-2.973		
4.689	-1.519		
4.739	-1.609		
4.743	.757		
4.828	-1.288		
4.885	2.445		
5.164	4.396		
5.491	2.899		

SUM OF RESIDUALS = 0

POWER MODEL FOR FILE - B:SUNG1
VARIABLES = IGT (IND.) AND CELL (DEP.)

INTERCEPT = 3.678341E-04
SLOPE = 5.223206
R-SQUARE = .9116351
PEARSON'S R = .9547958

STANDARD ERROR OF ESTIMATE = 2.118369
SIGNIFICANCE OF EQUATION: F = 196.0175 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = .3730695

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
5.223-T(.373) < B < 5.223+T(.373)

SUMMARY STATISTICS IGT (IND.), CELL (DEP.)

SUMX = 19.10313 SUMY = -66.28591 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 32.242 SUMY^2= 964.888 SUMXY= 168.407

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	879.6257	1	879.6257
ERROR	85.26221	19	4.487485
TOTAL	964.8879	20	********

YHAT VALUES	RESIDUALS	IND= IGT	DEP= CELL
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
.002	.598		
.003	.597		
.219	3.071		
1.21	.79		
1.322	.028		
2.524	2.416		
2.559	2.851		
6.422	-4.742		
7.117	-3.947		
8.198	-5.068		
8.286	-2.786		
10.533	-6.993		
12.377	-5.047		
27.313	-17.753		
68.883	-60.493		

SUM OF RESIDUALS = -96.4788

EXPONENTIAL MODEL FOR FILE - B:SUNG1
VARIABLES = IGT (IND.) AND CELL (DEP.)

INTERCEPT = 2.004363E-05
SLOPE = 1.804565
R-SQUARE = .6883435
PEARSON'S R = .8296647

STANDARD ERROR OF ESTIMATE = 3.97832
SIGNIFICANCE OF EQUATION: F = 41.96456 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = .278568

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
1.805-T(.279) < B < 1.805+T(.279)

SUMMARY STATISTICS IGT (IND.), CELL (DEP.)

SUMX = 89.15369 SUMY = -66.28591 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 203.956 SUMY^2= 964.888 SUMXY= 368.052

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	664.1743	1	664.1743
ERROR	300.7136	19	15.82703
TOTAL	964.8879	20	********

YHAT VALUES RESIDUALS IND= IGT DEP= CELL

YHAT VALUES	RESIDUALS
0	0
0	0
0	0
0	0
0	0
0	0
0	.6
0	.6
8.999999E-03	3.281
.099	1.901
.115	1.235
.358	4.582
.368	5.042
2.439	-.759
3.077	.093
4.27	-1.14
4.379	1.121
7.806	-4.266
11.688	-4.358
102.608	-93.04799
2047.053	-2038.662

SUM OF RESIDUALS = -2123.782

SIMPLE LINEAR MODEL FOR FILE - B:SUNG1
VARIABLES = SHEF (IND.) AND CELL (DEP.)

INTERCEPT = -.5054343
SLOPE = 2.186857E-02
R-SQUARE = .7459179
PEARSON'S R = .8636653

STANDARD ERROR OF ESTIMATE = 1.541809
SIGNIFICANCE OF EQUATION: F = 55.77897 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = 2.928095E-03

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
.022-T(.003) < B < .022+T(.003)

SUMMARY STATISTICS SHEF (IND.), CELL (DEP.)

SUMX = 3251.431 SUMY = 60.49001 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 277262.3 SUMY^2= 177.763 SUMXY= 6063.33

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	132.5964	1	132.5964
ERROR	45.16632	19	2.377175
TOTAL	177.7627	20	********

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= CELL
-.432	.432		
-.427	.427		
-.426	.426		
-.403	.403		
.188	-.188		
.225	-.225		
1.332	1.958		
1.606	-1.006		
1.634	-1.034		
2.992	1.948		
3.089	2.321		
4.13	-2.13		
4.141	-.971		
4.196	-2.846		
4.2	-.66		
4.211	-2.531		
4.22	-1.09		
5.226	2.104		
5.296	.204		
7.456	.934		
8.036	1.524		

SUM OF RESIDUALS = 0

LOG MODEL FOR FILE - B:SUNG1
VARIABLES = SHEF (IND.) AND CELL (DEP.)

INTERCEPT = -2.624047
SLOPE = 1.266493
R-SQUARE = .4823152
PEARSON'S R = .6944891

STANDARD ERROR OF ESTIMATE = 2.200778
SIGNIFICANCE OF EQUATION: F = 17.70187 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = .3010184

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
1.266-T(.301) < B < 1.266+T(.301)

SUMMARY STATISTICS SHEF (IND.), CELL (DEP.)

SUMX = 91.27177 SUMY = 60.49001 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 53.452 SUMY^2= 177.763 SUMXY= 67.697

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	85.73763	1	85.73763
ERROR	92.02503	19	4.843423
TOTAL	177.7627	20	********

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= CELL
-1.093	1.093		
-1.002	1.002		
-.991	.991		
-.667	.667		
1.754	-1.754		
1.819	-1.819		
2.988	.302		
3.164	-2.564		
3.18	-2.58		
3.803	1.137		
3.838	1.572		
4.16	-2.16		
4.163	-.993		
4.178	-2.828		
4.179	-.639		
4.182	-2.502		
4.184	-1.054		
4.429	2.901		
4.444	1.056		
4.845	3.545		
4.934	4.626		

SUM OF RESIDUALS = 0

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POWER MODEL FOR  FILE - B:SUNG1
VARIABLES = SHEF (IND.) AND CELL (DEP.)

INTERCEPT    =  1.705981E-09
SLOPE        =  3.918909
R-SQUARE     =  .8507848
PEARSON'S R  =  .92238

STANDARD ERROR OF ESTIMATE     =  2.752759
SIGNIFICANCE OF EQUATION:  F  =  108.3329 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE        =  .3765174

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
      3.919-T( .377) < B <  3.919+T( .377)
------------------------------------------------------------------

        SUMMARY STATISTICS    SHEF (IND.), CELL (DEP.)
------------------------------------------------------------------
SUMX   =  91.27177    SUMY   = -66.28591    N     =  21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2=  53.452       SUMY^2=  964.888      SUMXY=  209.475

------------------------------------------------------------------
                A N O V A    T A B L E
                     SS            D.F.            MS
------------------------------------------------------------------
REGRESSION          820.912        1             820.912
ERROR               143.976        19             7.577682
TOTAL               964.8879       20            ********
```

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= CELL
0	0		
0	0		
0	0		
0	0		
.001	-.001		
.002	-.002		
.059	3.231		
.102	.498		
.108	.492		
.739	4.201		
.824	4.586		
2.231	-.231		
2.252	.918		
2.357	-1.007		
2.365	1.175		
2.387	-.707		
2.405	.725		
5.124	2.206		
5.374	.126		
18.577	-10.187		
24.471	-14.911		

SUM OF RESIDUALS = -8.8886

EXPONENTIAL MODEL FOR FILE - B:SUNG1
VARIABLES = SHEF (IND.) AND CELL (DEP.)

INTERCEPT = 2.390207E-05
SLOPE = 4.834383E-02
R-SQUARE = .6715771
PEARSON'S R = .819498

STANDARD ERROR OF ESTIMATE = 4.08393
SIGNIFICANCE OF EQUATION: F = 38.85225 WITH 1, 19 D.F.
STANDARD ERROR OF SLOPE = 7.755914E-03

CONFIDENCE INTERVAL FOR SLOPE BASED ON T-STAT. W/ 19 D.F.
.048-T(.008) < B < .048+T(.008)

SUMMARY STATISTICS SHEF (IND.), CELL (DEP.)

SUMX = 3251.43 SUMY = -66.28591 N = 21

CORRECTED (for mean) SUM OF SQUARES AND CROSS PRODUCT
SUMX^2= 277262.2 SUMY^2= 964.888 SUMXY= 13403.92

A N O V A T A B L E

	SS	D.F.	MS
REGRESSION	647.9966	1	647.9966
ERROR	316.8912	19	16.67849
TOTAL	964.8879	20	********

YHAT VALUES	RESIDUALS	IND= SHEF	DEP= CELL
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
.001	3.289		
.003	.597		
.003	.597		
.054	4.886		
.068	5.342		
.675	1.325		
.691	2.479		
.78	.57		
.786	2.754		
.806	.874		
.822	2.308		
7.602	-.272		
8.878	-3.378		
1052.057	-1043.667		
3791.762	-3782.202		

SUM OF RESIDUALS = -4804.5