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A Study of how coated paper's roughness, gloss and absorptivity affect on side and print gloss

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A STUDY OF HOW COATED PAPER'S ROUGHNESS, GLOSS AND ABSORPTIVITY AFFECT ON SID AND PRINT GLOSS

by

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A thesis submitted in partial fullfillment of the requirements for the degree of Master of Science in the School of Printing Management and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

March, 1991

Thesis Advisor: Mr. Chester Daniels

Certificate of Approval -- Master's Thesis

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

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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
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Title of thesis: A Study of How Coated Paper's Roughness, Gloss and Ink Absorption Affect SID and Print Gloss

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Abstract

The effect and relationship of paper roughness, gloss and ink absorption on printed solid ink density and print gloss are investigated. Eight kinds of gloss coated paper are selected to represent the high and low levels of paper roughness, gloss and ink absorbency in a factorial experiement. The responses are solid ink density and printed gloss. The values of SID and print gloss are produced in the laboratory by means of a duplicator and a little Joe offset proving press. The papers that were collected were measured for paper thickness, grammage, paper roughness, gloss, K&N ink absorption density, printed SID and print gloss. The measurements are made at random points on the paper samples. The printed SID and print gloss on the gloss coated papers depend mainly on Parker-Print-Surf (PPS) roughness, K&N ink absorption, paper gloss and ink film thickness. Variations of PPS roughness, K&N ink absorption, paper gloss, physical and laboratory test printing results are used to understand the effect and the relationship on printed SID and print gloss. The results of these measurements are plotted graphically to demonstrate correlation; values of paper characteristics are shown on the abscissa,

and printed SID and print gloss as ordinates. Flint heatset ink was used on the duplicator to generate printed SID and print gloss. The inks used for the Little Joe offset proving press to produce printed SID and print gloss are Dainippon magenta linseed oil ink and Morrison quickset process black ink. Linseed oil ink has a tack value of fourteen.

Based on the results and analyses, it was found that K&N ink absorption may be said to produce a partially significant effect on printed SID. Paper roughness and gloss have a less significant effect on print SID. However, paper roughness has a significant effect on print gloss. K&N ink absorption and paper gloss are shown to have a fewer significant effect on print gloss. In addition, Preucil's PSE theory failed to predict printed SID and print gloss well for gloss coated papers. An alternative equation is suggested.

CHAPTER ONE

INTRODUCTION

1.1 Research Motivation

There is little doubt that certain paper surface characteristics will have an effect on print quality and printability. According to the Technical Association of the Pulp and Paper Industry (TAPPI) and the Scandinavian Standard (SCAN), paper properties can be characterized into four categories: optical, physical, mechanical and chemical. Optical properties include color, brightness, opacity and gloss. Physical properties include roughness/smoothness, permeability, stiffness, wettability, ink absorption, surface strength etc. Mechanical properties are primarily related to folding endurance, tearing strength, tensile strength, bursting strength and rub resistance. Chemical properties are concerned with resistance to weather, light, heat or specific chemicals etc. Print quality is a function of ink/press/fountain solution as well as the four paper properties outlined above.

This thesis will attempt to determine the existence of a functional relationship between the paper variables affecting lithographic print density and print gloss, and rank the paper variables which have impact on lithographic print quality. In this study the mechanical and chemical properties will not be examined.

1.2 Purpose and Significance

Once the printer and papermaker thoroughly understand the major factors of the paper surface that affect print quality or tone reproduction, the papermaker should be in a position to supply paper of optimal quality that satisfies the needs of printers. The printers would be in a position to take advantage of these factors to facilitate the job and to improve tone reproduction.

The need for a better understanding of print quality and printability of paper has existed in the paper and printing industry for many years. There are however a number of professional reports or standards that define or explain print quality and print quality index by means of print density, set off, and print through.[1,2,3] According to the author's study and experience in print quality of paper and many of the published reports that have been reviewed, only some of the fundamental variables that affect print quality have been explored. The functional relationship between surface properties of paper and print quality has not been well defined. Thus the major objective of this thesis is to compare and analyze by using descriptive statistics to denote the primary paper surface variables that

affect lithographic print density and print gloss. There is linear relationship between print density and paper surface variables as well as print gloss and paper surface variables will be investigated.

1.3 Scope

Paper is manufactured in a variety of apparent grades of "quality". These can be described as cast-coated paper, pigment-coated paper, matte, uncoated paper, art paper, newspaper and specialty paper etc.. These different papers have different surface properties, printability and runnability. Pigment-coated papers are mostly used for commercial printing including magazines, catalogs and annual reports.

Thanks to coating that improves appearance, surface uniformity and ink receptivity for gloss coated papers. Uncoated paper and matte are thought to be better suited for book printing. In order to acheive high quality of print, a printer should understand there is not a particular paper type which is suitable for all printing conditions. Further, the fact that the "fit-for-use" criteria changes among various types of printing, a printer needs to differentiate the primary effects of paper properties on print quality.

FOOTNOTES FOR CHAPTER ONE

1. SCAN-P 36:77, Evaluation of Test Prints

2. Ian C. White, Quality Management in Canadian Government Printing, Tappi Conference, Printing and Reprography Testing, p.1-12, (1977).

3. Lars O. Larrson, Physical Background of Some Terms Used to Describe Print Quality, The Swedish Newsprint Research Center, Stockholm, Sweden, p114-119.

CHAPTER TWO

REVIEW OF LITERATURE

"The appearance and printability of pigment-coated papers are highly dependent on the degree of surface smoothness and surface structure unifomity"[1]. Michael H. Bruno and W.C. Walker[2] state "Printability is not a single property of paper. Instead, it is a broad, general term referring to all the properties of a paper that contribute to printed matter of good quality". GATF[3] defines print quality "the degree to which the appearance and other properties of a print approach the desired result." In general, offset papers need to have strong surface strength to avoid picking problems during printing. Because no matter how glossy or smooth the paper is, if paper has picking problems during printing, usually the printer will ask the paper agent to replace or discount the cost of the order. Therefore, paper surface strength is one of the most important concerns for paper manufacturers. Any further exploration of paper variables affecting print density and print gloss is based on pigment-coated paper free from picking problems. Otherwise, such an exploration will not be fruitful.

2.1 General Approach

The following paper properties are generally considered to be important factors that affect the lithographic printing process.[4,5,6]

1. Structural Properties:
   --basis weight
   --caliper
   --density/bulk
   --moisture content
   --compressibility
   --fiber formation/oil absorption

2. Surface Properties:
   --smoothness/roughness
   --porosity
   --surface strength/dry strength/wet strength
   --dust/speck

3. Optical Properties:
   --color
   --brightness
   --gloss
   --opacity

4. Chemical Properties:
   --surface sizing
   --ash content
   --acidity and pH

2.2 Methods of Measurement

Using the following methods for primary paper properties measurement:[7]

Property	Method	Standard
1. Thickness	using a micrometer under $0.5 kg/cm^2$	Tappi-411
2. Basis weight		Tappi-410
3. Roughness	Parker-Print-Surf tester	ISO
4. Smoothness	Bekk smoothness tester	Tappi-479
5. Compressibility	the ratio roughness changes at 10 kgf and 20 kgf	paper industry
6. Ink absorption	Croda Ink or K&N Testing Ink	"
7. Gloss	Specular glossmeter	Tappi-480
8. Optical density	X-Rite 418 densitometer	ANSI PH2.18

2.3 Dry Pick and Wet Pick Resistance

Water or fountain solution in the offset lithographic printing process can contribute significantly to paper surface failure problems.[8] The water may weaken the surface and penetrate into the paper fibers and destroy fiber bonding.

In multicolor offset printing the so called "wet pick" test is very important. The second and subsequent colors are applied to stock that has been exposed to a film of moisture from the nonprinting areas of the blanket. The wet pick resistance of the moistened area of pigment-coated papers can become significantly lower than dry pick resistance of unmoistened area of pigment-coated papers.[9] In other words, wet picking problems are more likely to happen than dry picking problems during multicolor offset printing.

There are many printing variables which can influence paper surfaces in the printing process. These printing variables are the following:

1. Ink tack, viscosity, temperature.
2. Press speed, nip width, pressroom temperature and relative humidity.
3. Paper moisture content.
4. Specific paper properties, interfiber bonding, wettability, roughness.
5. Ratio of image to nonimage area.
6. Press design and operation---levels of dampening and ink application and compressibility of the press blanket.

2.4 Why Are Optical Solid Ink Density and Print Gloss Important?

In evaluating print quaity, the uniformity of print density and print gloss can be judged by the naked eye without using a densitometer or glossmeter. End users and printers using visual assessment usually pay more attention to uniform ink coverage and image gloss. Any variation in the optical print density and print gloss of images can be detected. Solid print uniformity and even print gloss are crucial aspects of print quality. Print density effects are not only limited to solids, but also extend to the line and halftone areas. Precision and complete control of all printing variables and paper surface variables are crucial in print uniformity.[10]

FOOTNOTES FOR CHAPTER TWO

1. R.L. Van Gilder, R.D. Purfeerst, Tappi Coating Conference p.45, (1986).

2. Michael H. Bruno, W.C. Walker, PULP AND PAPER Chemistry and Chemical Technology, Vol. IV, p.2261, (1983)

3. GATF, What The Printer Should Know About Paper, p.286, (1983)

4. GATF, What The Printer Should Know About Paper, p37-129, (1986).

5. James. P. Casey, PULP AND PAPER Chemistry and Chemical Technology, p.1715-1972, Vol.3, (1983).

6. Lars C. Ingman, Tappi Annual Meeting, p.131-132, (1988).

7. TAPPI Standard

8. Tappi, Paper Surface Strength, (1983).

9. S.W.P. Wyszkowski, Printability Testing: A Critical Review, Tappi Conference, p.53-63, (1979).

10. Consulted Mr. Chester Daneils, and Mr. Chin-yih Chen, Senior Technologist, Paper and Ink Laboratory at RIT T&E Center, Aug. (1990).

CHAPTER THREE

THERORETICAL BASIS OF THE STUDY

3.1. Optical Properties of Paper

The optical properties of paper are sometimes more critical for the sale of paper than the physical and mechanical properties. The appearance of paper is the result of its optical properties. Morever, most printers and paper merchants buy or sell paper on the basis of the color, brightness, gloss, and evaluate paper quality visually rather than testing in the lab.

Basically, the Kubelka-Munk[1,2] theory is very useful for predicting optical properties of papers. This theory is based on the assumption that the interaction between diffuse light and the material can be described in terms of two fundamental optical constants: the specific scattering coefficient (S) and the specific absorption coefficient (K). K is the limiting value of the absorption of light energy per unit thickness as the thickness becomes very small; and S is the limiting value of light energy scattered backward per unit of thickness as the thickness becomes very small. Although the Kubelka-Munk theory

holds strictly for homogeneous sheets only, it works quite well for sheets containing up to ten percent filler. The Kubelka-Munk equation can be expressed as follows for diffuse light:

$$R = 1 + K/S - [2K/S + (K/S)^2]^{1/2}$$

There are many paper manufacturing parameters which have a profound effect on the optical properties of the finished paper including the following:

1. type of pulp used in the paper machine
   ---semichemical pulp
   ---ground pulp
   ---bleached chemical thermal mechanical pulp etc..
2. freeness of pulp/degree of refining
3. bleaching methods
   ---oxygen bleaching
   ---chlorine dioxide
   ---hydrogen and sodium peroxide
4. coating pigments
   ---binder/latex/starch/gum
   ---filler/kaolin clay/calcium carbonate/TiO_2

3.2 Brightness

Brightness is a fundamental optical property of paper. The brightness of paper is influenced by many factors including the amount and kind of filler, fluoresence, degree of bleaching and coating colors etc. Tappi T452 om-87 is a standard technique for the determination of the brightness of white, near-white paper and paperboard. Brightness is the numerical value of the reflectance of paper at 457nm (Blue light reflectance).[3]

Pigment-coated paper (glossy paper) has a higher brightness than uncoated paper. The brightness of newsprint is not as important as pigment-coated printing paper partly due to the end use requirement of these products. The method to determine the brightness of paper requires a reflectometer applying 45^{o} illumination.[4]

Brightness testing of paper requires the sample to be prepared in accordance with Tappi T400 "Sampling and Accepting A Single Lot of Paper, Paperboard...". In short, all samples in the experiment will be tested at 23^{o} C +/- 1.0^{o} C (73.4^{o} +/- 1.8^{o} F) and 50.0% +/- 2.0% relative humidity condition.

3.3 Opacity

Opacity is another important optical property of paper. High opacity is desirable in printing because low opacity paper produces a defect referred to as show-through. Show-through is a severe defect of print quality usually resulting in rejection by printers or end-users. As a rule, the higher the opacity of paper, the lower the possibility of show-through. However, paper opacity is also affected by its caliper and physical density. Generally, the thicker the paper, the lower the show-through. Usually, the opacity of paper is required to be 93% or higher for commercial printing. There are many factors affecting opacity of paper, these include the type of filler (TiO_2, $CaCO_3$, Clay), coat weight and degree of fiber refining. It has been proven that low opacity is a major factor causing show-through. Therefore, paying attention to paper opacity not only is a concern of the printer but also a concern of the paper manufacturer.

One of the measurements of paper opacity is the so called "contrast ratio" method. Contrast ratio is obtained from the ratio of the reflectance of the sample with the black and white backing of 89% absolute reflectance respectively. Therefore this method is also called 89% reflectance backing. Another method is called "printing opacity". This is accomplished in the following manner: first, calibrate the opacity meter, then place the paper sample over the white backing. Place the measuring head on the

paper sample and set the reflection reading to 100.0, then move the paper sample to standard black backing. The meter reading gives opacity value of 100 R_o/R_∞ . The opacity measurement of paper samples is proceeded in accordance with Tappi T425 om-81.[5]

In the lab, these two different methods will yield a very similar values for paper opacity. The value of contrast ratio and the value of printing opacity can be expressed as a percentage by multiplying the meter reading by 100. The peak wavelength of the green filter used in opacity testing is 572nm.[6]

3.4 Gloss

The gloss of pigment-coated paper far exceeds the gloss of both uncoated paper and newspaper. This is due to coating colors and coating formulations on the paper surface. The appearance and printability of pigment-coated paper are greatly dependent on the degree of surface macrosmoothness and surface structure uniformity. Better paper surface smoothness highly increases ink holdout and ink transfer during printing. In general, coating pigments are from 62% to 68% solid content. The degree of gloss is the dominant factor in the classification of matte, dull and art paper. Coated art paper has gloss values from 60% to 70%. Matte or dull has a gloss value from 15% to 25%. Uncoated paper or newspaper usually has gloss level lower than 15%.

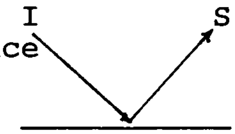
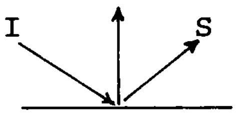
In commercial printing, high print gloss is considered one of the most desirable factors of print quality. Catalogs, annual reports require a glossy paper and this is thought to achieve color saturation, high resolution, integrated dot shape and good color rendition.

The experimental procedure for measuring specular gloss of paper is based on the Tappi T480 om-85 and T400 om-88 official test methods. The angle of incidence of this method for measuring coated and uncoated paper is 75.0° +/- 0.1°. When measuring paper gloss, the test values include both machine and cross direction for wire side and felt side. Directionality will generally affect the gloss values obtained. Normally, higher gloss values will be obtained when the machine direction of the paper is parallel to the long axis of the instrument. Conversely, if the machine direction is perpendicular to the long axis of the instrument, lower gloss value can be expected.[7]

3.4.1 Three Criteria for Gloss

Hunter stated six types of gloss, but only three of them are applicable in the paper and graphic arts industry. These are specular gloss, sheen, and contrast gloss.[8] These are tabulated as follows:

Tabulation of Three Criteria for Gloss[9]

Type of gloss	Perceptual Appearance Aspect	Reflectance Function	Classes of Surface Involved
Specular Gloss	Shininess, brilliance of hightlights		Medium-gloss surfaces of paint, plastics
Sheen	Shininess at grazing angles		Low-gloss surfaces of paper, paints etc.
Contrast gloss	Contrast between specularly reflecting areas and other areas		Low gloss surfaces of paints, textile, cloth.

I: incidence
S: specular reflection

3.4.2 Glossmeter Optical Schematic Diagram[10]

T480 Glossmeter
Optical Schematic

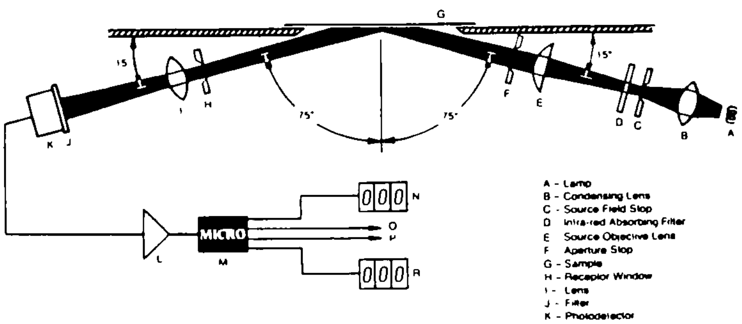


Fig. 1

3.5 Color

It is unusual for printers to buy white papers based on paper color. Usually, paper is sold on the basis of its appearance, basis weight or its grade rather than color. Therefore, the expression of paper color is not as common as brightness. Brightness is expressed by reflectance, but color is expressed by Hunter L,a,b, or by CIE 1976 $L^*a^*b^*$, or by CIE X,Y,Z tristimulus values. In general, "white or near-white paper, Y value is greater than 64, and L value is greater than 80, or L^* greater than 84. On the average neither $(a^2 + b^2)^{1/2}$ nor $(a^{*2} + b^{*2})^{1/2}$ should exceed 10."[11]

In the lab or printing shop, papermakers and printers are not accustomed to expressing the brightness of paper by means of colorimetry; colorimetry is usually utilized in distinguishing color difference of color reproduction. The concept of paper color is more complex than paper brightness.

3.6 Physical Properties of Paper

According to the TAPPI and the Scandinavian Standard, paper has more than twenty physical properties. Not all physical properties of paper will affect print quality. The primary physical properties of paper affecting print quaity are grammage, caliper, surface smoothness, ink absorption, surface strength, moisture content, porosity, wettability, bulk, dimensional stability, compressibility and two-sidedness.

3.7 Testing of Physical Properties of Paper

3.7.1 Grammage

Weight is the most commonly measured characteristic of paper. Paper weight is expressed as grams per square meter in the metric system and is termed grammage. In the English system it is termed basis weight and is expressed as pounds per ream. A ream is 500 sheets and has several different standard sizes based on apparent end use (News, business form etc.). The proper procedure for measuring paper grammage is described in the TAPPI Standard T410 om-88---Grammage of Paper and Paperboard (Weight Per Unit Area).

Weight affects all physical properties and many of the optical and mechanical properties of paper. Uniformity in weight is important. Variations in weight can cause misregister when paper is printed.[12,13]

3.7.2 Thickness

Standardized ways of measuring the paper thickness are described in SCAN[14] and TAPPI[15]. Paper thickness is defined as the distance between the felt side and the wire side of the sheet under a specified pressure. SCAN Standard uses a pressure of 1.00 kg/cm^2. TAPPI uses a pressure of 0.50 kg/cm^2. Paper is compressible, a difference in pressure can yield a small difference in thickness. Therefore, the expression for paper density will be affected by the technique employed for measuring paper thickness.

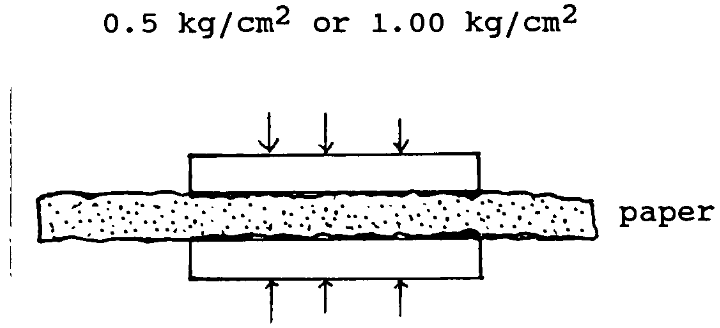


Fig.2 Principle of standard methods for determination of paper thickness

3.7.3. Importance of Surface Smoothness:

Surface smoothness or levelness of surface structure is one of the most significant physical properties of paper. Smoothness is related to the surface contour of paper and it is increased by calendering. Paper gloss is increased by calendering, but smoothness and gloss are not the same. There are many different approaches and apparatus used to evaluate surface smoothness. These include the use of instruments such as Bekk, Bendtsen, Sheffield, Gurley and the Parker-Print-Surf (PPS) roughness tester. All these instruments are based on the air-leak principle. Another approach to evaluate the macrosmoothness or macroroughness of paper surface is a scanning electronic microscope (SEM). This optical instrument can help us measure tiny and intricate fiber formation, dispersion and regularity of the paper surface. The microphotographic technique for measuring smoothness, however is very subjective, and depends on the assessment and judgment of the operator. Air-leak smoothness testing generates a numerical value in a short period of time and this accounts to a great extent for the popularity of this technique.

Many printers believe that a high level of smoothness is required for lithography and gravure. Irregularity and nonuniformity of the paper surface will cause poor coverage of printing ink, resulting in speckle in solid areas and/or blotchy appearance of the halftone dot areas. These defects are not acceptable to printers or end users. Moreover, print gloss of the image is also influenced by paper smoothness. When rough paper has irregular absorption of printing ink, there also is a nonuniformity of print gloss. Print gloss is a very important visible attribute of print quality. Paper with excessive wire marks or paper which is lumpy, wavy, fuzzy and rough is regarded to have contour defects. These would be expected to decrease print quality or the printability of paper. Do paper smoothness and paper gloss and print gloss have any correlationship? The answer should be investigated further, and is a key point in this thesis.

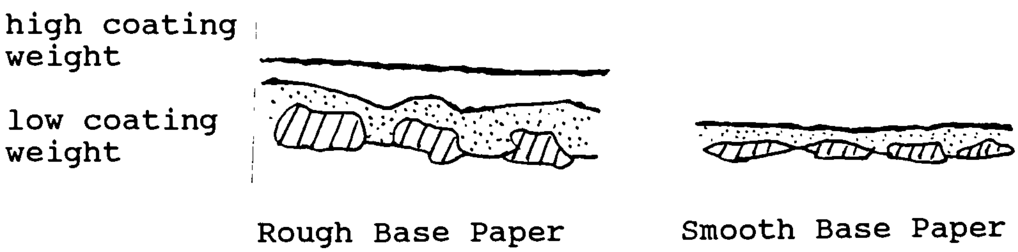
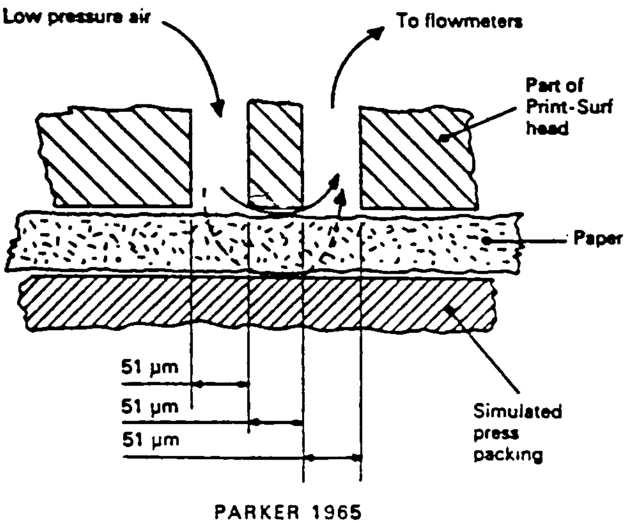


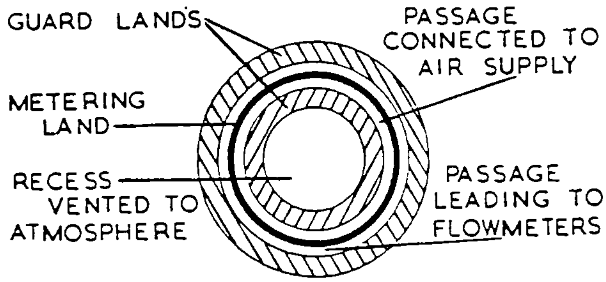
Fig.3 Paper Topography

3.7.4 Types of Air-leak Smoothness Instrument [16,17,18,19]

	PPS	Bekk	Bendtsen	Sheffield	Gurley
Unit	micron	sec/10cc	min/100cc	cc/min	---
Coated	1.0~1.8	400~2000	500~200	20~100	---
Matte	2.0~3.5	100~400	200~60	100~150	---
Uncoated	3.5~6.5	10~100	60~10	150~300	---
Who use	World wide	American Government	Europe	America	
Clamping pressure	5, 10 20 kgf	1.0 kgf	1, 5 kgf	1 kgf	0.21 kgf
Measuring area	$10cm^2$	$10cm^2$	$0.25mm^2$	$14.45cm^2$	$6.45\ cm^2$
Standard	ISO	Tappi-479	SCAN-P 21:67	UM-518	
Deformable backing	yes	yes	no	no	no

3.7.5 Parker Print-Surf Schematic Diagram[20]





Bekk Smoothness Test Schematic Diagram[21]

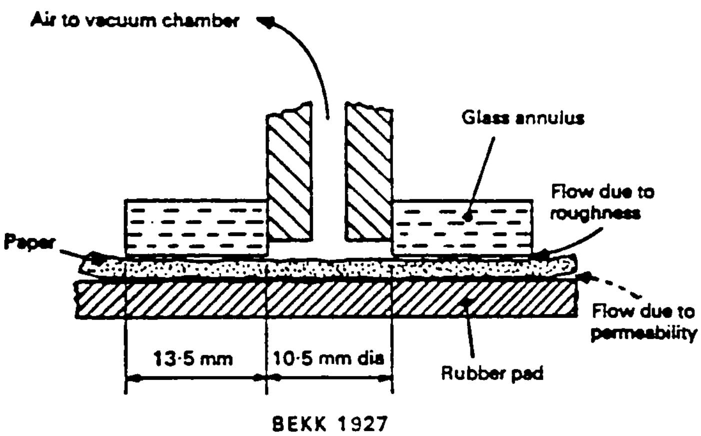


Fig.4 Schematic diagram of air-leak smoothness tester

3.7.6 Factors Affecting Paper Smoothness

There are a number of factors that affect surface smoothness of raw stock. Raw stock is the base for pigment-coated printing paper. The contour of pigment-coated paper smoothness is strongly influenced by several paper manufacturing variables including:

1. types of pulp used
2. freeness of pulp/beating/refining
3. type of wire and felts in fourdrinier
4. internal sizing
5. types, shapes and particle size of filler
6. fiber length/fiber coarseness
7. moisture content
8. calendering process
9. press section configuration

Most printing papers considered to be of top quality are pigment-coated and are calendered to increase their smoothness. Surface sizing improves surface smoothness as well. In general, surface smoothness of pigment-coated printing paper is not only influenced by the coating color but also by the coating weight and the calendering process.

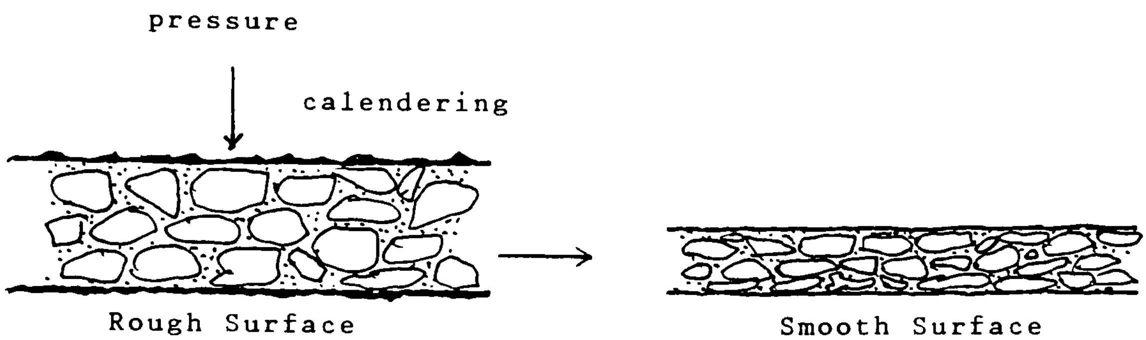


Fig.5 Calendering improves surface smoothness

3.7.7 Smoothness Affecting Print Quality

Smoothness affects almost all the attributes of visible print quality including solid density, ink coverage, print gloss, evenness of halftone, image sharpness, contrast, and color saturation. It is believed that present air-leak methods for measuring smoothness do not completely correlate with actual print quality in the printing plant. This belief is based on two major reasons: (1) Paper is compressible and its smoothness increases under pressure, therefore, the property of smoothness should be determined under appropriate compression. Some air-leak methods that measure the paper surface under low compression, may provide misleading results. Due to this, most printers are interested in printing smoothness under the pressure of the printing form rather than the smoothness of the paper which is under normal unstressed conditions. (2). Present air-leak methods do not measure microstructure of paper surfaces. This is another drawback in understanding fiber formation, coarseness and dispersion.

In general, smoothness is greatly affected by pressure. Increasing the pressure at the time of testing, tends to increase the levelness and uniformity of paper surfaces.[22] Figure 6 and 7 provide some graphic expression of the effect of pressure on smoothness.[23]

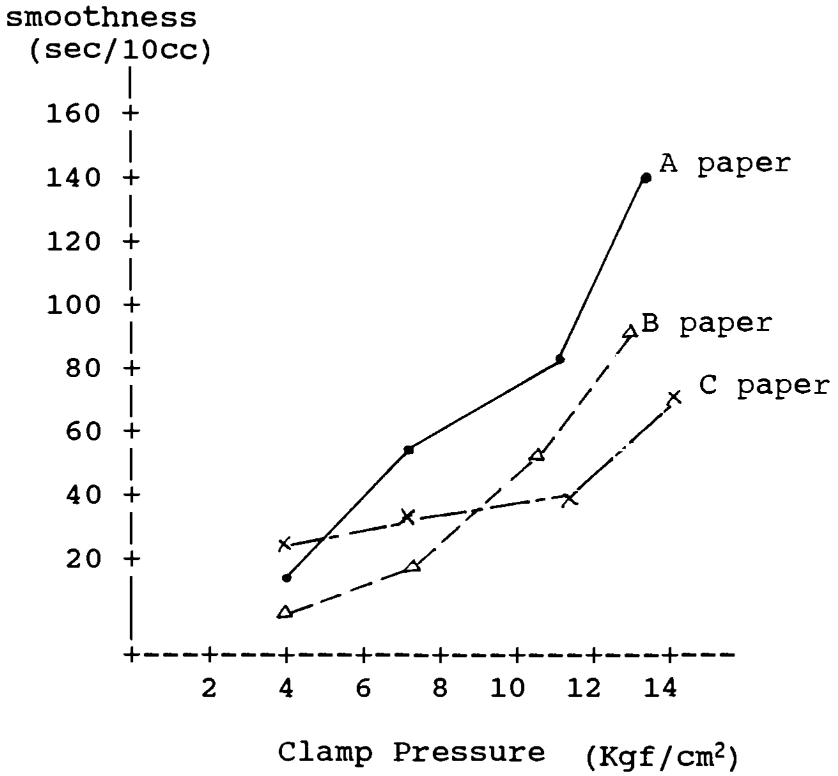


Fig.6 The effect of pressure on smoothness of paper

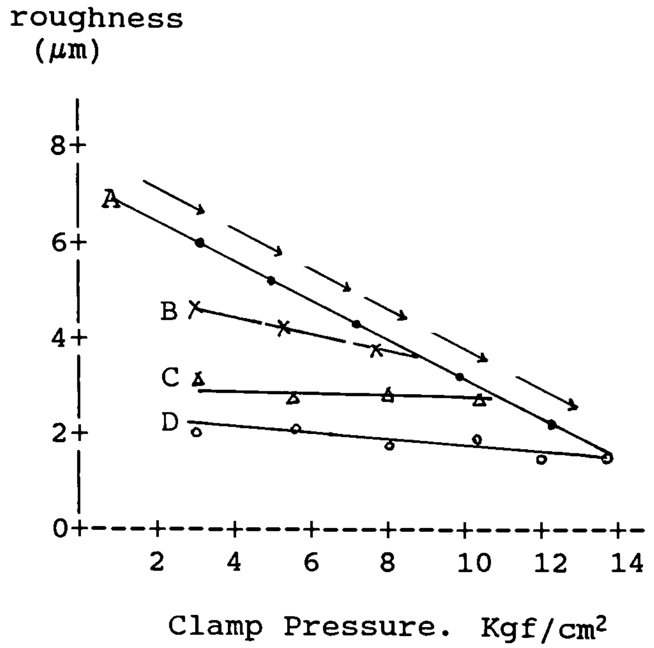


Fig.7 Roughness of paper is decreased by adding pressure on reference plane. Roughness = f (pressure) "All papers will reach perfect printing smoothness if the printing pressure is great enough."[24]

A, B, C, D represents different paper.

3.7.8 Air Flow Measurements of Paper Roughness

In practice, paper roughness is commonly determined by measuring the air flow between the paper surface and a reference plane under specified conditions. As stated previously, the Bekk, Sheffield, Bendtsen, and Parker-Print-Surf (PPS) being the best known instruments in this category. Certainly, the first three are used to express the roughness of paper in air resistance (min/ml) or air flow (ml/min) units, but the Parker-Print-Surf instrument goes a step further and provides a value for the roughness R in μm of the surface from the reference plane, calculated according to a relationship derived by Parker[25]

$$R = k \cdot Q^{1/3}$$

where Q is the air-flow rate or discharge under the PPS metal annulus ($\mu m^3 s^{-1}$).

R is the PPS roughness (μm).

k is a constant related to the instrument configuration.

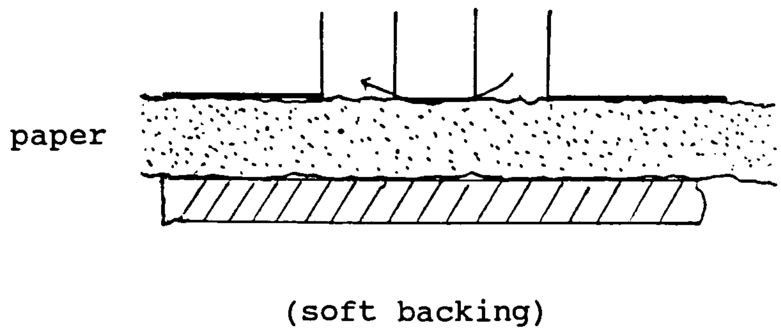


Fig. 8 PPS roughness test uses soft backing for measuring sheetfed pigment-coated paper

3.7.9 Significance and Measurement of Surface Compressibility

The measurement of the thickness and density of paper is complicated by the fact that the surface is not smooth, therefore, some corrections need to be made for the roughness. The measurement of roughness is complicated by the fact that the surface is compressible. The roughness decreases under the pressure which is applied when a reference plane is brought into contact with the surface, so that some attention must also be given to the magnitude of the compressibility if the structure and its properties are to be fully understood.

The compressibility of the surface is very important for the behavior of paper in the nip of the printing press and for the response of the paper to a calendering operation and it is therefore somewhat surprising that not much quantitative attention has been paid to this property or to its significance. Usually printers do not pay much attention to the property of the paper surface compressibility which is simply determined by the bulk of the network.

The basic concept of surface compressiblity may be expressed by the equation[26,27]

$$\text{Compressibility} = \frac{\text{Roughness at 10 kg/cm}^2}{\text{Roughness at 20 kg/cm}^2} \text{ (for offset)-----(1)}$$

However, J. Anthony Bristow and Petter Kolseth[28,29] use the following equation to define paper compressibility. "This report refers solely to measurements made with a Parker-Print-Surf(PPS) instrument."[30]

$$Kc = -\frac{R2 - R1}{P2 - P1} \text{ (slope of range)} \text{------------------} (2)$$
$$= - f(P)$$

Where the compressibility Kc of the surface is defined as the change in surface roughness R resulting from a change in the pressure P applied to the surface.

P1: pressure of 10 kgf
P2: pressure of 20 kgf
R1: roughness at the pressure of 10 kgf
R2: roughness at the pressure of 20 kgf

The surface compressibility coefficient Kc defined in Equation (2) is not necessarily a constant but may be a function of the applied pressure."[31,32]

3.8 Ink-Stain Test to Understand Ink Absorption of Paper

There are many well known ink-stain testing inks used in the lab and paper mill for quality control purposes.[33] The most famous of these are K & N Ink, Croda Red Ink and Lorrileux Porometriquex Black Ink. Croda and Porometriquex testing ink are non-drying oils that produce a dark opaque stain. K & N testing ink is a non-drying oil with a lighter stain.

Usually, rough and bulky paper surface will have higher ink absorption, which is apt to produce a rough and uneven ink film. On the other hand, higher absorption is easily associated with many printing problems such as print through, unsatisfactory ink holdout, mottle etc.

The primary purpose of ink-stain test of coated paper is to allow prediction of the possibility of mottling. Paper with uneven ink absorption is more likely to produce mottle that causes unacceptable variation in print density and print gloss. This is not the goal of printing .

Basically, the mechanism of ink absorption is to let K&N ink penetrate into the fiber of paper, but the mechanism of print is to let the process ink adhere or sit on the paper surface. There is a certain degree of difference between these two mechanisms.

Mottling is a severe printing problem. There are many different experiments to explain the factors that cause mottle. Using an optical approach. H. Fujiwara and N. Fujisaki[34] demonstrate "Water that penetrates the base stock affects the surface binder concentration, which in turn induces mottling." P.A.C. Gane[35] says "Mottle is caused by inhomogenities of the surface structure." "Inhomogenity of the coated surface caused by differential point-to-point binder migration or concentration is thought to result in water interference and secondary mottling in multi-station offset press." As stated above, mottling is related to uneven paper surface absorption with printing ink or fountain solution. Therefore, even ink absorption becomes a primary characteristic of print quality for pigment-coated paper.

3.8.1 Experimental Procedure of Ink Absorption Test

1. Apply a very thick film of Croda Red Ink or K&N Ink to the paper surface and allow it to absorb for two minutes.

2. Wipe the excess of ink from the paper surface with a ink knife and clean tissue.

3. Study the appearance of this stain by observing intensity and uniformity of the stain that remains.

4. Measure the optical density or reflectance of the stained area.

3.9 Optical Print Density and Print Gloss

Print quality is not only influenced by the printability of paper, but is also affected by ink and the performance of the printing press. Generally, most printers attribute printing problems to the papermaker instead of the ink maker or themselves. For example, printers blame drying problems on slow ink absorption and roughness of paper but do not consider the fact that the ink film may be too thick. Mottling problems probably result from binder migration of the coating layer of paper because of water interference but the effect of the fountain solution is often ignored. Picking problems are due to weak surface strength but the printer may also be using an unreasonably high tack of ink. In general, visual assessment of a printing problem from the viewpoint of printers is associated with variation of optical print density and print gloss. On the other hand, print efficiency, dot gain, hue error, percentage of trapping, set off and print through are important print quality criteria. Many of these however are not obvious to the naked eye. Therefore, uniform optical print density and even print gloss become significant parameters for print quality.

3.10 Print Quality

Everyone has his or her opinions of acceptable print quality. Some people like glossy prints, some people don't. Some people prefer bright and saturated color, some people don't. It seems that many of the criteria for good print quality are psychophysical and individual. As for good quality of prints, people almost will completely agree in a sense. Asian and American may have different color performance, but there is little difference in opinion of print quality. Of course, good print quality has its necesary properties.

3.10.1 Viewpoints of Measuring Print Quality from GATF[36]

1. Solid Density
2. Trapping
3. Print Gloss
4. Plate Exposure
5. Slur
6. Doubling
7. Dot Gain
8. Hue Error/Grayness
9. Gray Balance
10. Print Contrast
11. Register
12. Hickies or spots in print

3.10.2 Viewpoints of Measuring Print Quality from Japan Tappi[37]

1. Paper Formation
2. Evenness of Paper Thickness
3. Surface Smoothness
4. Surface Strength
5. Dimensional Stability
6. Bulk
7. Brightness
8. Gloss
9. Opacity
10. Two-sidedness
11. Ink Receptivity
12. Dot Shape
13. Dot/Tone Rendition/Tone Gradation
14. Print Gloss
15. Evenness of Gloss and Optical Density

3.10.3 D.J. Andella's Viewpoints on Print Quality[38]

1. Uniformity of Formation
2. Smoothness
3. Ink Receptivity
4. High Surface Strength
5. Uniformity in Thickness
6. High Opacity
7. High Brightness
8. Good Color
9. Resiliency
10. Balanced Moisture Content
11. High Degree of Permanence

FOOTNOTES FOR CHAPTER THREE

1. James, J. Casey, Pulp and Paper, p.1858-1859, (1983).
2. J. Anthony Bristow, Paper Structure and Properties, p.207-208, (1983).
3. Tappi Standard, T452 om-87, Brightness of Pulp, Paper and Paperboard (Directional Reflectance 457 nm).
4. Ibid
5. Tappi Standard, T425 om-81, Opacity of Paper (15°/Diffuse Illuminant A, 89% Reflectance Backing and Paper Backing)
6. Tappi Standard, T425 om-81
7. Technidyne T-480 Glossmeter Manual, p.9.
8. James, J. Casey, Pulp and Paper, p.1823, (1983).
9. Ibid
10. Technidyne T480 Glossmeter Manual
11. Tappi Standard, T524 om-86, Color of White and Near-White Paper and Paperboard by L,a,b, 45°, 0° Colorimetry.
12. James. P. Casey. Pulp and Paper, Chemistry and Chemical Technology. Vol 3. p.1743, (1981).
13. J. Anthony Bristow, Paper Structure and Properties, p.124, (1983).
14. Scandinavian Pulp, Paper and Board Testing Committee. Standard SCAN-P7:75, Thickness and apparent density.
15. TAPPI T411 om-83. Thickness (Caliper) of Paper and Paperboard

16. J.F. LaFaye, JP. Maume, G. Gervason, P. Piette, Some Aspects of Coating with Surfactants upon Quality and Offset Printability, Tappi Coating Conference, p.107-115, (1987).

17. J.F. LaFaye, JP. Maume, J.M. Schwob, R. Chiodi, The Effect of Some Coating Variables on Gravure Print Quality Using LWC Paper, Tappi Journal, p.63-69, Dec. (1988).

18. R.H. Crotogino, Supercalendered Conventionally Calendered Newsprint--A Comparison of Surface and Printing Properties, Tappi Printing & Reprography Conference, p.89-93 (1980)

19. J.R. Parker, Fundamental and Practical Aspects of Air Leak Roughness Measurement with Particular Reference to the Parker-Print-Surf Roughness Tester, Tappi Printing & Reprography Conference, p.71, (1980).

20. J.R. Parker, Bowater Technical Services Ltd. England, Tappi Printing & Reprography Conference, p.65-72, (1980).

21. Japan Paper and Pulp Technology Times, B/M Seminar, p.59, Oct. (1989)

22. James. P. Casey, Pulp and Paper, p.1761, (1983).

23. J.Anthony Bristow, Peter Kolseth, Paper Structure and Properties, p.179, (1983)

24. J.H. Bardsley and L.J. Marin, Paper Ind., 29(3), P.438-440, (1947)

25. J. R. Parker. An air leak instrument to measure printing roughness of paper and board. Pap. Technol. 6:126-130 (1965)

26. Parker-Print-Surf Roughness Tester Manual.

27. a letter for Authur I. Lowell, Sun Chemical Corp. June, (1989).

28. J. Anthony Bristow, Petter Kolseth, Paper Structure and Properties, p.174-181, (1983)

29. J. Anthony Bristow, The Surface Compressibility of Paper--A Printability Property, Advances in Printing Science and Technology, p.373-383, (1980)

30. Ibid.

31. Ibid.

32. Conculted Mr. Chester Daniels and Mr. Ching-yih Chen, Senior Technologist, Paper and Ink Laboratory at the RIT T&E Center, September, (1990)

33. Anthony Bristow and Hanss Begenblad, STFI, Interpretations of Ink-Stain Tests on Coated Papers, p.373-391, (A report from Mr. Chester Daniels, RIT T&E Center).

34. H. Fujiwara, N. Fujisaki, I. Shimizu, I. Kano, Tappi Journal, The Effect of Water Penetration on Offset Mottling, p.91-97, (May 1989).

35. P.A.C. Gane ECC Internation Convertex 88, Mottle and the Influence of Coating and Binder Migration, p.34-41, April (1989).

36. GATF Print Quality Survey, (1989).

37. Japan Tappi Journal, May (1989).

38. D.J. Andella, Tappi, 123A-128A (1952),

CHAPTER FOUR

STATEMENT OF PROBLEM

4.1 Statement of the Problem:

1. What is the relationship between the paper properties that are expected to be critical to printed SID and print gloss? Which property is the most significant factor to affect solid ink density and print gloss?

2. Is gloss coated paper with low ink absorption better than gloss coated paper with high ink absorption for printed SID or for print gloss?

3. Paper Surface Efficiency[1] (PSE) is a good approach for paper quality control, but paper smoothness/roughness is another important factor that affects tone reproduction. Should we regard paper smoothness/roughness as a factor that should be used to fine tune PSE?

4.2 Hypotheses:

1. There is no significant effect due to paper gloss on printed SID or print gloss.

2. There is no significant effect due to ink absorption on printed SID or print gloss.

3. There is no significant effect due to paper roughness on printed SID or print gloss.

4. There is no interaction of paper roughness, gloss, and ink absorption on printed SID or print gloss.

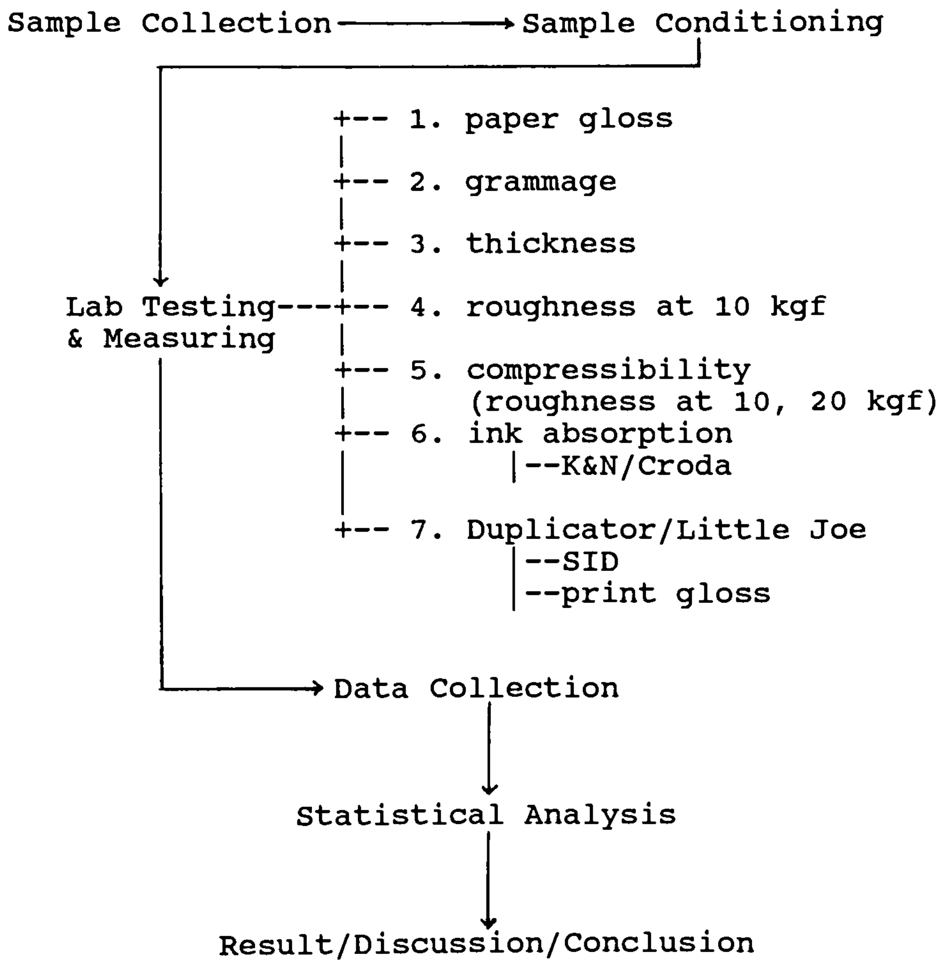
FOOTNOTES FOR THE CHAPTER FOUR

1. Frank. M. Preucil, A New Method of Rating the Efficiency of Paper for Color Reproduction, GATF Research Progress General Memo #8, 1963

CHAPTER FIVE

METHODOLOGY

5.1. Experimental Flow Chart



5.2 Experimental Design:

Two-level Three-factor Experimental Design

		Gloss Coated Paper			
		Paper Gloss < 65% L		Paper Gloss > 65% H	
		K&N Ink Absorption Density		K&N Ink Absorption Density	
		< 0.06 L	> 0.06 H	< 0.06 L	> 0.06 H
Roughness < 1.1 μm	L	000	010	100	110
Roughness > 1.1 μm	H	001	011	101	111

"1" designates the high level of all three factors.
"0" designates the low level of all three factors.

Each factor is tested at each of two levels---high or low. In designating the treatment combination, we use the corresponding capital letter to indicate that treatment involving the high or low level of the factor.

Note: Gloss Coated Papers

	gloss %	Roughness μm	K&N ink absorption density
Low range	55.0 ~ 64.13	0.67 ~ 1.06	0.03 ~ 0.06
High range	66.4 ~ 74.9	1.12 ~ 1.37	0.065 ~ 0.12

The low K&N ink absorption density of gloss coated paper is between 0.03 and 0.06. (paper absorptivity is between 9.25% and 17.20%)
The high K&N ink absorption density of gloss coated paper is between 0.065 and 0.122. (paper absorptivity is between 18.53% and 34.26%)

5.2.1 Paper Sample

	E	F	G	I	K	L	M	P
Grammage g/m^2	100.9	100.9	99.2	101.0	105.2	114.5	100.9	103.5
Thickness 1/1000 inch	3.3	3.2	3.4	3.3	3.8	3.8	3.1	3.3
Paper Grade	#2	#3	#1	#3	#1	#1	#1	#2

5.2.2 Ink Used for Duplicator and Little Joe

a. Flint heat-set Bk ink for Duplicator
--ink tack value 8-10 (400 rpm, 90^{o} F)
--ink film thickness: 3 microns

b. Dainippon Magenta linseed oil and Morrison quickset Bk ink for Little Joe
--tack value of linseed is 14
--the scaled medal wedge is from 0 to 25μm

5.2.3 Lab Test Conditioning

a. Room Temperature: 23.0^{o} +/- 1^{o} C

b. Relative Humidity: 50.0% +/- 2.0% RH

5.3 Equipment & Instrument Used

5.3.1 Laboratory Testing

1. Reflectometer (for reflectance testing)
2. Glossmeter
3. Parker-Print-Surf Roughness tester
4. Basis Weight
5. Micrometer
6. Croda Red Ink or K & N Testing Ink
7. X-Rite Densitometer
8. Duplicator/Little Joe Offset Proving Press

5.3.2 Detailed Specification of Materials and Instruments Used

a. HunterLab Model D16 Multipurpose Glossmeter:

--75^{o} incidence angle

--The polished black glass standard is considered the primary calibration standard and is used to set the gloss measurement scale near 100%.

--All of the light being reflected from the black standard is specular.

b. Parker-Print-Surf 78 Roughness Tester:

--a modern instrument based on the air-leak principle, evolved by Dr. John Parker.

--clamping pressure is equivalent to printing pressures of approximately 5, 10, 20 kg/cm^2

--The instrument has a range from 0.6 to 9.6μm and will accommodate paper and board up to approximately 1mm in thickness.

--manufactured by H.E. MESSMER Co. England

c. K&N Ink:

--a non-drying ink consisting of a colored oil with a white pigment extender.

--manufactred by K&N Ink Corp.

d. Croda Ink:

--a non-drying red ink

--It yields an opaque stain and does not spread laterally.

--manufactured by Croda Chemical Co.

e. X-Rite 418 densitometer:

--Filter set ANSI Status T

--density accuracy and reproducibility to 0.01

f. Little Joe Offset Proving Press

--The blanket size is 7" across and 13.25" around the cylinder.

--Manufactured by Little Joe Color Swatcher Inc.

5.3.3 Procedure, Sampling and Test Specimens

a. Sampling and accepting a single lot of paper refers to Tappi T400 om-85

b. Grammage refers to Tappi T410 om-88

c. Thickness refers to Tappi T411 om-84

d. Paper gloss refers to Tappi T480 om-85

e. Paper roughness refers to ISO and PPS roughness manual

f. Ink absorption, paper gloss and roughness are measured only on the felt side of the papers.

g. Various kinds of paper sample are only printed on the one side by a duplicator or Little Joe offset proving press.

5.4 Statistical Analysis

Common Term	Significance
1. mean	arithmetic mean, μ for the population, $\bar{x}$ for a sample
2. standard error	degree of variation of measuring a sample dispersion
3. standard error of mean $s/n^{1/2}$	standard deviation divided by the square root of sample number
4. coefficient of variation (relative standard deviation) $s/\bar{x}$	standard deviation divided by mean
5. coefficient of determination	to determine the correlation of two samples, whether has linear regressional relationship
6. coefficient of correlation	to determine two samples how much they correlated
7. ANOVA analysis/F-test	to determine the difference of two populations whether significant or insignificant
8. degree of freedom	sample number minus one
9. confidence interval $\bar{x} +/- t_5 \cdot s/(n)^{1/2}$	a given dgree of probability, which includes an estimate value.

FOOTNOTES FOR CHAPTER FIVE

1. SCAN-G2:63 Statistcal Treatment of Test Results
2. James P. Casey, Pulp and Paper, III, P.1720-1724, (1983)

CHAPTER SIX

RESULTS AND ANALYSIS

Surface gloss and other physical properties of the paper used in this study are shown in Table 1. The resulting printed SID and print gloss are presented in Tables 2 & 3. These properties selected for this study were measured on one side of the gloss coated paper. Table 4-a to 8-c are the analysis of variance summary tables that are intended to show the effect of paper roughness, gloss and K&N ink absorption on printed SID and print gloss. An asterisk "*" indicates a significant effect at a confidence level of 95 percent. A summary of the F-ratios of printed SID and print gloss is shown in the Table 9 and Table 10. The author used a Little Joe offset proving press with Dainippon magenta linseed oil ink and Morrison quick-set process black ink to produce different ink film thicknesses on the paper samples including here for testing. These were measured for the resulting printed SID and print gloss. The author also used a duplicator printing with Flint heatset process black ink to present each paper sample with the same uniform ink film thickness. The correlation coefficient of paper roughness, gloss, ink

absorption, and PSE with printed SID is shown in Table 11. The correlation coefficient of paper roughness, gloss, ink absorption and PSE with print gloss is shown in Table 12. Table 16 shows the PSE of each tested sample.

Table 1. Summary of Paper Properties

Paper Property	Paper Sample							
	E	F	G	I	K	L	M	P
Basis Weight								
Mean lb.	68.09	66.97	70.80	68.20	71.02	77.27	68.29	69.55
Grammage								
Mean g/m^2	100.88	99.22	104.04	101.04	105.22	114.48	100.88	103.05
Thickness (1/1000')								
Mean	3.33	3.25	3.38	3.32	3.82	3.76	3.07	3.31
Std dev.	0.091	0.053	0.112	0.046	0.088	0.074	0.707	0.064
Coef. Var.	2.74	1.64	3.32	1.39	2.31	1.97	2.29	1.93
Roughness (10-S μm)								
Mean	1.12	0.98	1.06	1.00	1.37	1.32	0.67	1.35
Std dev.	0.019	0.018	0.096	0.098	0.083	0.062	0.025	0.036
Coef. Var.	1.77	1.86	9.06	9.81	6.05	4.73	3.85	2.69
K&N Ink Absorptivity								
Mean	16.40	19.85	9.25	15.86	34.26	18.53	29.36	17.20
Std dev.	1.25	0.00	1.00	1.44	3.08	1.41	1.09	0.00
Coef Var.	7.58	0.00	10.81	9.13	9.01	7.61	3.73	0.00
Paper Gloss								
Mean	71.65	58.86	74.93	64.13	58.48	66.37	68.01	55.00
Std dev.	3.32	1.33	3.50	2.02	3.25	2.86	1.80	2.05
Coef. Var.	4.64	2.26	4.68	3.15	5.55	4.31	2.65	3.91
Compressibility								
Mean	1.37	1.33	1.37	1.31	1.43	1.35	1.39	1.37
Std dev.	0.065	0.041	0.063	0.089	0.114	0.063	0.084	0.054
Coef. Var.	4.74	3.07	4.63	6.82	8.03	4.65	6.04	3.98
Croda Ink Absorption Density								
Mean	0.205	0.153	0.251	0.210	0.201	0.177	0.195	0.157
Std dev.	0.009	0.007	0.012	0.016	0.013	0.007	0.016	0.008
Coef. Var.	4.51	4.83	4.96	8.04	6.73	3.98	8.66	5.62

Table 2. Summary of Printed SID of Tested Samples

ink film thickness	Paper Sample							
	E	F	G	I	K	L	M	P
Duplicator Flint ink (unknown)	2.00	2.07	2.02	2.06	2.00	2.01	2.05	2.11
Little Joe Dainippon ink								
10μm	1.64	1.63	1.74	1.62	1.58	1.62	1.57	1.68
15μm	1.89	1.91	1.96	1.87	1.84	1.88	1.81	1.96
Little Joe Morrison ink								
7μm	1.97	2.01	1.98	1.95	1.95	1.97	1.98	2.02
10μm	2.23	2.28	2.23	2.20	2.23	2.26	2.25	2.25
15μm	2.31	2.37	2.32	2.29	2.32	2.36	2.32	2.36

Table 3. Summary of Print Gloss of Tested Samples

ink film thickness	Paper sample							
	E	F	G	I	K	L	M	P
Duplicator Flint ink (unknown)	72.99	80.13	80.60	81.50	77.15	80.31	79.34	79.78
Little Joe Dainippon ink								
5-10μm	68.93	76.65	75.53	76.78	69.13	72.70	71.90	72.58
10-15μm	68.65	77.23	73.43	76.48	67.68	71.18	70.40	75.83
15-20μm	67.57	78.98	74.03	76.18	66.73	74.23	67.90	75.38
Little Joe Morrison ink								
5-10μm	76.12	79.55	78.70	79.65	78.72	80.15	83.63	72.48
10-15μm	73.68	80.78	78.80	79.10	80.43	79.55	80.70	74.98
15-20μm	69.98	78.68	76.68	76.40	79.18	80.53	80.35	75.70

The analysis of variance results of this experiment is shown in Tables 4-a to 8-c and Table 9 (see the following pages), the interaction of paper roughness, gloss and K&N ink absorption has a significant effect on printed SID at a 95 percent confidence level. The number of significance tests is five out of six. Paper roughness, gloss, interaction of paper roughness and gloss, interacton of paper roughness and K&N, interaction of paper gloss and K&N has no significant effect on printed SID at a 95 percent confidence level. The number of significance tests of paper roughness is zero out of six. The number of significance tests of paper gloss is one out of six. Regardless of which approach was used to print the paper samples in different ink film thickness (5μm to 15μm), the paper roughness in a high-low range of 0.67μm to 1.37μm, gloss in a high-low range of 55% to 75% has no significant effect on printed SID, but K&N ink absorption density in a high-low range of 0.03 to 0.12 (paper absorptivity in a high-low range of 8.89% to 32.19%) has a significant effect on printed SID at a 95 percent confidence level. The number of significance tests is four out of six.

Table 4-a. Analysis of Variance Summary Table of Printed SID Using Duplicator with Flint Heatset Black Ink

Factors	Levels of Factors
A (roughness)	2
B (paper gloss)	2
C (K&N ink absorption)	2

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0030	1	0.0030	2.0461	
B	0.0102	1	0.0102	6.9177	*
C	0.0020	1	0.0020	1.3307	
AB	0.0005	1	0.0005	0.3598	
AC	0.0102	1	0.0102	6.9177	*
BC	0.0102	1	0.0102	6.9177	*
ABC	0.0043	1	0.0043	2.9148	
Error	0.0352	24	0.0015		
Total	0.0754	31			

Note: $F_{1,24,0.05} = 4.2597$

Table 4-b. Analysis of Variance Summary Table of Print Gloss Using Duplicator with Flint Heatset Black Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	63.4220	1	63.4220	42.7106	*
B	13.1970	1	16.1970	8.8873	*
C	1.9751	1	1.9751	1.3301	
AB	1.3001	1	1.3001	0.8755	
AC	27.4726	1	27.4726	18.5010	*
BC	47.4095	1	47.4095	31.9272	*
ABC	46.6820	1	46.6820	31.4378	*
Error	35.6381	24	1.4849		
Total	237.0962	31			

Table 5-a. Analysis of Variance Summary Table of Printed SID at 10μm Ink Film Thickness Using Little Joe with Dainippon Magenta Linseed Oil Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0010	1	0.0010	0.5664	
B	0.0015	1	0.0015	0.8462	
C	0.0364	1	0.0364	20.3916	*
AB	0.0018	1	0.0018	1.0070	
AC	0.0010	1	0.0010	0.5664	
BC	0.0036	1	0.0036	2.0210	
ABC	0.0364	1	0.0364	20.3916	*
Error	0.0429	24	0.0018		
Total	0.1247	31			

Table 5-b. Analysis of Variance Summary Table of Printed SID at 15μm Ink Film Thickness Using Little Joe with Dainippon Magenta Linseed Oil Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0004	1	0.0004	0.8789	
B	0.0005	1	0.0005	1.2276	
C	0.0294	1	0.0294	68.3462	*
AB	0.0003	1	0.0003	0.5884	
AC	0.0003	1	0.0003	0.5884	
BC	0.0026	1	0.0026	6.1090	*
ABC	0.0413	1	0.0413	96.0654	*
Error	0.0103	24	0.0004		
Total	0.0851	31			

Table 6-a. Analysis of Variance Summary Table of Printed SID at 7μm Ink Film Thickness Using Little Joe with Morrison Quick-Set Process Black Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0000	1	0.0000	0.0000	
B	0.0001	1	0.0001	0.0243	
C	0.0003	1	0.0003	0.1521	
AB	0.0000	1	0.0000	0.0000	
AC	0.0055	1	0.0055	2.6836	
BC	0.0006	1	0.0006	0.2982	
ABC	0.0120	1	0.0120	5.8479	*
Error	0.0493	24	0.0021		
Total	0.0678	31			

Table 6-b. Analysis of Variance Summary Table of Printed SID at 10μm Ink Film Thickness Using Little Joe with Morrison Quick-Set Process Black Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0000	1	0.0000	0.0000	
B	0.0001	1	0.0001	0.0386	
C	0.0066	1	0.0066	5.1029	*
AB	0.0002	1	0.0002	0.1543	
AC	0.0045	1	0.0045	3.4823	
BC	0.0001	1	0.0001	0.0868	
ABC	0.0066	1	0.0066	5.1029	*
Error	0.0311	24	0.0013		
Total	0.0492	31			

Table 6-c. Analysis of Variance Summary Table of Printed SID at 15μm Ink Film Thickness Using Little Joe with Morrison Quick-Set Process Black Ink

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	0.0009	1	0.0009	1.4670	
B	0.0004	1	0.0004	0.6142	
C	0.0038	1	0.0038	6.2183	*
AB	0.0000	1	0.0000	0.0051	
AC	0.0030	1	0.0030	4.8782	*
BC	0.0000	1	0.0000	0.0051	
ABC	0.0140	1	0.0140	22.7868	*
Error	0.0148	24	0.0006		
Total	0.0369	31			

Table 7-a. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Dainippon Magenta Linseed Oil Ink

Ink Film Thickness: 10 μm to 5 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	153.5628	1	153.5628	34.6293	*
B	18.4528	1	18.4528	4.1612	
C	5.8653	1	5.8653	1.3227	
AB	17.5528	1	17.5528	3.9583	
AC	8.3028	1	8.3028	1.8723	
BC	6.9378	1	6.9378	1.5645	
ABC	57.5128	1	57.5128	12.9695	*
Error	106.4275	24	4.4344		
Total	374.6147	31			

Note: $F_{1,24,0.05} = 4.2597$

Table 7-b. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Dainippon Magenta Linseed Oil Ink

Ink Film Thickness: 15 μm to 10 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	100.8200	1	100.8200	23.2271	*
B	91.8013	1	91.8013	21.1493	*
C	31.2050	1	31.2050	7.1891	*
AB	19.2200	1	19.2200	4.4279	*
AC	5.6112	1	5.6112	1.2927	
BC	23.8050	1	23.8050	5.4842	*
ABC	104.4013	1	104.4013	24.0521	*
Error	104.1750	24	4.3406		
Total	481.0387	31			

Table 7-c. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Dainippon Magenta Linseed Oil Ink

Ink Film Thickness: 20 μm to 15 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	86.9023	1	86.9023	32.4731	*
B	91.5778	1	91.5778	34.2202	*
C	14.1326	1	14.1326	5.2810	*
AB	83.4180	1	83.4180	31.1711	*
AC	0.8891	1	0.8891	0.3322	
BC	20.3745	1	20.3745	7.6135	*
ABC	293.6313	1	293.6313	109.7221	*
Error	64.2273	24	2.6761		
Total	655.1529	31			

Table 8-a. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Morrison Quick-set Process Black Ink

Ink Film Thickness: 10 μm to 5 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	98.7013	1	98.7013	17.0985	*
B	33.6200	1	33.6200	5.8242	*
C	114.0050	1	114.0050	19.7497	*
AB	1.9012	1	1.9012	0.3294	
AC	14.8512	1	14.8512	2.5728	
BC	3.9200	1	3.9200	0.6791	
ABC	26.2813	1	26.2813	4.5528	*
Error	138.5400	24	5.7725		
Total	431.8200	31			

Table 8-b. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Morrison Quick-set Process Black Ink

Ink Film Thickness: 15 μm to 10 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	57.7813	1	57.7813	12.3772	*
B	3.2513	1	3.2513	0.6964	
C	113.0050	1	113.0050	23.7783	*
AB	1.6200	1	1.6200	0.3470	
AC	30.0312	1	30.0312	6.4330	*
BC	0.2112	1	0.2112	0.0453	
ABC	0.0200	1	0.0200	0.0043	
Error	112.0400	24	4.6683		
Total	315.9600	31			

Table 8-c. Analysis of Variance Summary Table of Print Gloss Using Little Joe with Morrison Quick-set Process Black Ink

Ink Film Thickness: 20 μm to 15 μm

Source of Variation	Sum of Squares	degree of freedom	Mean of Square	F-ratio	Significant
A	22.6128	1	22.6128	8.0416	*
B	2.9403	1	2.9403	1.0456	
C	199.5003	1	199.5003	70.9466	*
AB	20.0028	1	20.0028	7.1134	*
AC	32.6028	1	32.6028	11.5943	*
BC	35.9128	1	35.9128	12.7714	*
ABC	16.1028	1	16.1028	5.7265	*
Error	67.4875	24	2.8120		
Total	397.1622	31			

Table 9. Summary of F-ratio of Printed SID at Different Ink Film Thicknesses Using Different Approaches with Different Inks

Factors	Levels of Factors
A: (roughness)	2
B: (paper gloss)	2
C: (K&N ink absorption)	2

	Little Joe					Duplicator Flint Ink	numbers of Significant
	Dainippon Magenta Linseed		Morrison Quickset Bk				
	Ink Film Thickness		Ink Film Thickness			Ink Film Thickness	
Factor	10μm	15μm	7μm	10μm	15μm	unknown	
A	0.566	0.878	0.000	0.000	1.467	2.046	0/6
B	0.846	1.227	0.024	0.038	0.614	6.917*	1/6
C	20.391*	68.346*	0.152	5.102*	6.218*	1.330	4/6
AB	1.007	0.588	0.000	0.154	0.005	0.359	0/6
AC	0.566	0.588	2.683	3.482	4.878*	6.917*	2/6
BC	2.021	6.109*	0.298	0.086	0.005	6.917*	2/6
ABC	20.391*	96.065*	5.847*	5.102*	22.786*	2.914	5/6

Note: $F_{1,24,0.05} = 4.2597$

Table 10 shows that paper roughness has a very significant effect on print gloss. The number of significance tests of paper roughness is seven out of seven. The interaction of paper roughness, gloss, and K&N ink absorption has rather significant effect on print gloss. The number of significance tests is six out of seven. It was found the single paper gloss has partially significant effect on print gloss. The number of significance tests is four out of seven. K&N ink absorption has partially significant effect on print gloss. The number of significance tests is five out of seven. The interaction of each property on print gloss has partially significant effect on print gloss for the gloss coated papers as well.

The scaled metal wedge loads the ink film from 0 micron to 25 microns, but the author only measured print gloss at three different levels which were 5-10 microns, 10-15 microns and 15-20 microns. Ink film thickness between 0-5 microns has lower density and higher standard deviation.

From the standpoint of variance analysis of Table 10, all the calculated F-ratioes of roughness are larger than $F_{1,24,0.05}$ = 4.2597. Therefore, paper roughness is a significant factor that will affect print gloss regardless of whether the Little Joe offset proving press or duplicator is used.

Table 10. Summary of F-ratio of Print Gloss at Different Ink Film Thicknesses Using Different Approaches with Different Inks

Factors	Levels of Factors
A: (roughness)	2
B: (paper gloss)	2
C: (K&N ink absorption)	2

	Little Joe						Duplicator Flint Ink	numbers of Significant
	Dainippon Magenta Linseed			Morrison Quickset Bk				
	Ink Film Thickness			Ink Film Thickness			Ink Film Thickness	
Factor	20-15 µm	15-10 µm	10-5 µm	20-15 µm	15-10 µm	10-5 µm	unknown	
A	32.47*	23.22*	34.62*	8.04*	12.37*	17.09*	42.71*	7/7
B	34.22*	21.14*	4.16	1.04	0.69	5.82*	8.88*	4/7
C	5.28*	7.18*	1.32	70.94*	23.77*	19.74*	1.33	5/7
AB	31.17*	4.42*	3.95	7.11*	0.34	0.33	0.87	3/7
AC	0.33	1.29	1.87	11.59*	6.43*	2.57	18.50*	3/7
BC	7.61*	5.48*	1.56	12.77*	0.05	0.68	31.92*	4/7
ABC	109.72*	24.05*	12.96*	5.72*	0.01	4.55*	31.43*	6/7

Note: $F_{1,24,0.05} = 4.2597$

Table 11 and Table 12 is a summary of correlation coefficients between gloss coated paper properties and printed SID as well as print gloss at different ink film thicknesses. Table 13, 14, 15 provides the average of each property of paper samples for the correlation analysis of printed SID and print gloss by using different approaches. The value of the correlation coefficient, r, lies between +1 and -1. For the r value to be nearly +1, the response of one variable (paper roughness, gloss, K&N, PSE) increases as the response of the other variable (printed SID, print gloss) also increases. If r value approaches -1, the response of one variable increases as the response of the other variable decreases. If r value is zero, this is an indication of no relationship between two variables that are being studied. The author used Little Joe offset proving press and a duplicator with different inks to study the relationship between paper roughness, gloss, K&N ink absorptivity, PSE and printed SID as well as print gloss. As a result, there is only a pronounced negative correlation between K&N and printed SID when implementing Little Joe with Dainippon magenta linseed oil ink. When the ink film thickness is 10 microns and 15 microns, the correlation coefficient is -0.839 and -0.778 respectively. (Please refer to page 74)

The r^2 (-0.839^2) is 0.7039, which implies that the association between K&N and printed SID accounts for 70.39

percent of the total variability, leaving 29.61 percent for error and for the other source of variation.

In the experiment, where all the calculated values r are not close to +/- 1, we may be uncertain whether there is a real relationship between roughness, gloss, K&N ink absorption and printed SID as well as print gloss. Table 11 and Table 12 also indicates most of the correlation coefficients lower than 0.7067 (significance level of correlation coefficient is 0.05), it would have very little meaning to show a relationship or regression analysis between input variables and output responses. Because most of the correlation coefficients are very small, the functional relationship between input variables and output responses hardly exists. In other words, we can not draw a regression line to predict printed SID or print gloss by using paper roughness, gloss or K&N ink absorption for gloss coated papers in terms of variance or correlation analysis.

Generally, "the judgement of K&N ink absorption test can only be useful in the hand of an experienced judge and can't give a general judgement of the printability of a paper."[1] J.M. Fetsko and W.C. Walker also used K&N Ink test to correlate the ink trasfer and print quality data during ink transfer studies with coated paper properties. Likewise, "no correlation could be made with the K&N Ink test."[2]

Table 11. Summary of Correlation Coefficient between Gloss Coated Paper Property and Printed SID at Different Ink Film Thicknesses

	Little Joe					Duplicator
	Dainippon Magenta Linseed		Morrison Quickset Bk			Flint Heatset Bk
paper property	Ink Film Thickness		Ink Film Thickness			Ink Film Thickness
	10μm	15μm	7μm	10μm	15μm	unknown
roughness	0.222	0.395	0.108	-0.011	0.326	-0.108
paper gloss	0.308	-0.015	-0.336	-0.300	-0.481	-0.587
K&N ink Absorptivity	-0.839*	-0.778*	-0.293	0.133	-0.025	-0.172
PSE	0.708*	0.490	-0.001	-0.256	-0.253	-0.219

Table 12. Summary of Correlation Coefficient between Gloss Coated Paper Property and Print Gloss at Different Ink Film Thicknesses

	Little Joe						Duplicator
	Dainippon Magenta Linseed			Morrison Quickset Bk			Flint Heatset Bk
	Ink Film Thickness			Ink Film Thickness			Ink Film Thickness
paper property	20-15 μm	15-10 μm	10-5 μm	20-15 μm	15-10 μm	10-5 μm	unknown
roughness	0.036	0.017	-0.338	-0.132	-0.364	-0.697	-0.158
paper gloss	-0.283	-0.277	-0.012	-0.274	-0.099	0.354	-0.199
K&N ink Absorptivity	-0.593	-0.560	-0.539	0.475	0.449	0.366	-0.222
PSE	0.216	0.196	0.333	-0.449	-0.451	0.216	0.031

Table 13. Average of Each Property for Regression Correlation Analysis

				Duplicator with Flint Heatset Bk Ink	
	Paper Property				
paper sample	rough-ness	paper gloss	paper absorp.	SID	print gloss
E	1.126	71.65	16.40	2.00	72.99
F	0.982	58.86	19.85	2.07	80.13
G	1.060	74.93	8.90	2.02	80.60
I	1.000	64.13	15.86	2.06	81.50
K	1.372	58.48	34.26	2.00	77.15
L	1.320	66.37	18.53	2.01	80.31
M	0.671	68.01	29.36	2.05	79.34
P	1.390	55.00	17.20	2.11	79.78

Table 14. Average of Each Property for Regression Correlation Analysis

				Little Joe with Dainippon Magenta Linseed Oil Ink				
	Paper Property			SID		print gloss		
paper sample	rough-ness	paper gloss	paper absorp.	10 μm	15 μm	20-15 μm	15-10 μm	10-5 μm
E	1.126	71.65	16.40	1.64	1.89	67.57	68.65	68.93
F	0.982	58.86	19.85	1.63	1.91	78.98	77.23	76.65
G	1.060	74.93	8.90	1.74	1.96	74.03	73.43	75.53
I	1.000	64.13	15.86	1.62	1.87	76.18	76.48	76.78
K	1.372	58.48	34.26	1.58	1.84	66.73	67.68	69.13
L	1.320	66.37	18.53	1.62	1.88	74.23	75.83	72.70
M	0.671	68.01	29.36	1.57	1.81	67.90	70.40	71.90
P	1.390	55.00	17.20	1.68	1.96	75.38	75.83	72.58

Table 15. Average of Each Property for Regression Correlation Analysis

				Little Joe with Morrison Quickset Bk				
	Paper Property			SID		print gloss		
paper sample	rough-ness	paper gloss	paper absorp.	10 μm	15 μm	20-15 μm	15-10 μm	10-5 μm
E	1.126	71.65	16.40	2.23	2.31	69.68	73.68	76.13
F	0.982	58.86	19.85	2.28	2.37	78.68	80.78	79.55
G	1.060	74.93	8.90	2.23	2.32	76.68	78.80	78.70
I	1.000	64.13	15.86	2.20	2.29	76.40	79.10	79.65
K	1.372	58.48	34.26	2.23	2.32	79.18	80.43	78.72
L	1.320	66.37	18.53	2.26	2.36	80.53	79.55	80.15
M	0.671	68.01	29.36	2.25	2.32	80.35	80.70	83.63
P	1.390	55.00	17.20	2.25	2.36	75.70	74.98	72.48

During the time the samples were being measured, the author could not detect the differences in printed SID and print gloss with the naked eye. Generally, all the tested samples appear to be quite alike in terms of printed SID and print gloss. In addition on the basis of visual observation the author could not see a strong relationship between ink film thickness and print gloss. Increase in ink film thickness on the paper does not equal an increase in print gloss on the paper. Basically, higher paper gloss will have higher print gloss, lower roughness also results in a higher print gloss. The author could not find the functional relationship for the gloss coated papers. (Please see the Fig. 6-4, Fig. 6-5)

In this experiment, the percentage of ink transfer from the scaled wedge to the blanket, and from the blanket to the paper samples is unknown. The actual ink film thickness transferred to the tested samples is unknown. J.M. Fetsko and W.C. Walker[1] indicated in their report "Measurements of Ink Transfer in the Printing of Coated Papers" that coated papers could have 50% to 70% maximum ink transfer from plate to papers. Thus, we assume the total ink transfer from the scaled wedge to the tested samples is probably lower than 50%.

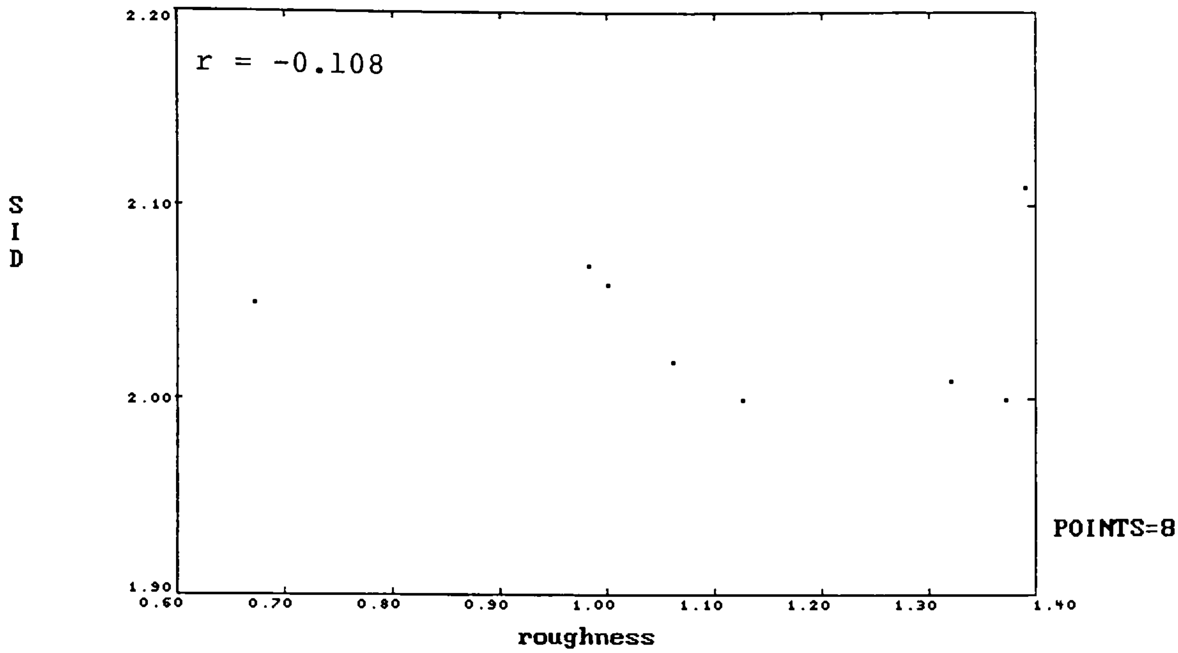


Figure 6-1. Roughness vs. SID
for Gloss Coated Papers Using Duplicator

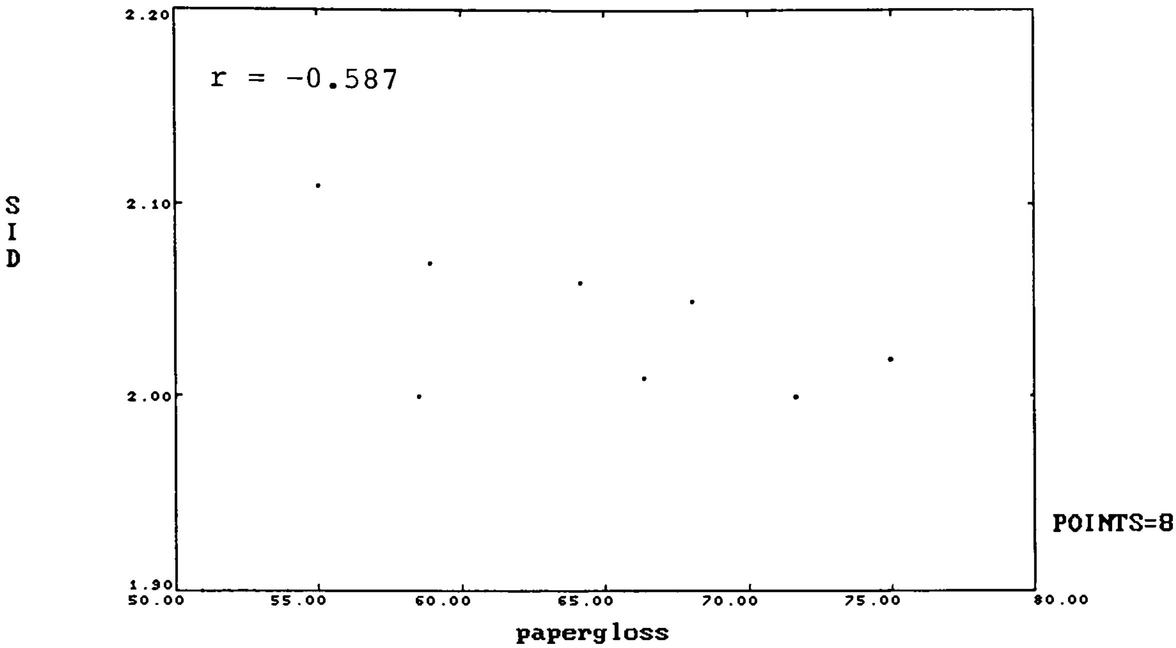


Figure 6-2. Paper Gloss vs. SID for
Gloss Coated Papers Using Duplicator

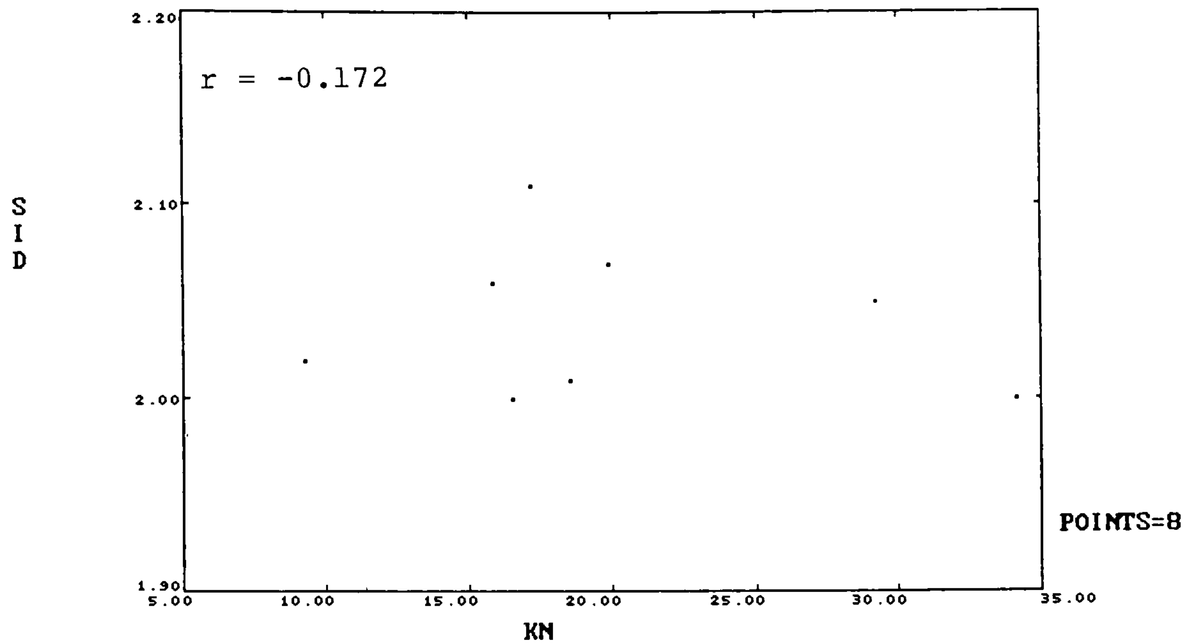


Fig 6-3 K&N Ink Absorptivity vs. SID for Gloss Coated Papers Using Duplicator

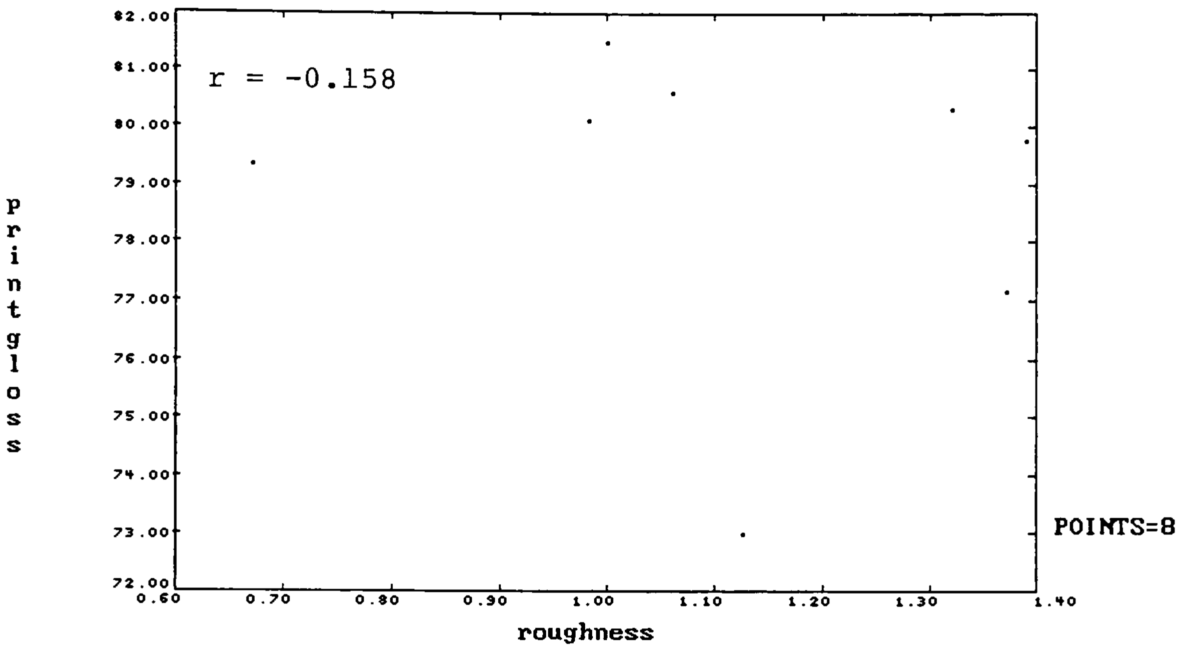


Figure 6-4. Roughness vs. Print Gloss for Gloss Coated Papers Using Duplicator

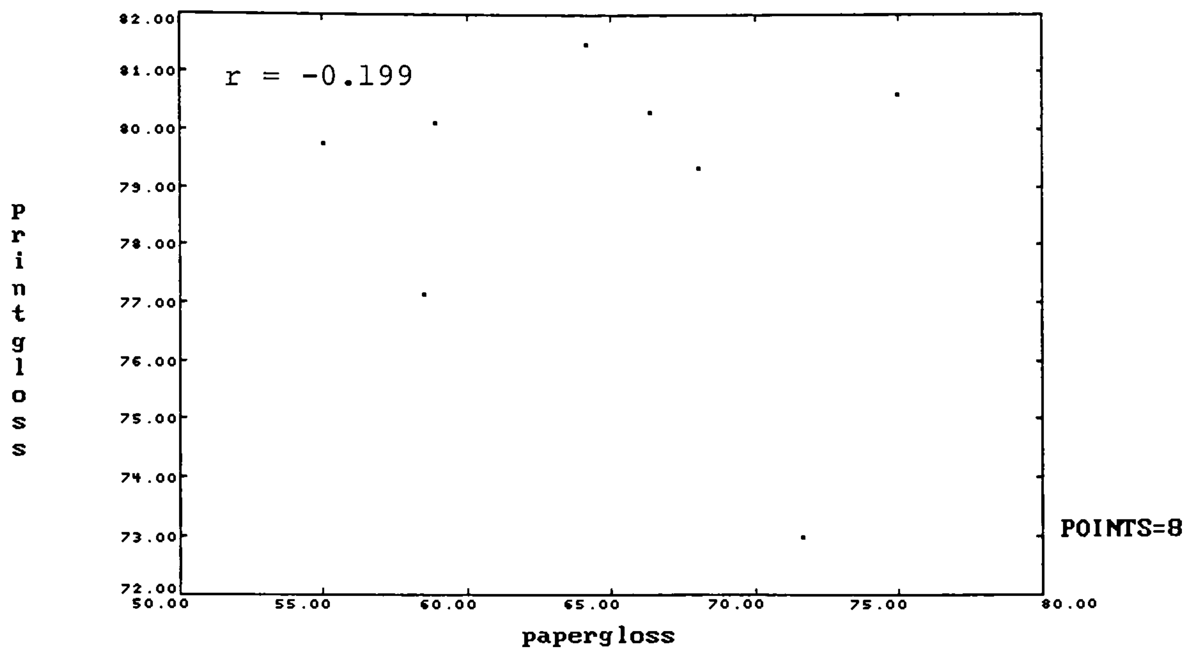


Figure 6-5. Paper Gloss vs. Print Gloss for Gloss Coated Papers Using Duplicator

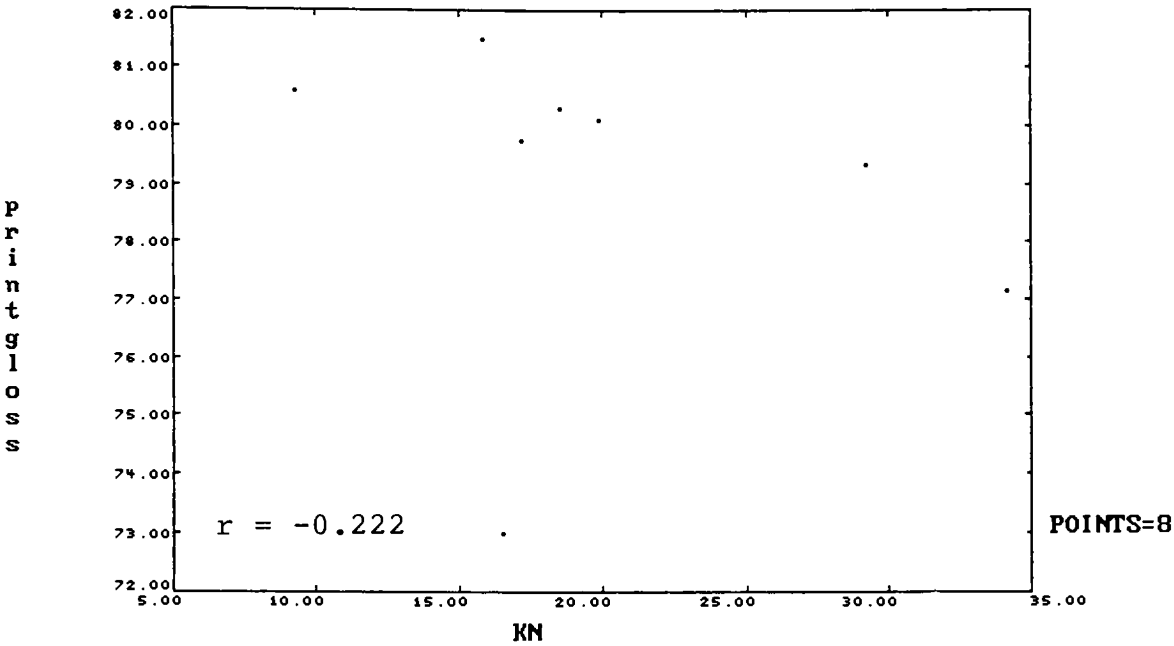


Fig. 6-6. K&N Ink Absorptivity vs. Print Gloss for Gloss Coated Papers Using Duplicator

In 1962, Preucil used six basic ink colors printed on eighteen different papers and found that differences in the gloss and absorptivity of paper are major factors in the variations of printed ink color that resulted from this experiment. As stated in Chapter one, different papers have different surface properties, the largest differences can probably be found between coated and uncoated papers. It is quite controversial to mix them together and compare their color reproduction. The author used eight different gloss coated papers with different grades to be printed by the same printing condition and found no significant correlation between PSE and printed SID as well as no significant correlation between PSE and print gloss. In Table 11 & 12, almost all the correlation coefficients between PSE and printed SID as well as the correlation coefficient between PSE and print gloss are less than 0.7067. (0.7067 is a value of the correlation coefficient for level of significance of 0.05, at 6 degrees of freedom). This is because ink absorptivity has no strong or significant effect on printed SID and print gloss for the gloss coated papers. When implementing duplicator with Flint ink on gloss coated paper samples, the F-ratio of paper absorptivity on printed SID and print gloss is 1.330 and 1.68 respectively in terms of variance analysis. Please refer to Table 16 for detailed PSE of each tested sample.

Table 16. PSE of Gloss Coated Paper Samples

Paper Property	Paper Sample							
	E	F	G	I	K	L	M	P
K&N % reflec- tance	87.70	85.11	93.33	88.10	74.30	86.10	77.98	87.10
Paper Gloss	71.65	58.86	74.93	64.13	58.48	66.37	68.01	55.00
Paper Absorp.	16.40	19.85	8.90	15.86	34.26	18.53	29.36	17.20
PSE	77.63	69.51	83.02	74.13	62.11	73.92	69.33	68.90

Paper Absorptivity = 4/3 (100 - K&N % reflectance)

$$PSE = \frac{(100 - P.A.) + \text{paper gloss}}{2}$$

P.A. is paper absorptivity

In addition to the study of eight kinds of gloss coated paper that were selected to fit the conditions of the ANOVA, the author used 21 kinds of pigment-coated paper to understand the effect of paper roughness, gloss, and K&N ink absorption on printed SID and print gloss. In the analysis of variance and correlation, it was found that paper roughness and gloss has a significant effect on printed SID and print gloss. The F-ratios of paper roughness on printed SID and print gloss are 115.9370 and 131.3880 respectively. The correlation coefficients of paper roughness on printed SID and print gloss are 0.9269 and 0.9346 respectively. The F-ratios of paper gloss on printed SID and print gloss are 41.2913 and 124.6570 respectively. The correlation coefficients of paper gloss on printed SID and print gloss are 0.8275 and 0.9315 respectively. The F-ratios of K&N ink absorption on printed SID and print gloss are 5.753 and 6.8873 respectively. The correlation coefficients of K&N ink absorption on printed SID and print gloss are 0.4971 and 0.5158 respectively. The author concludes that paper roughness and gloss affect printed SID and print gloss significantly for pigment coated papers. Since the importance of paper roughness can not be ignored, PSE should be modified to better predict the printed SID and print gloss.

The Parker-Print-Surf roughness tester has a range from reference 0.6 to 9.6 microns. The lowest detectable level for PPS tester is 0.6 micron. We might assume perfect smoothness at a roughness of 0.6 micron or less, since this is not measurable with the instrument used here. Based on this idea, we can

formulate a ratio of "0.6/roughness (R) X 100%" to indicate the levelness of paper surface. If R is 0.6μm, it is as smooth as the Parker-Print-Surf will measure.

We apply this idea to the PSE Equation to formulate a new equation for predicting printed SID and print gloss. The new equation, correlation matrix and diagrams are presented as follows:

$$NEWPSE = \frac{0.6/R \times 100\% + P.G.}{2}$$

From the correlation matrix analysis, the new PSE equation yields a higher correlation coefficient than the old PSE equation to better predict printed SID and print gloss. (see Table 16-a. as follows)

Table 16-a. Correlation Coefficient for PSE and NEWPSE

equation	Duplicator		Little Joe	
	SID	print gloss	SID	print gloss
PSE	0.8225	0.9192	0.6770	0.8579
NEWPSE	0.8779	0.9359	0.5855	0.8846

The Preucil PSE approach can be fine tuned to help predict the printing result. In addition, it was also found that the Little Joe offset proving press correlates well with the duplicator in terms of gloss response. The correlation coefficient is 0.9549 as shown in the Correlation Matrix 6-1.

*** Correlation Matrix 6-1***

Variables:					
PSE	1.0000				
NEWPSE	0.9332*	1.0000			
SIDDUP	0.8225*	0.8779*	1.0000		
GLOSSDUP	0.9192*	0.9359*	0.9108*	1.0000	
SIDJOE	0.6770*	0.5855*	0.4617	0.5540*	1.0000
GLOSSJOE	0.8579*	0.8846*	0.9330*	0.9549*	0.5992*
	PSE	NEWPSE	SIDDUP	GLOSSDUP	SIDJOE

Note: 1. Value of Correlation Coefficient at Significance Level of 0.01 is 0.5487 (degree of freedom is 19)

2. SIDDUP = Solid Ink Density, Duplicator

SIDJOE = Solid Ink Density, Little Joe

GlOSSDUP = Print Gloss, Duplicator

GLOSSJOE = Print Gloss, Little Joe

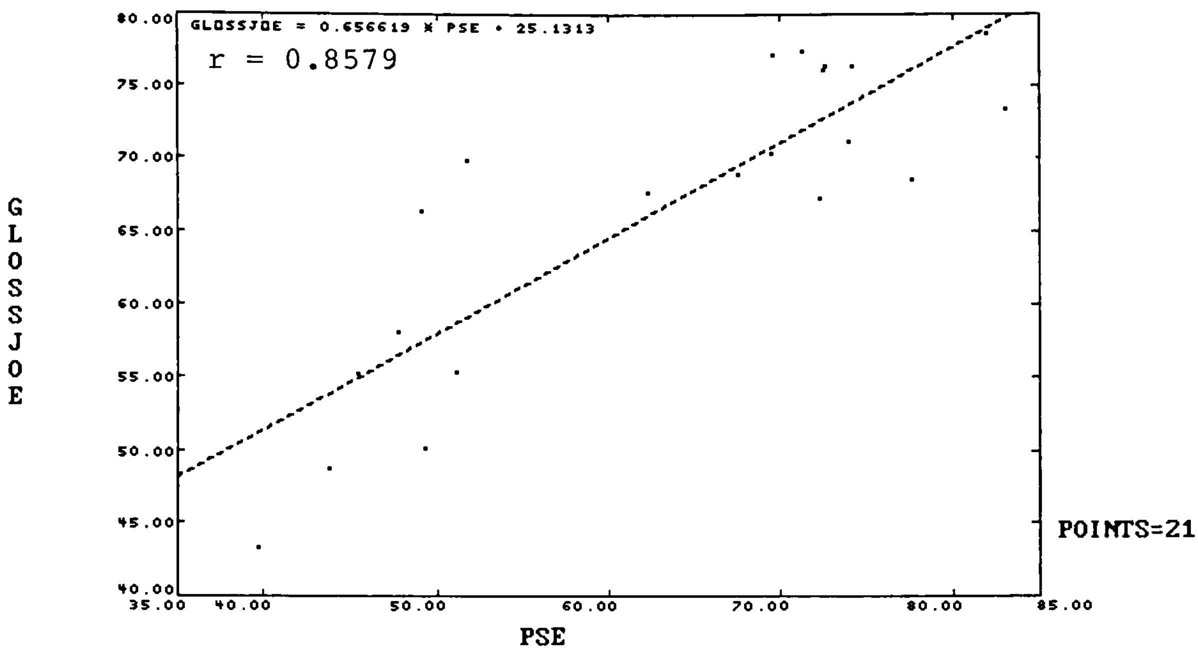


Fig. 6-7 PSE vs. Print Gloss (little Joe)

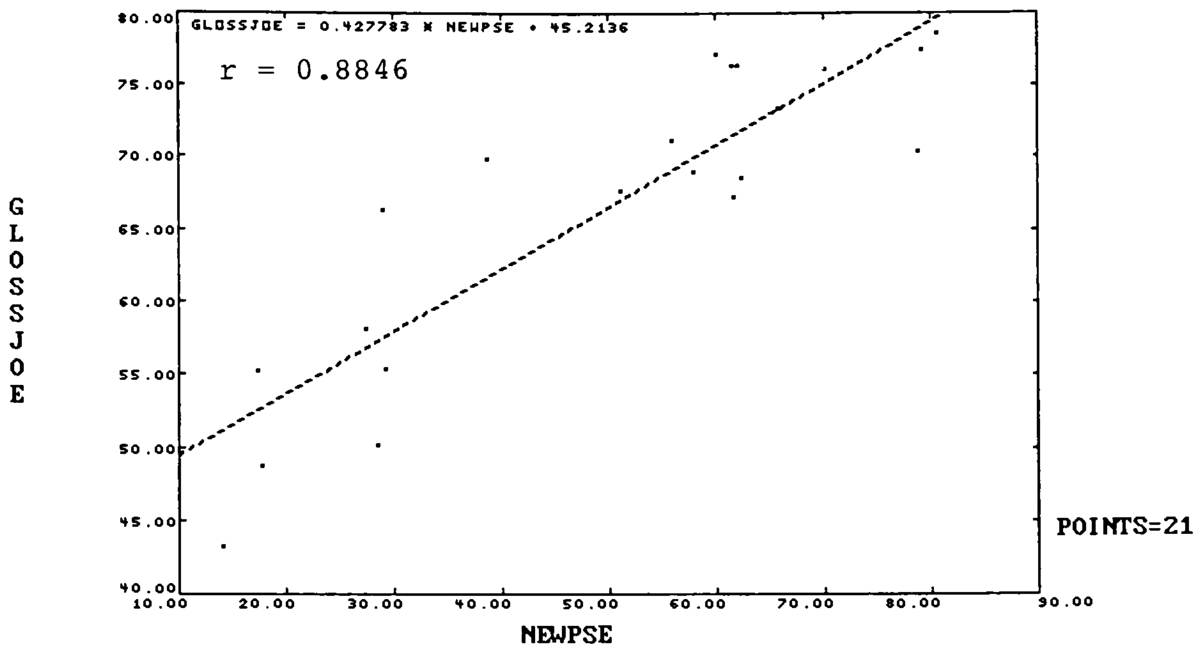


Fig. 6-8 NEWPSE vs. Print Gloss (little Joe)

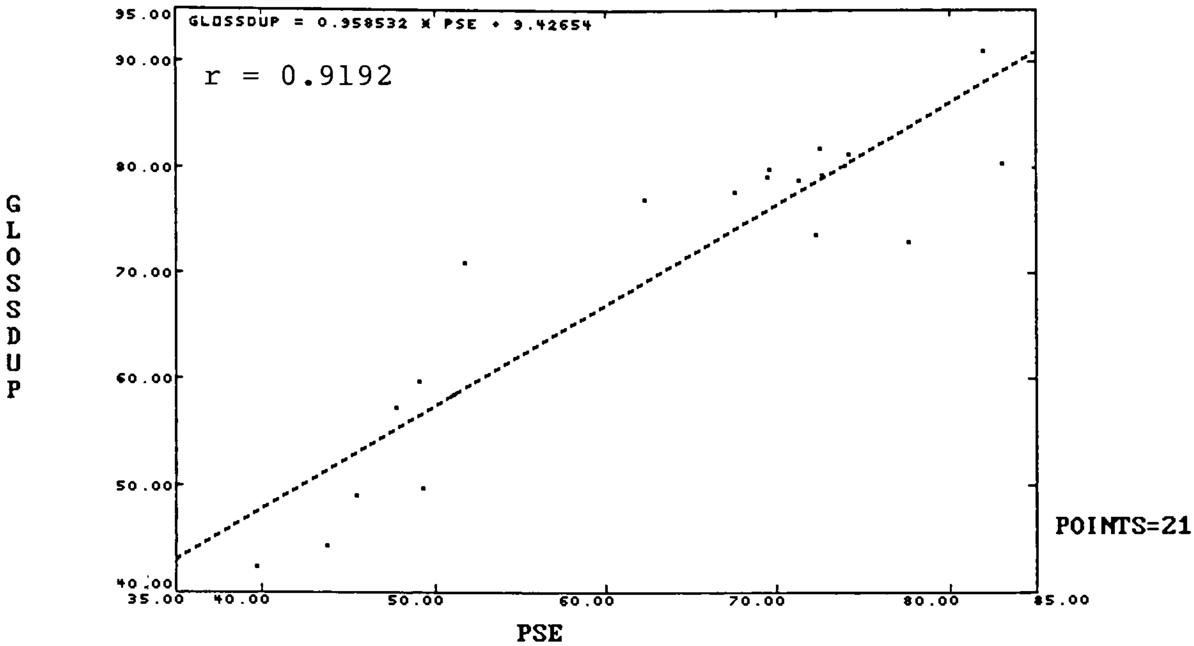


Fig. 6-9 PSE vs. Print Gloss (Duplicator)

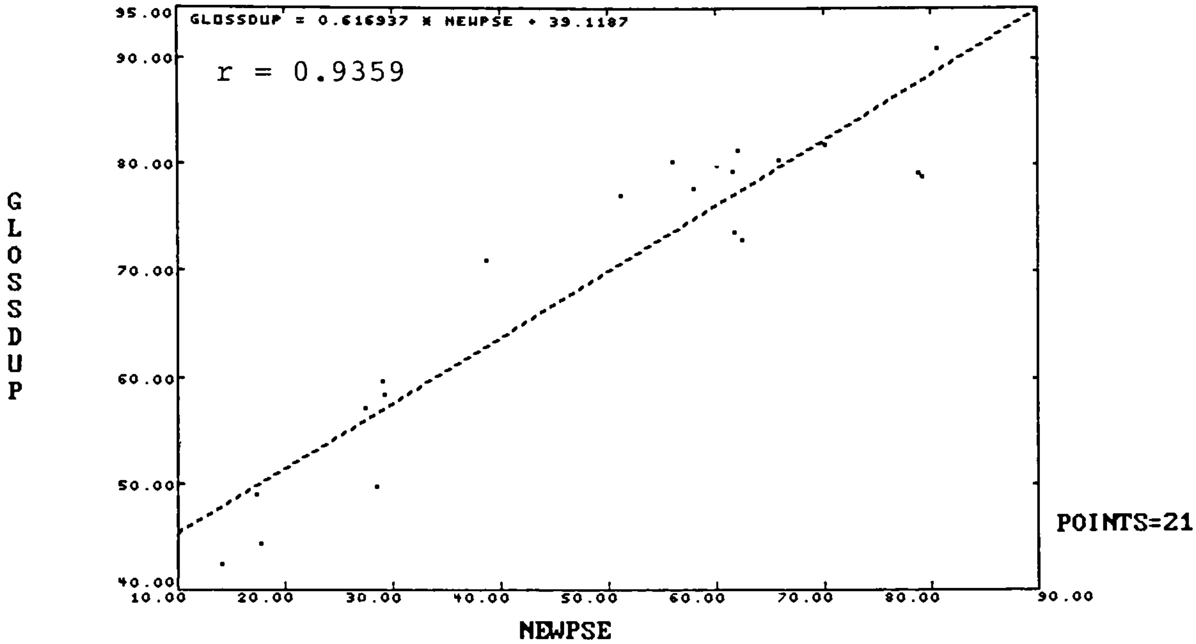


Fig. 6-10 NEWPSE vs. Print Gloss (Duplicator)

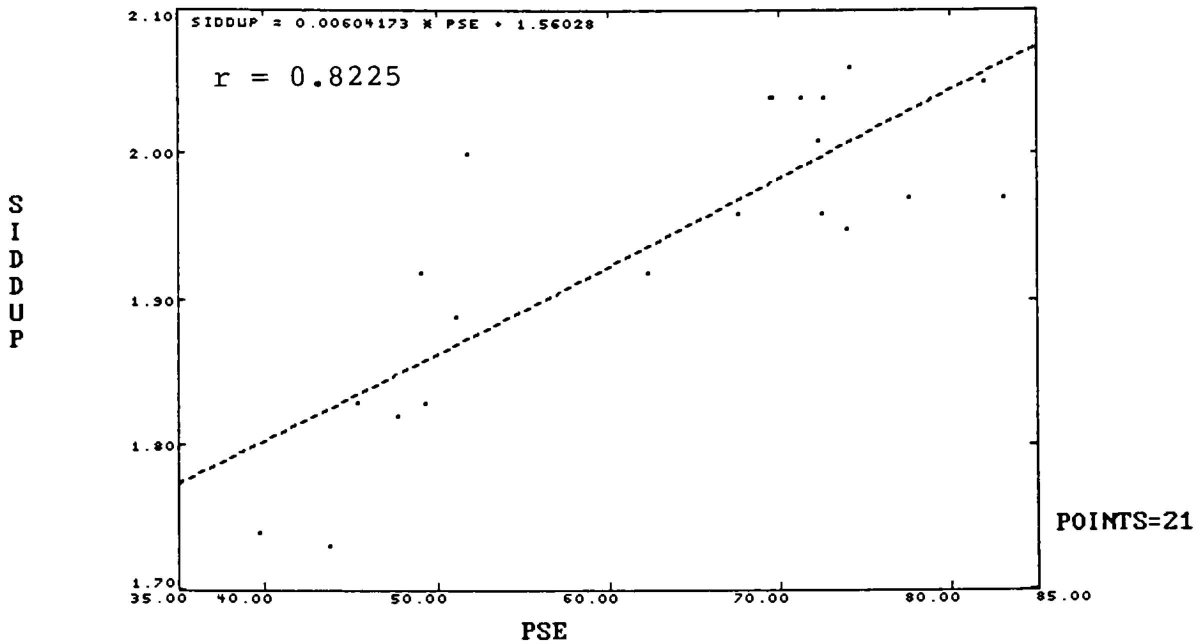


Fig.6-11 PSE vs. Printed SID (Duplicator)

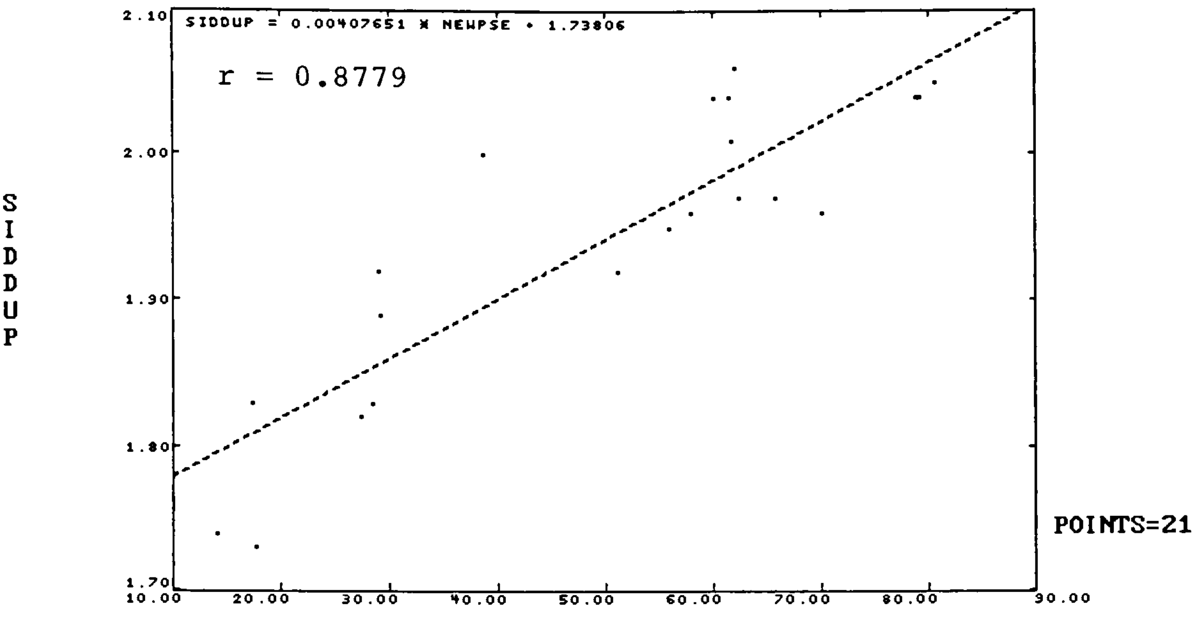


Fig. 6-12 NEWPSE vs. Printed SID (Duplicator)

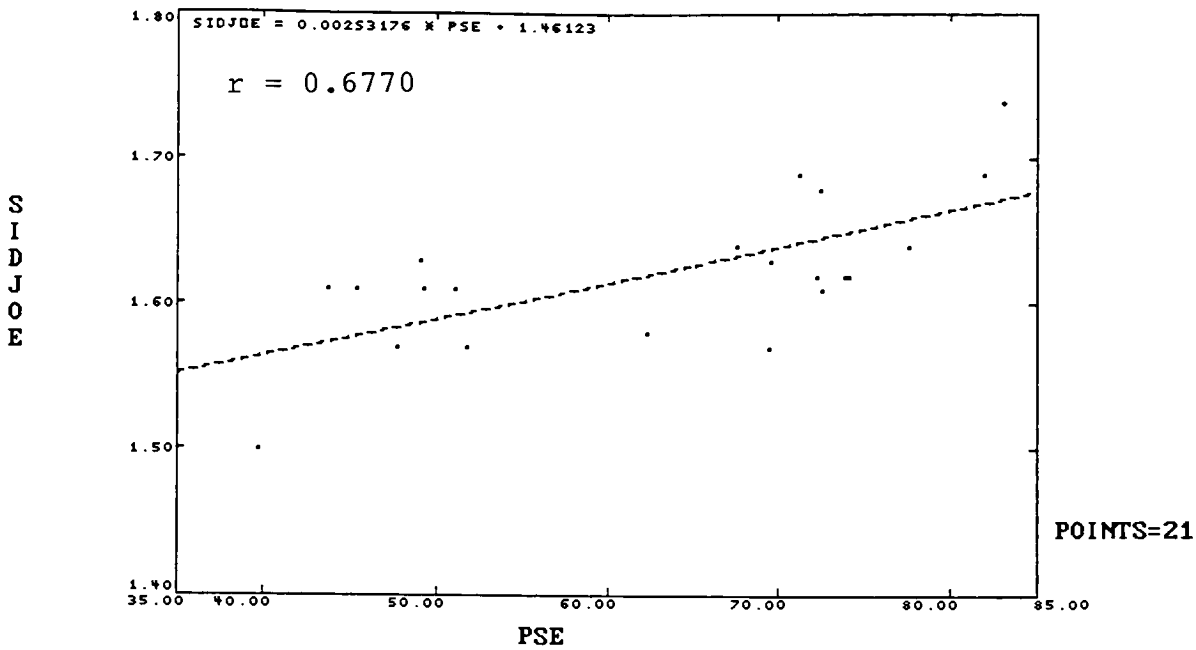


Fig. 6-13 PSE vs. Printed SID (little Joe)

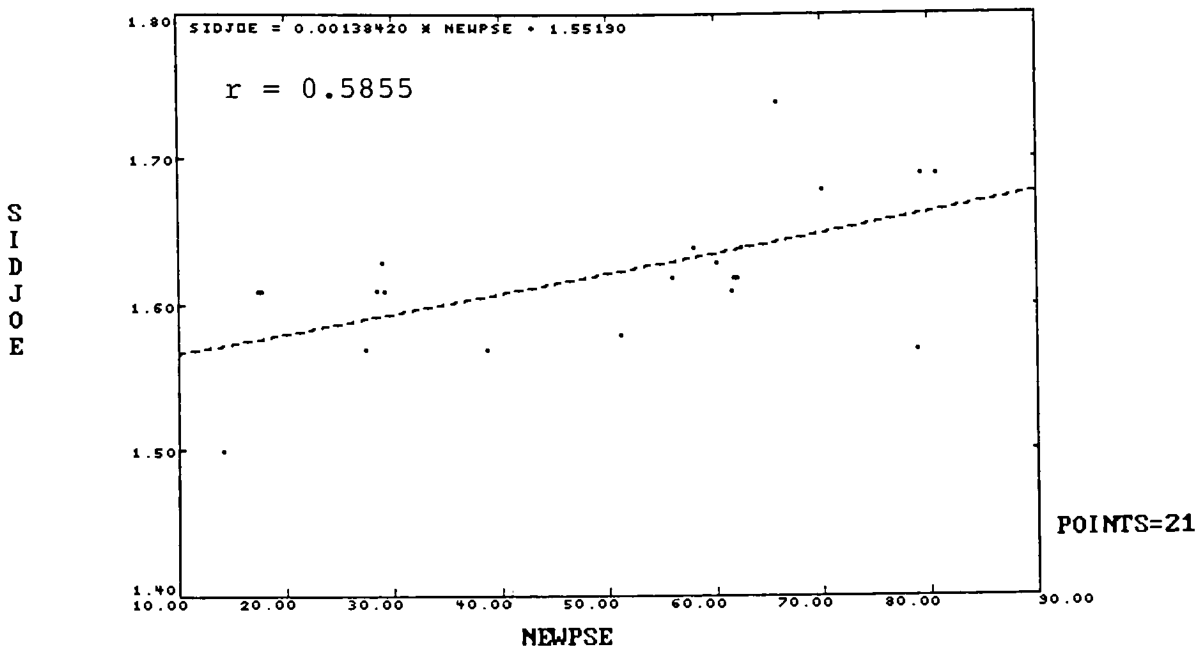


Fig. 6-14 NEWPSE vs. Printed SID (little Joe)

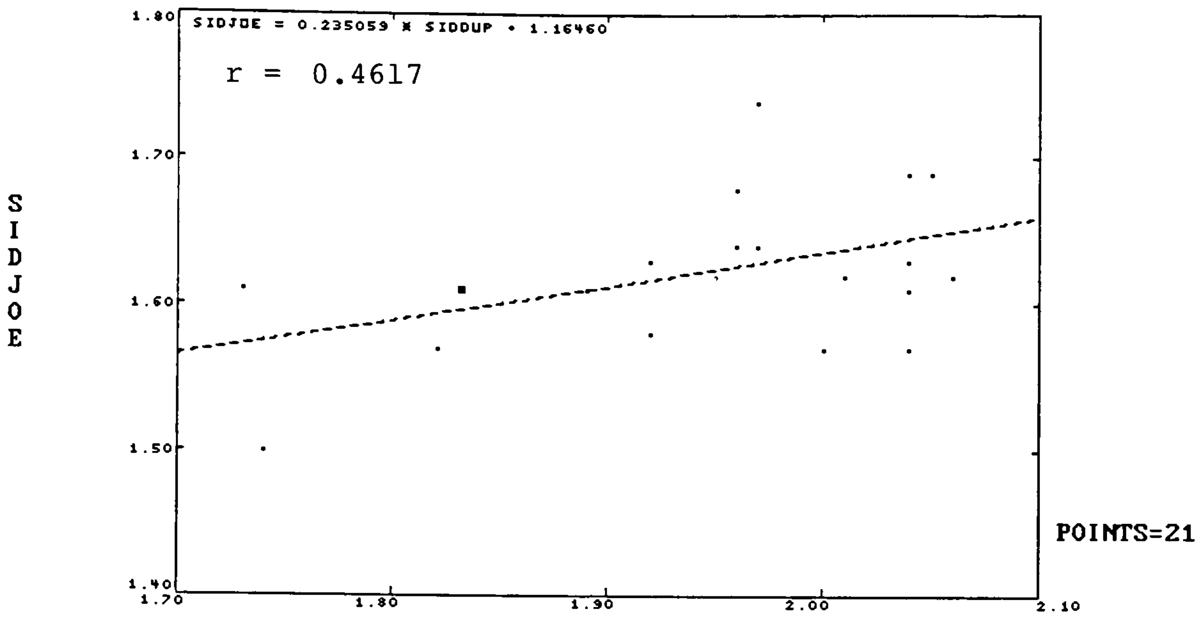


Fig. 6-15 Little Joe vs. Duplicator in Printed SID

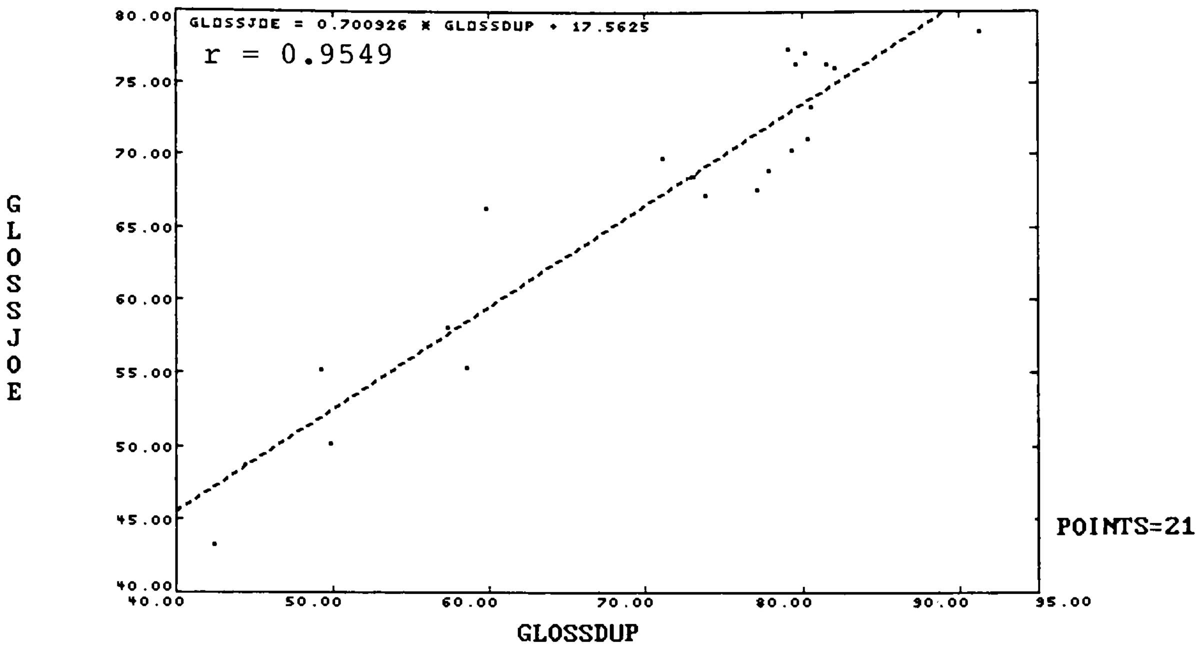


Fig. 6-16. Little Joe vs. Duplicator in Print Gloss

The author used a duplicator with Flint heatset process black to print on twenty one different kinds of pigment coated-paper, including two kinds of cast paper, eleven kinds of gloss coated paper, four kinds of dull coated and four kinds of matte coated paper. It was found that the effect of paper roughness and gloss were very significant on printed SID and print gloss at a confidence level of 99% and well correlated to each other. The correlation coefficients between roughness and printed SID, roughness and print gloss are -0.9269 and -0.9347 respectively. The correlation coefficients between paper gloss and printed SID, paper gloss and print gloss are 0.8275 and 0.9315 respectively. The correlation of K&N and Croda ink absorption to printed SID and print gloss is insignificant at a 99 percent confidence level. Paper compressibility is a significant factor to printed SID and print gloss at a 95% confidence level. The correlation coefficient matrix and regression analysis of printed SID as well as print gloss and their scatter diagrams are presented as follows:

*** Correlation Matrix 6-2***

Variables:

	Roughness	Compress	K&N	Croda	Papergloss
Roughness	1.0000				
Compress	-0.5642*	1.0000			
K&N	0.4791	-0.2338	1.0000		
Croda	0.3693	-0.3305	0.3889	1.0000	
Papergloss	-0.8795*	0.7567*	-0.4971	-0.2482	1.0000
SID	-0.9269*	0.5368	-0.4821	-0.3990	0.8275*
Printgloss	-0.9347*	0.6944*	-0.5158	-0.4794	0.9315*

	SID	Printgloss
SID	1.0000	
Printgloss	0.9108*	1.0000

Table 17. Linear Regression Analysis of Printed SID for Pigment-Coated Papers Using Duplicator with Flint Heat-set Process Black Ink

Regression Analysis	Independent Variable				
	Roughness	Paper Gloss	K&N	Croda	Compress
Determination Coefficient	0.859	0.684	0.232	0.159	0.288
Correlation Coefficient	0.926*	0.827*	0.482	0.399	0.536*
Estimated Constant Term (Intercept)	2.091	1.749	2.116	2.073	1.102
Regression Coefficient (Slope)	-0.089	-0.003	-0.006	-0.588	0.624
Total degree of freedom	20	20	20	20	20
F-ratio	115.937*	41.291*	5.753*	3.599	7.693*

Note: $F_{1,19,0.05} = 4.3808$

Table 18. Linear Regression Analysis of Print Gloss for Pigment-Coated Papers Using Duplicator with Flint Heat-set Process Black Ink

Regression Analysis	Independent variables				
	Roughness	Paper Gloss	K&N	Croda	Compress
Determination Coefficient	0.873	0.867	0.266	0.229	0.482
Correlation Coefficient	0.934*	0.931*	0.515	0.479	0.694*
Estimated Constant Term (Intercept)	91.376	39.236	96.539	92.389	-84.217
Regression Coefficient (Slope)	-12.858	0.583	-0.988	-100.393	114.685
Total degree of freedom	20	20	20	20	20
F-ratio	131.3880*	124.6570*	6.8873*	5.6703*	17.7020*

Note: $F_{1,19,0.05} = 4.3808$

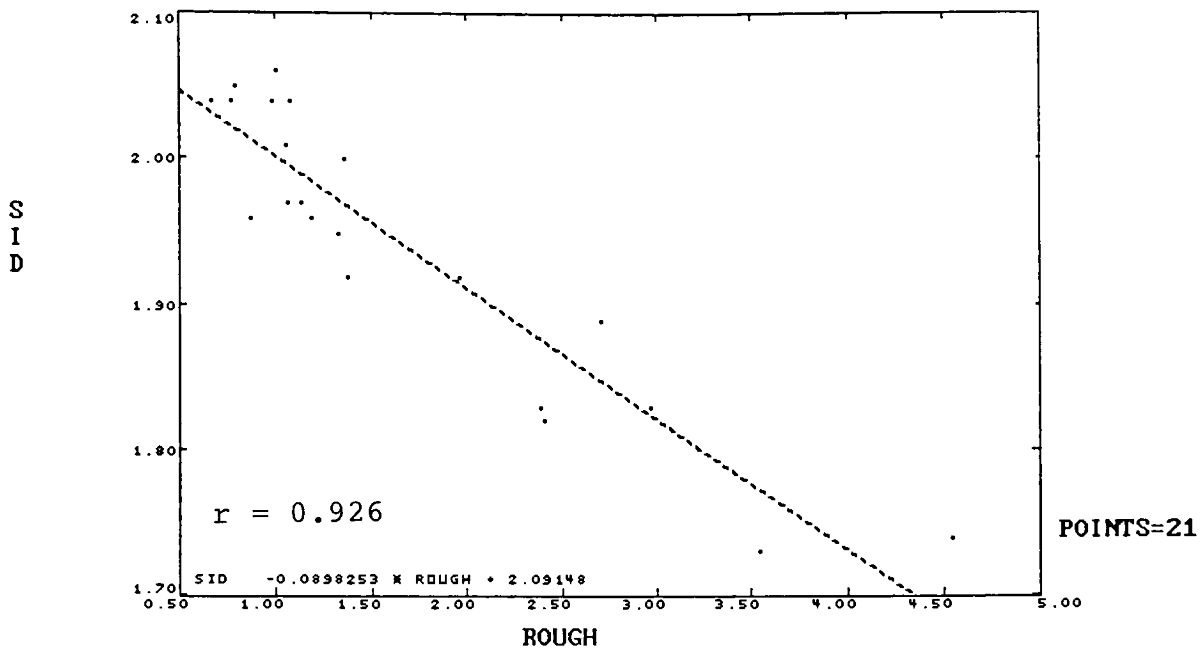


Fig. 6-17. The Relationship Between Roughness and Printed SID for Pigment Coated Papers Using Duplicator

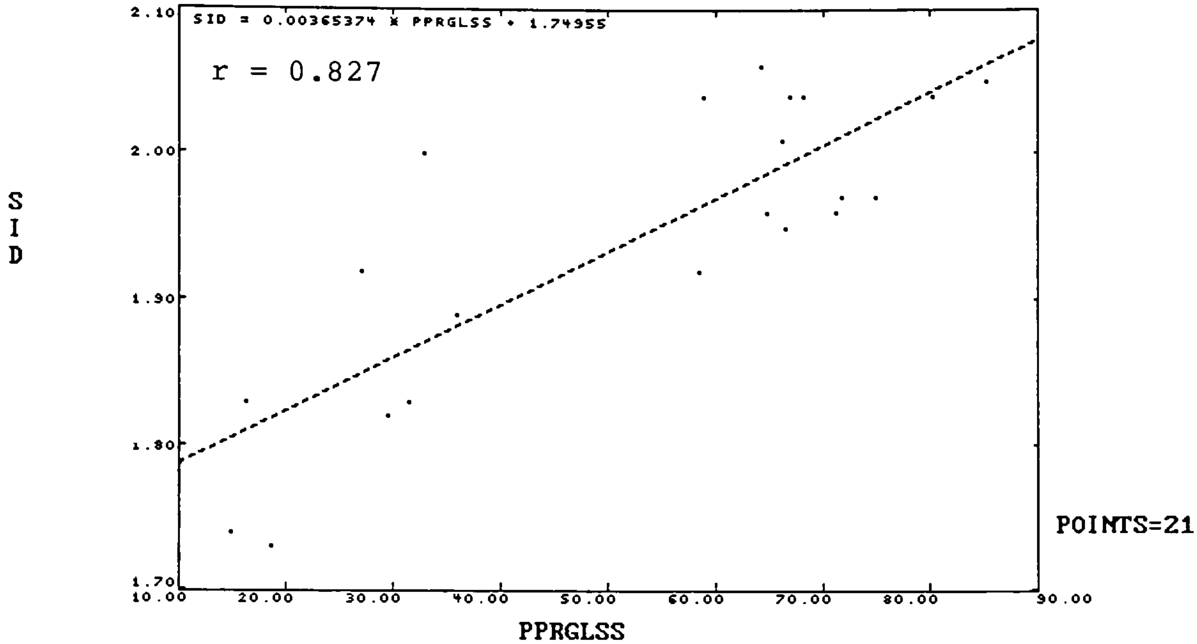


Fig. 6-18. The Relationship Between Paper Gloss and Printed SID for Pigment Coated Papers Using Duplicator

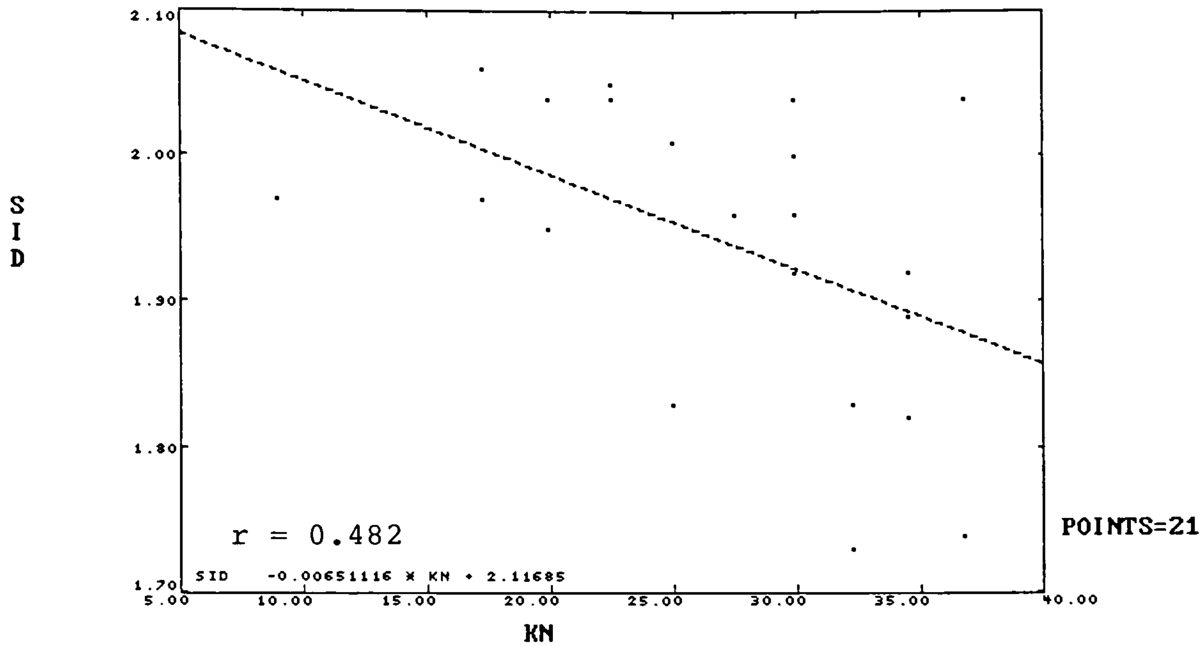


Fig. 6-19. The Relationship Between K&N Ink Absorptivity and Printed SID for Pigment Coated Papers Using Duplicator

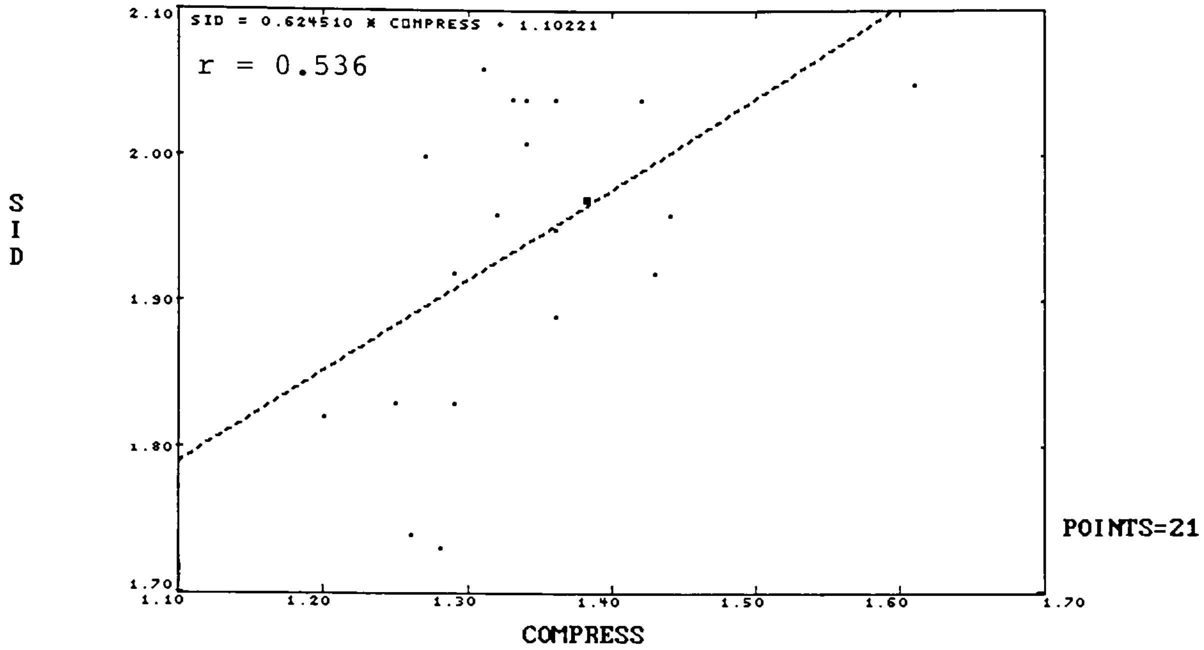


Fig. 6-20. The Relationship Between Paper Compressibility and Printed SID for Pigment Coated Papers Using Duplicator

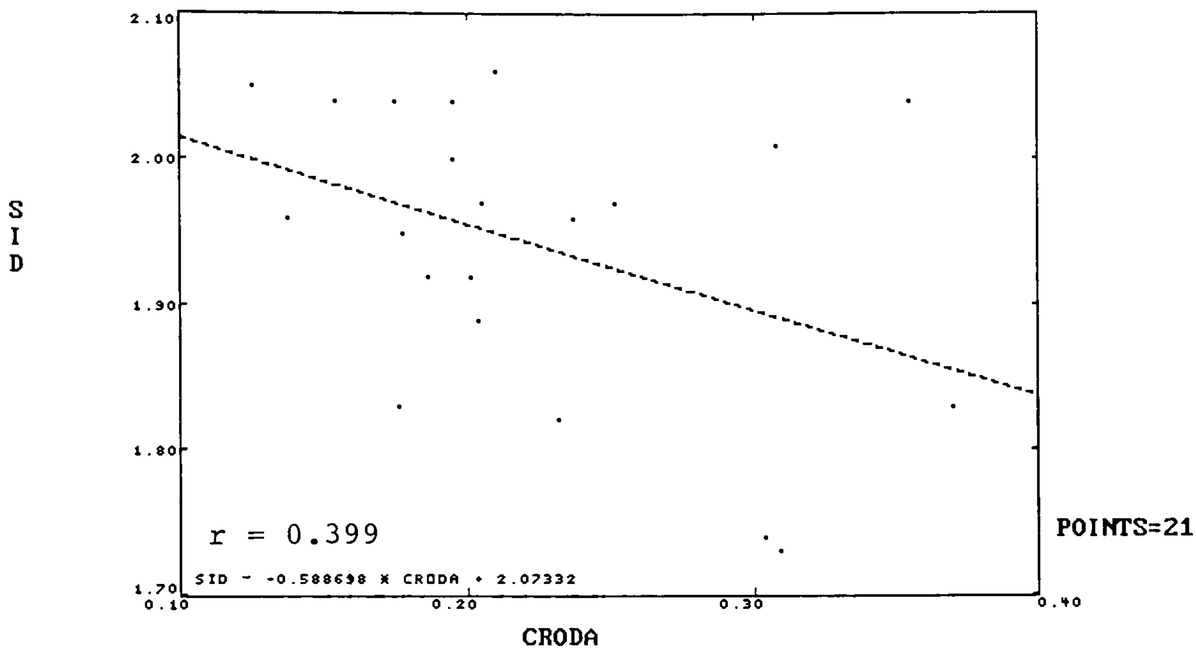


Fig. 6-21. The Relationship Between Croda Ink Absorption Density and Printed SID for Pigment Coated Papers Using Duplicator

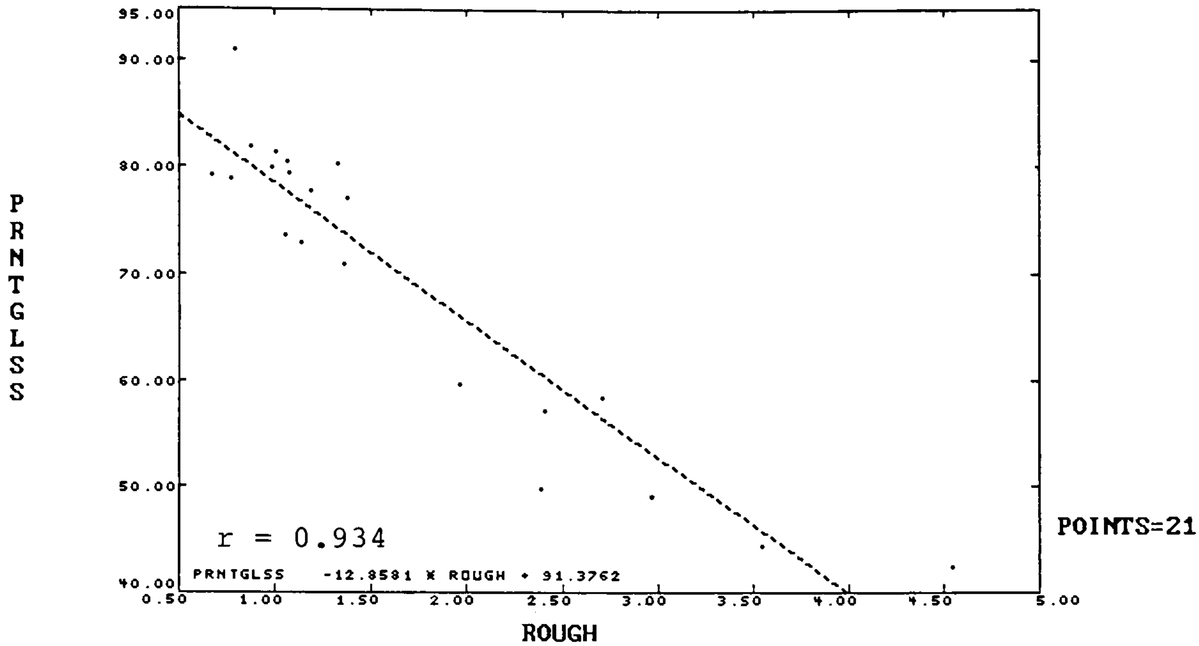


Fig. 6-22. The Relationship Between Roughness and Print Gloss for Pigment Coated Papers Using Duplicator

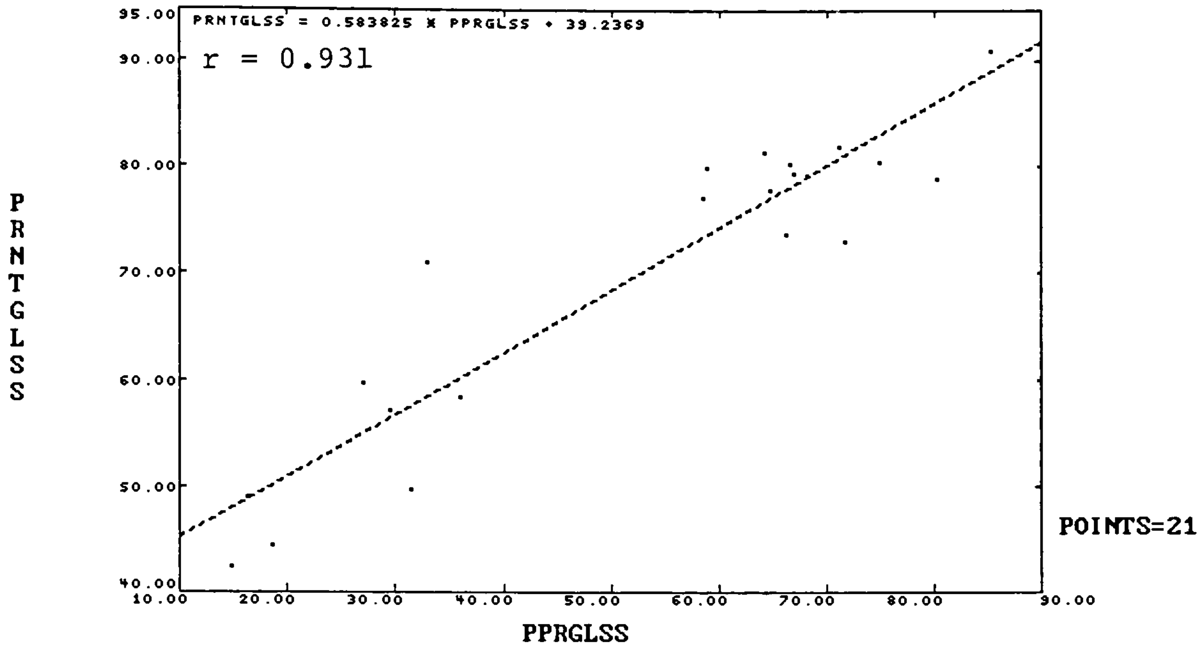


Fig. 6-23. The Relationship Between Paper Gloss and Print Gloss for Pigment Coated Papers Using Duplicator

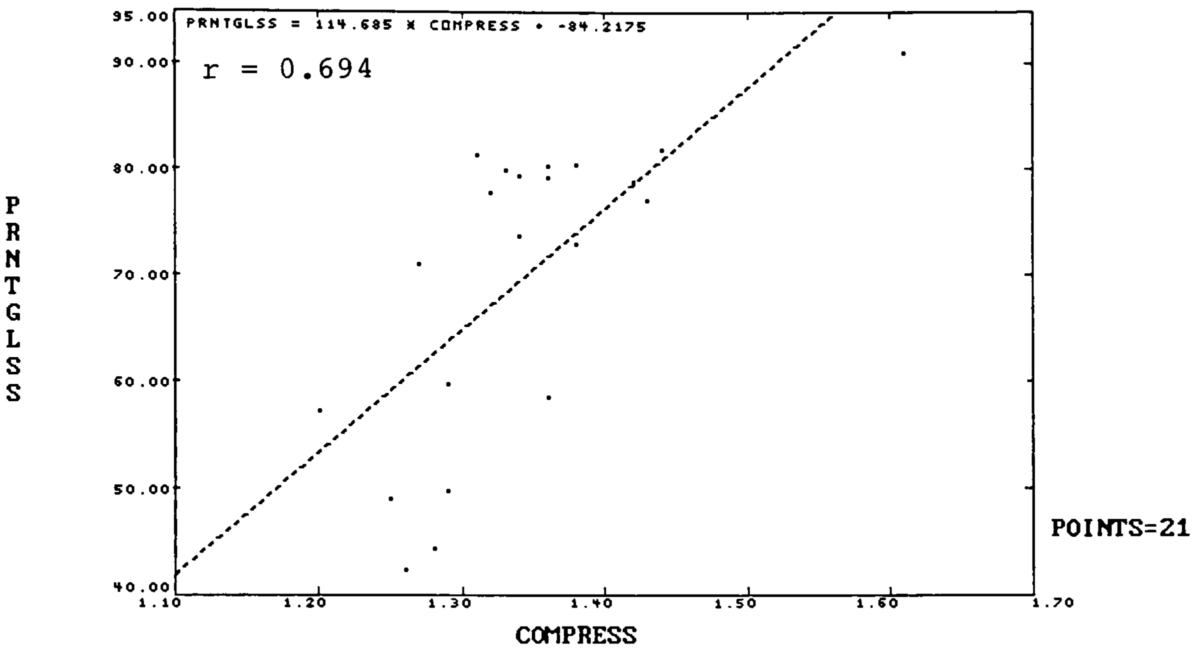


Fig. 6-24. The Relationship Between Paper Compressibility and Print Gloss for Pigment Coated Papers Using Duplicator

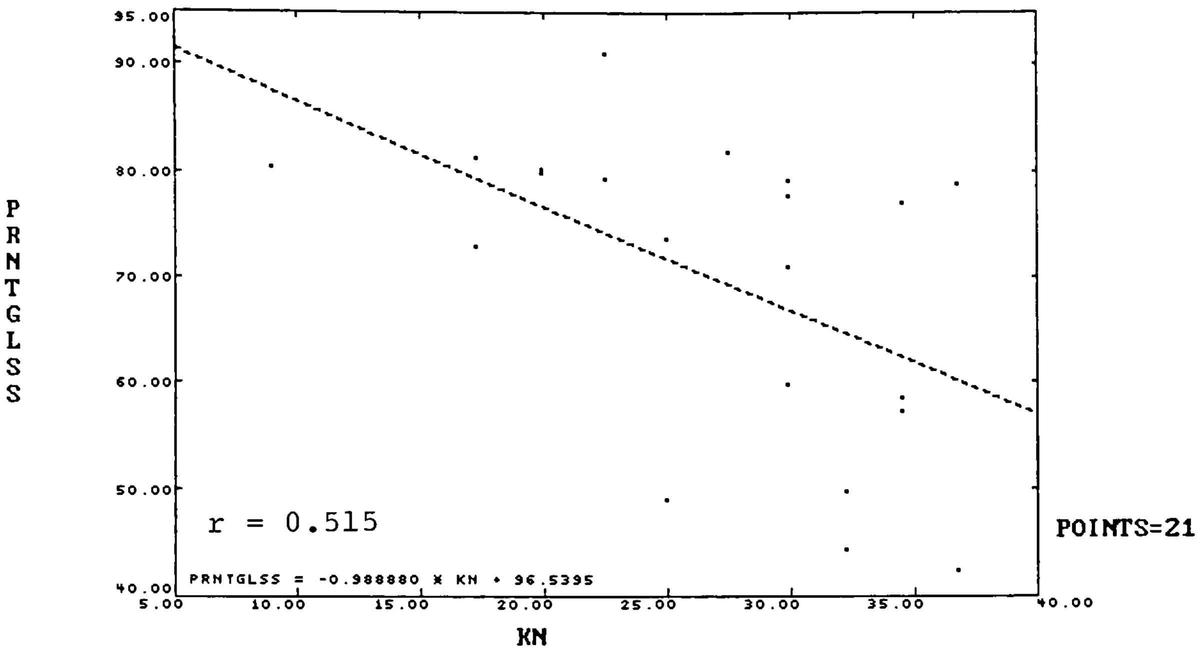


Fig. 6-25. The Relationship Between K&N Ink Absorptivity and Print Gloss for Pigment Coated Papers Using Duplicator

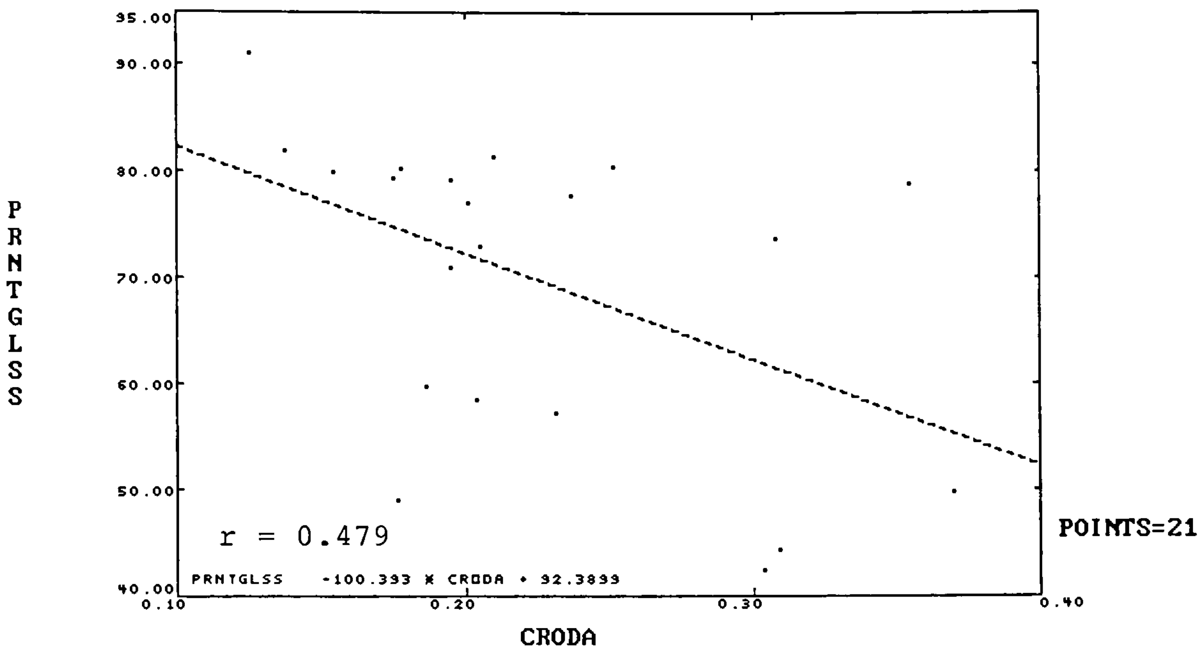


Fig. 6-26. The Relationship Between Croda Ink Absorption Density and Print Gloss for Pigment Coated Papers Using Duplicator

The author also used a Little Joe offset proving press with Dainippon magenta linseed oil ink to print on twenty four different kinds of pigment coated-paper, including two kinds of cast paper, fourteen kinds of gloss coated paper, four kinds of dull coated and four kinds of matte coated paper. We found the effect of paper roughness, gloss, K&N ink absorption and PSE on printed SID and print gloss were very significant at a 99% confidence level and correlated. The correlation coefficients between roughness and printed SID, roughness and print gloss are -0.6482 and -0.9404 respectively. The correlation coefficients between paper gloss and printed SID, paper gloss and print gloss are 0.6971 and 0.8724 respectively. The correlation coefficients between K&N ink absorption and printed SID, K&N ink absorption and print gloss are -0.6433 and -0.6458 respectively. The correlation coefficients of PSE and printed SID, PSE and print gloss are 0.7461 and -0.8856 respectively. The correlation coefficient matrix and regression analysis of printed SID as well as print gloss and their scatter diagrams are presented as follows:

*** Correlation Matrix 6-3***

Variables:

	Roughness	Papergloss	K&N	PSE	SID
Roughness	1.0000				
Papergloss	-0.8966*	1.0000			
K&N	0.5684*	-0.5845*	1.0000		
PSE	-0.8827*	0.9719*	-0.7596*	1.0000	
SID	-0.6482*	0.6971*	-0.6442*	0.7461*	1.0000
Printgloss	-0.9404*	0.8724*	-0.6408*	-0.8856*	0.7041*

Note: Value of Correlation Coefficient at Significnace Level of 0.01 is 0.5368 (degree of freedom is 22)

Table 19. Linear Regression Analysis of Printed SID for Pigment-Coated Papers Using Little Joe Offset Proving Press with Dainippon Linseed Oil Ink

Regression Analysis	Independent Variable			
	Roughness	Paper Gloss	K&N	PSE
Determination Coefficient	0.4201	0.4860	0.4150	0.5567
Correlation Coefficient	0.6482*	0.6971*	0.6442*	0.7461*
Estimated Constant Term (Intercept)	1.6779	1.5323	1.7312	1.4383
Regression Coefficient (Slope)	-0.0346	0.0016	-0.0042	0.0028
Total degree of freedom	23	23	23	23
F-ratio	15.9425*	20.8029*	15.6086*	27.6340*

Note: $F_{1,22,0.05} = 4.3009$

Table 20. Linear Regression Analysis of Print Gloss for Pigment-Coated Papers Using Little Joe Offset Proving Press with Dainippon Linseed Oil Ink

Regression Analysis	Independent Variable			
	Roughness	Paper Gloss	K&N	PSE
Determination Coefficient	0.8844	0.7612	0.4106	0.7843
Correlation Coefficient	0.9404*	0.8724*	0.6408*	0.8856*
Estimated Constant Term (Intercept)	83.4606	44.8758	88.6825	23.8067
Regression Coefficient (Slope)	-9.9964	0.4171	-0.8460	0.6793
Total degree of freedom	23	23	23	23
F-ratio	168.4570*	70.1359*	15.3300*	80.0367*

Note: $F_{1,22,0.05} = 4.3009$

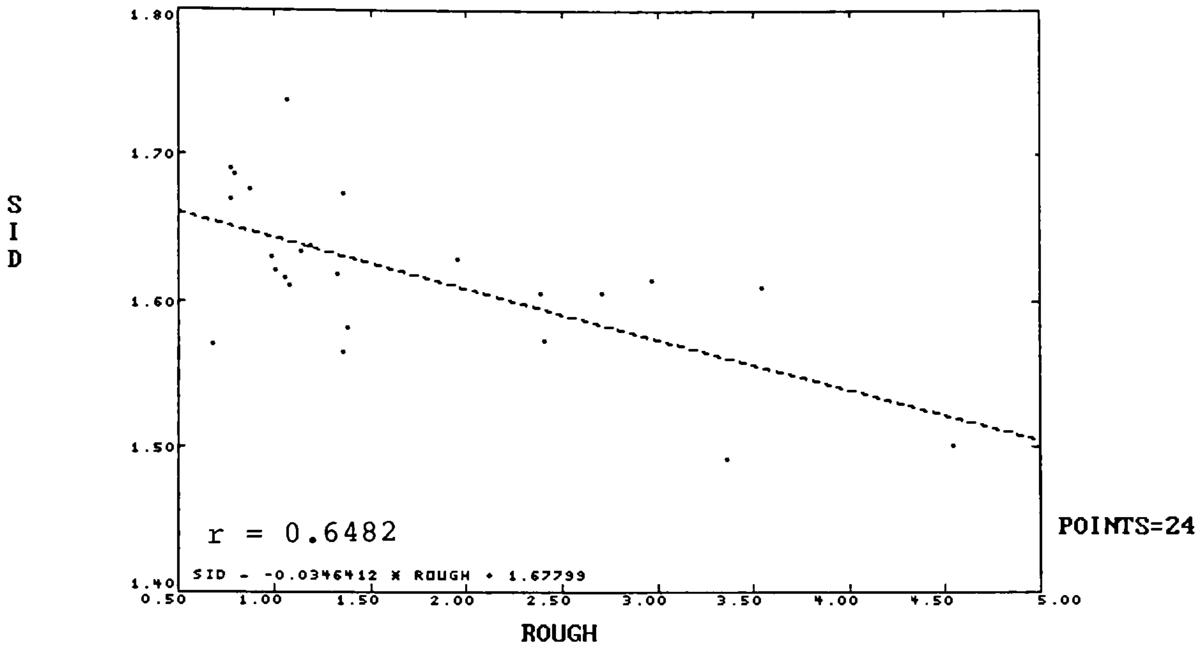


Fig. 6-27 Paper Roughness vs. Printed SID Using Little Joe

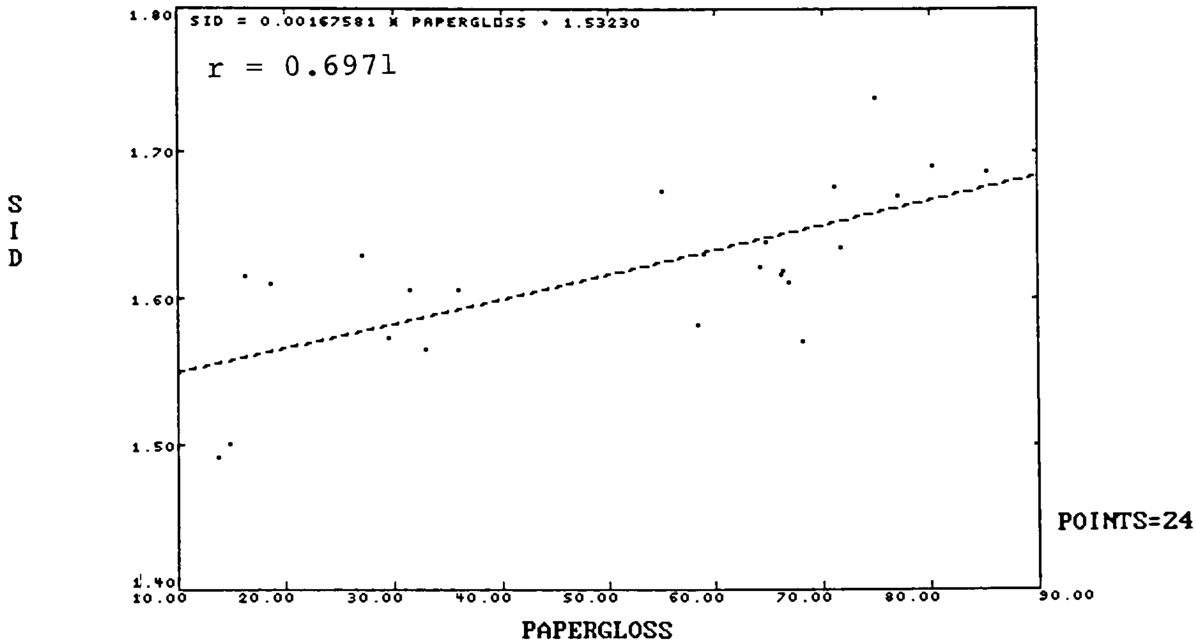


Fig. 6-28 Paper Gloss vs. Printed SID Using Little Joe

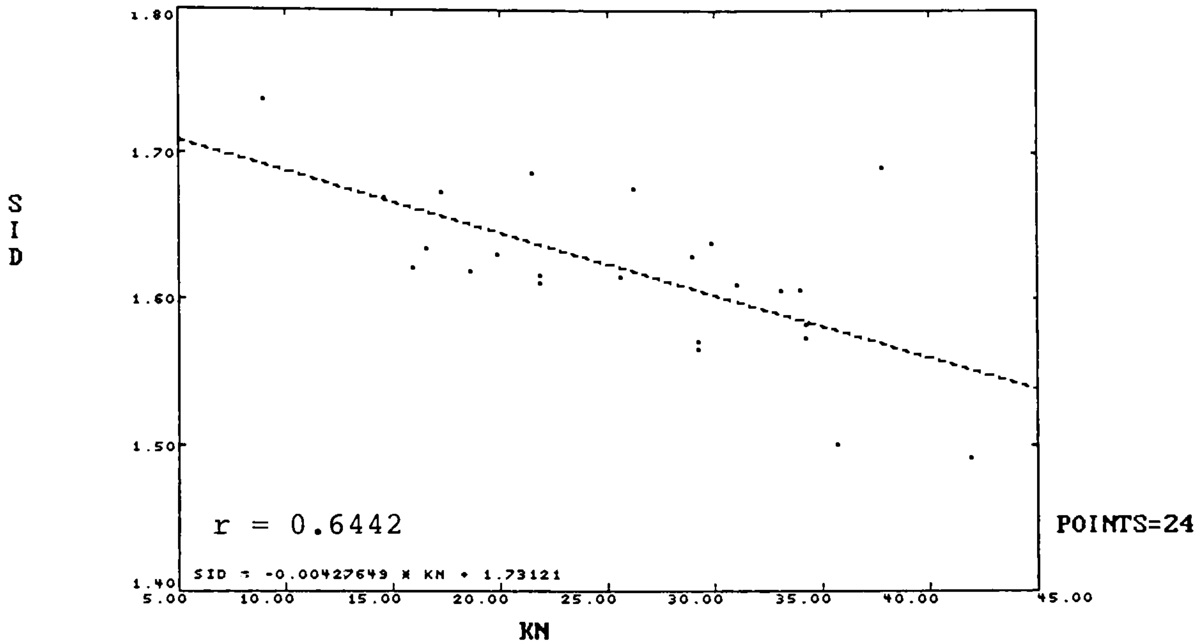


Fig. 6-29 Paper Absorptivity vs. Printed SID Using Little Joe

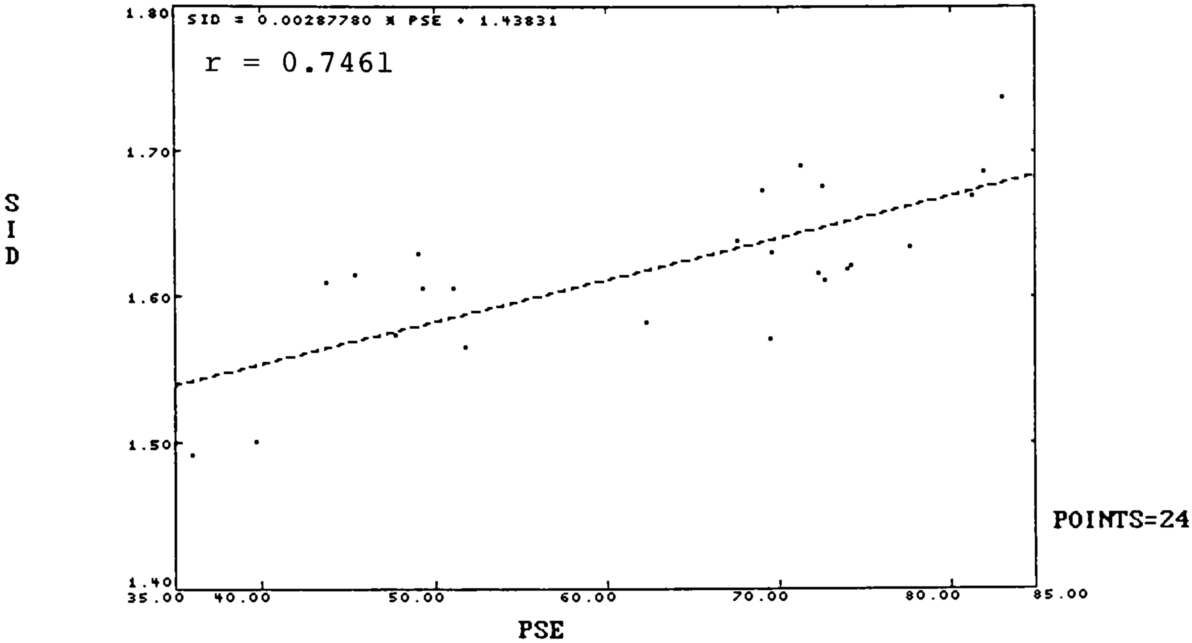


Fig. 6-30 Paper Surface Efficiency vs. Printed SID Using Little Joe

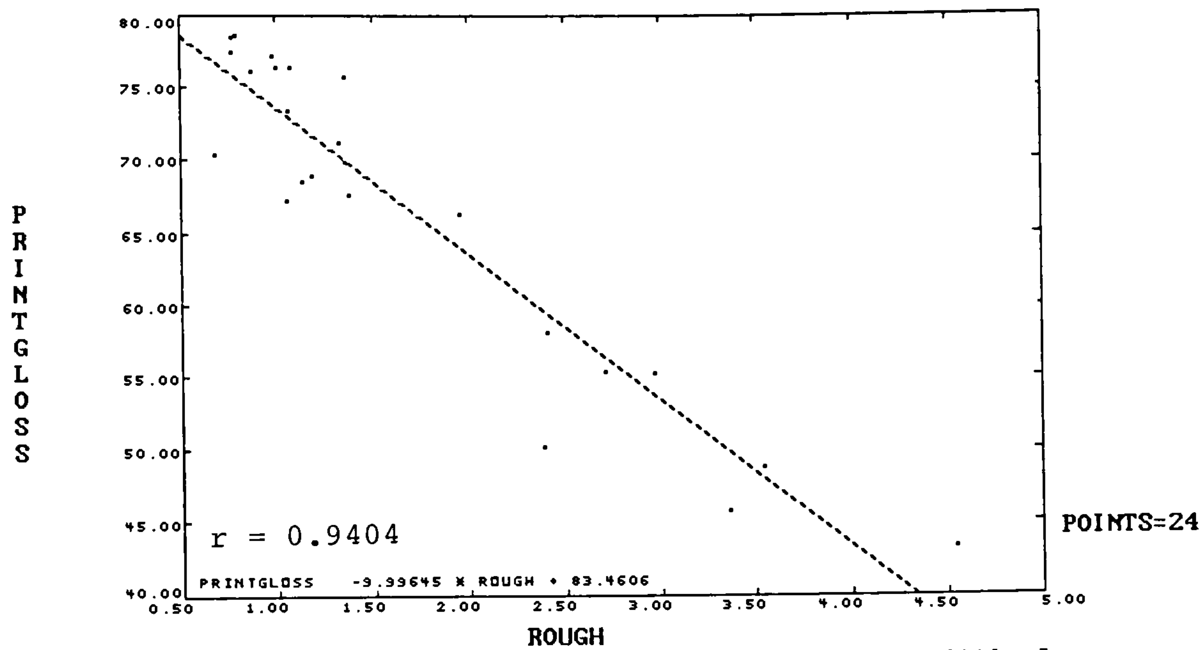


Fig. 6-31 Paper Roughness vs. Print Gloss Using Little Joe

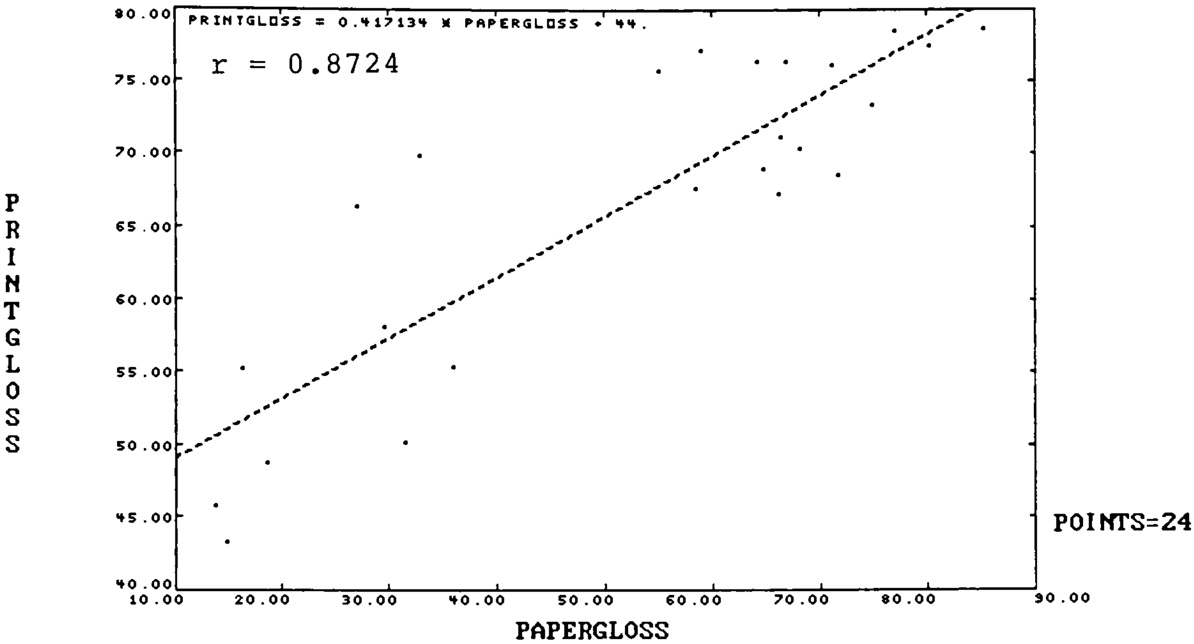


Fig. 6-32 Paper Gloss vs. Print Gloss Using Little Joe

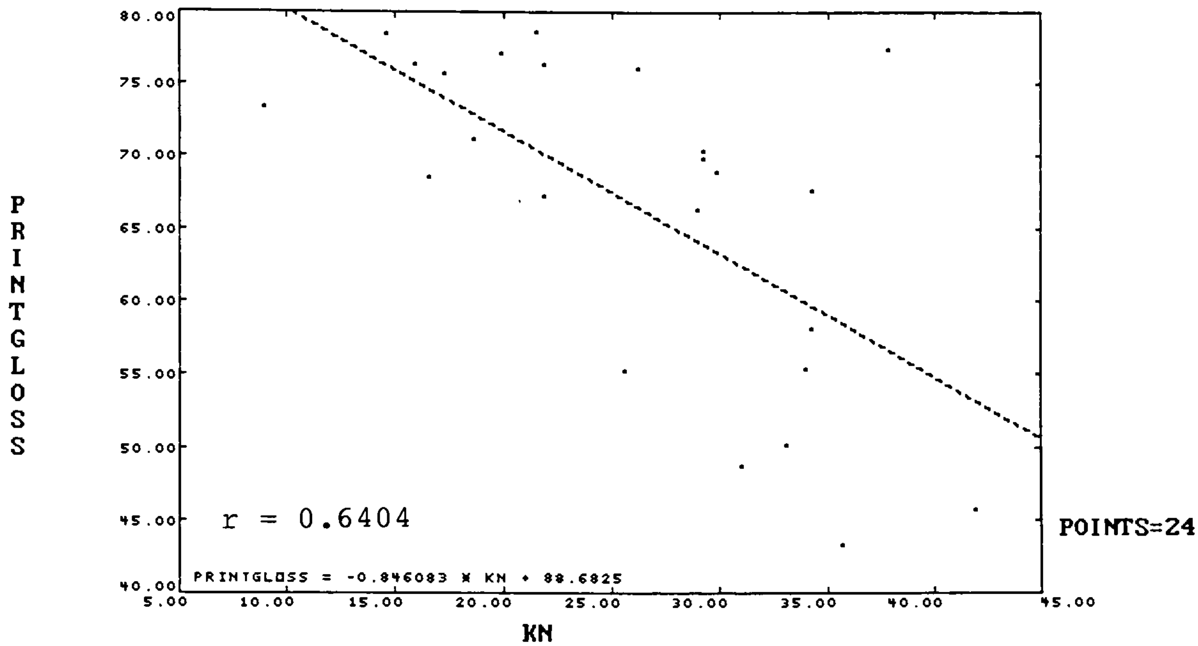


Fig. 6-33 Paper Absorptivity vs. Print Gloss Using Little Joe

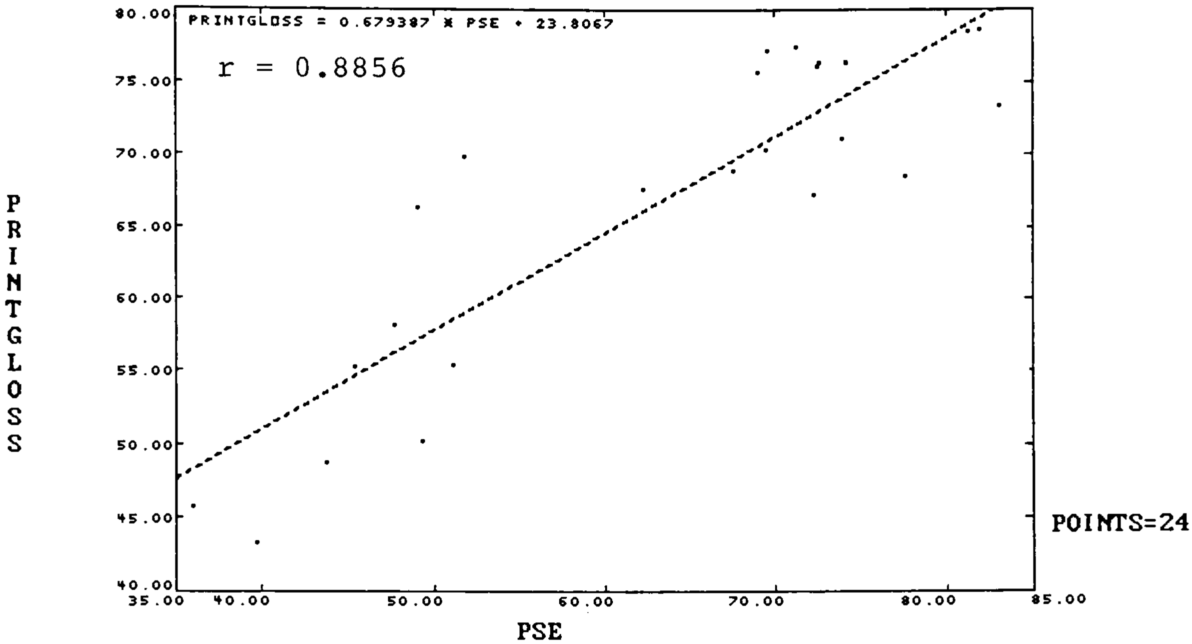


Fig.6-34 Paper Surface Efficiency vs. Print Gloss Using Little Joe

FOOTNOTES OF CHAPTER SIX

1. Jacqueline M. Fetsko and William C. Walker, Measurements of Ink Transfer of Coated Papers, TAGA Proceedings, p.130-138, 1955

2. Jacqueline M. Fetsko and William C. Walker, Measurements of Ink Transfer of Coated Papers, TAGA Proceedings, p.133, 1955

3. Tappi Coating Conference, p169. 1988

CHAPTER SEVEN

CONCLUSION

In the introduction of this paper, the stated objective of this study was to decide whether paper roughness, gloss and K&N ink absorption has an effect on printed SID or print gloss and also to see if Preucil's PSE equation can be improved.

The following are from the initially proposed project and the extension of this work, the conclusions drawn from the findings and analyses presented. Each hypothesis is stated again. Initially, three hypotheses were stated: 1. There is no significant effect due to paper gloss on printed SID or print gloss. 2. There is no significant effect due to paper roughness on printed SID or print gloss. 3. There is no significant effect due to K&N ink absorption on printed SID or print gloss. 4. There is no interaction of paper roughness, gloss and ink absorption on printed SID or print gloss. Two conclusions can be drawn:

1. Regardless of whether the Little Joe proving press or the duplicator is used for measuring, it is shown that paper roughness in a range of 0.67μm to 1.37μm, gloss in a range of 55% to 75% has no significant effect on printed SID at a 95 percent confidence level. But K&N ink absorption density in a range of 0.03 to 0.12 (paper absorptivity in a range of 8.89% to 32.19%) shows partially significant effect on printed SID at a 95 percent confidence level. The number of significant tests is four out of six.

2. It was found that paper roughness has a significant effect on print gloss at a 95 percent confidence level, but paper gloss in a range of 55% to 75% may be said to have partially significant effect on print gloss. The number of significance tests is four out of seven. The K&N ink absorption in a range of 0.03 to 0.12 (paper absorptivity in a range of 8.89% to 32.19%) has significant effect on print gloss. The number of significance tests is five out of seven. Based on the analysis of variance, the first and second hypothesis are accepted but the third hypothesis is rejected.

The last hypothesis was stated as: There is no significant interaction of paper roughness, gloss and K&N ink absorption. A conclusion follows:

It was found that the interaction of paper roughness, gloss, and K&N ink absorption has a significant effect on printed SID or print gloss regardless of using either the Little Joe offset

proving press or the duplicator with different inks at a 95% confidence level. Therefore, the last hypothesis is rejected. Since there is a significant high order interaction each of the individual main effects when considered in combination as they must, can not be disregarded as having no effect on the response variables of this study.

Some Comments on the Statement of the Problem of the Study

1. Paper roughness and gloss are expected to be critical to printed SID and print gloss for the pigment-coated papers. Paper roughness is the most significant factor of all the paper surface variables investigated. Decreasing paper roughness predicts an increase in printed SID and print gloss. Decreasing paper gloss will lead to a decrease in printed SID and print gloss. This relationship is always significant for pigment coated papers.
2. It was not found that gloss coated paper with low K&N ink absorption always yields higher printed SID and print gloss than the gloss coated paper with high K&N ink absorption. Also the K&N ink absorption did not show a significant effect on printed SID and print gloss at a 99% confidence level when the duplicator was used for pigment coated papers.
3. The new PSE equation provides improved prediction of print gloss over that of the Preucil's PSE equation in terms of correlation coefficient for the pigment coated papers. Even though Preucil's PSE equation failed to predict printed SID and print gloss significantly for the gloss coated papers, it still

could predict printed SID and print gloss significantly at a 95% confidence level for pigment coated papers.

Recommendations for Further Study

1. Since the K&N ink absorption does not alone predict printed SID and print gloss for gloss coated papers, can K&N ink absorption be used to predict SID or print gloss for uncoated papers? Does K&N ink absorption have a significant effect on printed SID or print gloss for uncoated papers? The answer should be further investigated.
2. The author suspects an increase in ink film thickness should lead to an increase in print gloss for gloss coated papers. The experimental results of this study did not show this trend. This needs further investigation.
3. Can the new equation be applied to all the pigment coated papers? The answer is positive. If the new PSE equaton can be used to verify its effectiveness by the other printing approaches, then this will benefit the paper manufacturers and the graphic art industry.
4. Another modified PSE equation probably can also predict printed SID or print Gloss stated as follows:

$$\text{Modified PSE} = \frac{0.6/R \times 100 + P.G. + (100 - P.A.)}{3}$$

P.G. stands for paper gloss
P.A. stands for paper absorptivity

Bibliogrphy

1. A letter from Authur I. Lowell, Sun Chemical Corp. June, (1989)

2. Anthony Bristow and Hnss Begenblad, STFI, Interpretations of Ink-Stain Tests on Coated Papers, p.373-391, (A report from Mr. Chester Daniels, RIT T&E Center)

3. Anthony Bristow, Petter Kolseth, Paper Structure and Properties, p.174-181, (1983)

4. Anthony Bristow, The Surface Compressibility of Paper---- A Printablity Property, Advances in Printing Science and Technology, p.373-383, (1980)

5. Chester Daniels, Senior Technologist, Paper and Ink Lab at the RIT T&E Center.

6. Chin-yih Chen, Senior Technologist, Paper and Ink Lab at RIT T&E Center.

7. D.J. Andella, Tappi, 123A-128A, (1952)

8. Frank M. Preucil, A New Method of Rating the Efficiency of Paper for Color Reproduction, GATF Research Progress General Memo #8, (1963)

9. GATF Print Quality Survey, (1989)

10. GATF, What The Printer Should Know About Paper, p.37-129, (1986)

11. GATF, What The Printer Should Know About Paper, p.286, (1983)

12. H. Fujiwara, N. Fujisaki, I. Shimizu, I. Kano, Tappi Journal, The Effect of Water Penetration on Offset Mottling, p.91-97, (May 1989)

13. Ian C. White, Quality Management in Canadian Government Printing, Tappi Conference, Printing and Reprography Testing, p.1-12, (1977)

14. J. F. LaFaye, JP. Maume, JM. Schwob, R. Chiodi, The Effect of Some Coating Variables on Gravure Print Quality Using LWC Paper, Tappi Journal, p.63-69, (Dec. 1988)

15. J. F. LaFaye, JP. Maume, G. Gervason, P. Piette, Some Aspects of Coating with Surfactants upon Quality and Offset Printability, Tappi Coating Conference, p.107-115, (1987)

16. Jacqueline M. Fetsko and William C. Walker, Measurements of ink Transfer in the Printing of Coated Papers, p.130-138, (1955)

17. James. J. Casey, Pulp and Paper, p.1715-1972, Vol.3, (1983)

18. James. J. Casey, Pulp and Paper, p.1823, (1983)

19. James. J. Casey, Pulp and Paper, p.1761, (1983)

20. James. J. Casey, Pulp and Paper, p.1720-1724, (1983)

21. Japan Tappi Journal, (May 1989)

22. J. H. Bardsley and L.J. Marin, Paper Ind., 29(3), p.438-440, (1947)

23. J.R. Parker. An air leak instrument to measure printing roughness of paper board. Pap. Technol. 6:126-130 (1965)

24. J.R. Parker, Bowater Technical Services Ltd. England, Tappi Printing & Reprography Conference, p.65-72, (1980)

25. J.R. Parker, Fundamental and Practical Aspects of Air-leak Roughness Measurement with Particular Reference to the Parker-Print-Surf Roughness Tester, Tappi Printing & Reprography Conference, p.71, (1980)

26. Lars C. Ingman, Tappi Annual Meeting, p.131-132, (1988)

27. Lars O. Larrson, Physical Background of Some Terms Used to Describe Print Quality, The Swedish Newsprint Research Center, Stockholm, Sweden, p.114-119.

28. Michael H. Bruno, W.C. Walker, Pulp and Paper Chemistry and Chemical Technology, Vol.4, p.2261, (1983)

29. P.A.C. Gane. ECC International Convertex 88, Mottle and the Influence of Coating and Binder Migration, p.34-41, (April 1989)

30. Parker-Print-Surf Roughness Tester Manual

31. R.H. Crotogino, Supercalendered Conventionally Calerdered Newsprint---A Comparison of Surface and Printing Properties, Tappi Printing & Reprography Conference, p.89-93 (1980)

32. R.L. Van Gilder, R.D. Purfeerst, Tappi Coating Conference p.45, (1986)

33. Scandinavian Pulp, Paper and Board Testing Committee. Standard SCAN-P7:75, Thickness and Apparent Density.

34. SCAN-G2:63, Statistical Treatment of Test Results

35. SCAN-P 36:77, Evaluation of Test Prints

36. S.W.P. Wyszkowski, Printability Testing: A Critical Review, Tappi Conference, p.53-63, (1979)

37. Tappi, Paper Surface Strength, (1983)

38. Tappi Standard, T452 om-87, Brightness of Pulp, Paper and Paperboard (Directional Reflectance 457 nm)

39. Tappi Standard, T425 om-81, Opacity of paper (15^{o}/Diffuse Illuminant A, 89% Reflectance backing and Paper backing)

40. Tappi Standard, T524 om-86, Color od White and Near-White Paper and Paperboard by L,a,b,45^{o}, 0^{o} Colorimetry.

41. Tappi T411 om-83, Thickness (Caliper) of Paper and Paperboard

42. Technidyne T480 Glossmeter Manual

Appendix A

Paper Samples Before Printing and After Absorping K&N Ink

Paper Samples and K&N Ink Absorption

sample: E	K&N Ink Absorp. of Sample E
sample: F	**K&N Ink Absorp. of Sample F**
sample: G	**K&N Ink Absorp. of Sample G**
sample: I	**K&N Ink Absorp. of Sample I**

Paper Samples and K&N Ink Absorption

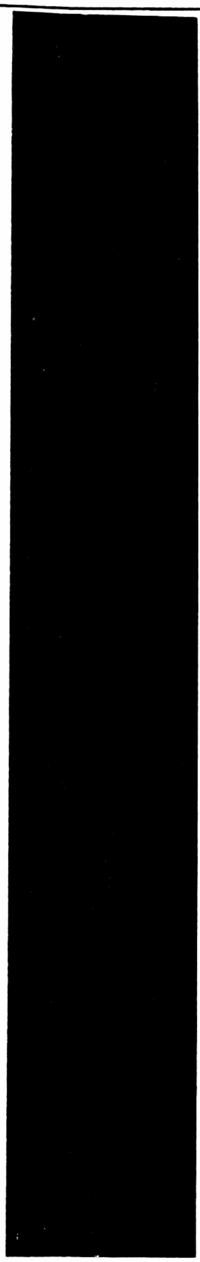
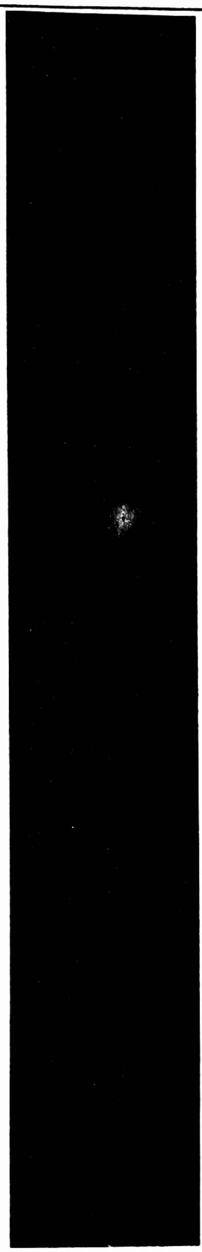
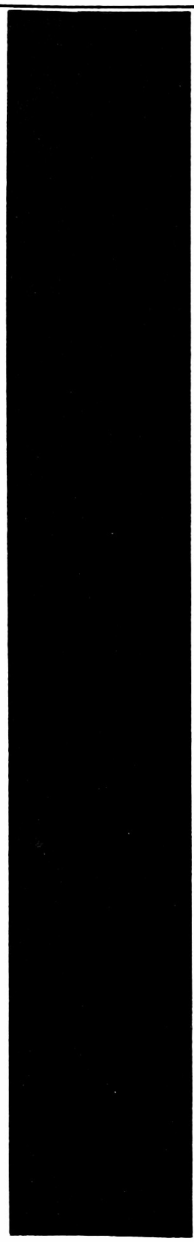
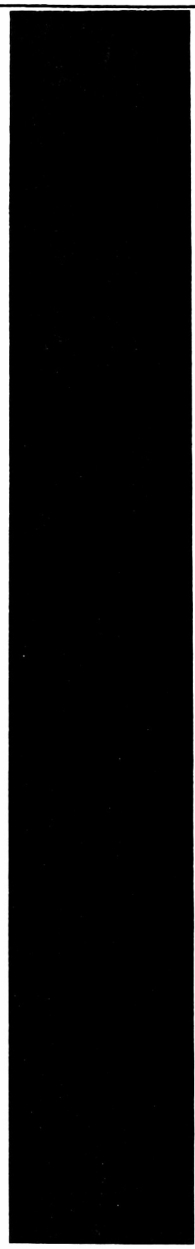
sample: K	K&N Ink Absorp. of Sample K
sample: L	K&N Ink Absorp. of Sample L
sample: M	K&N Ink Absorp. of Sample M
sample: P	K&N Ink Absorp. of Sample P

Appendix B

Paper Samples Printed from Duplicator with Flint Heatset Process Black Ink

sample: E	sample: F	sample: G	sample: I

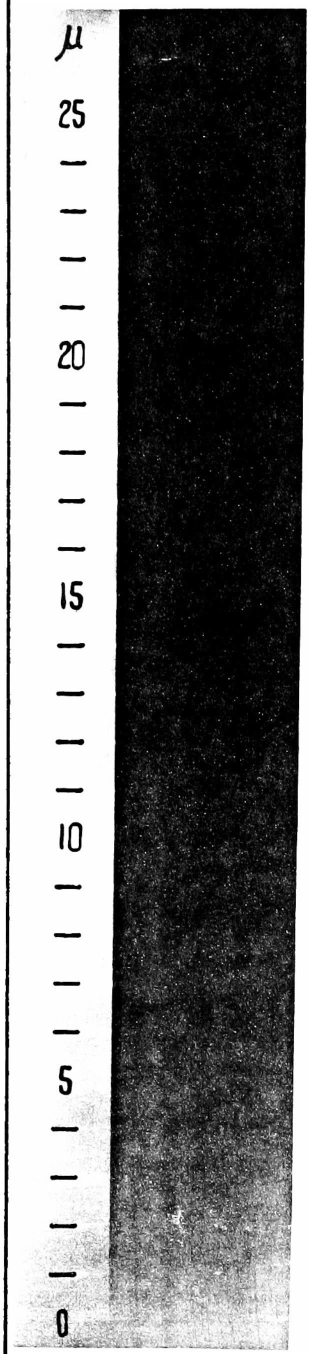
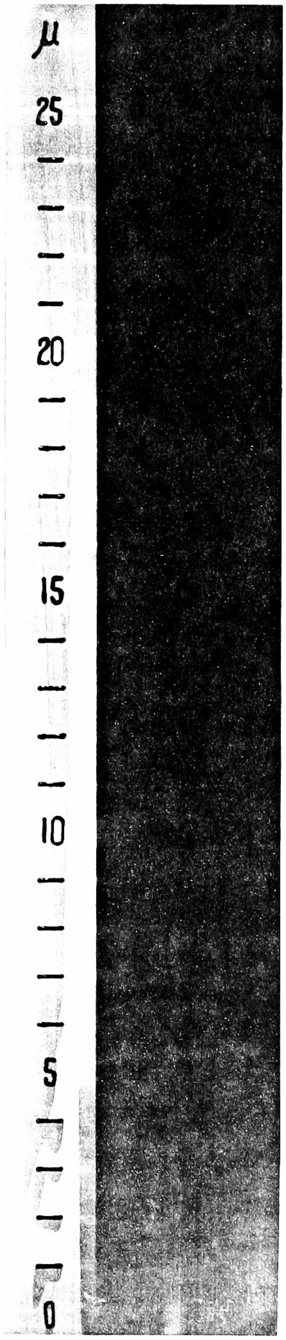
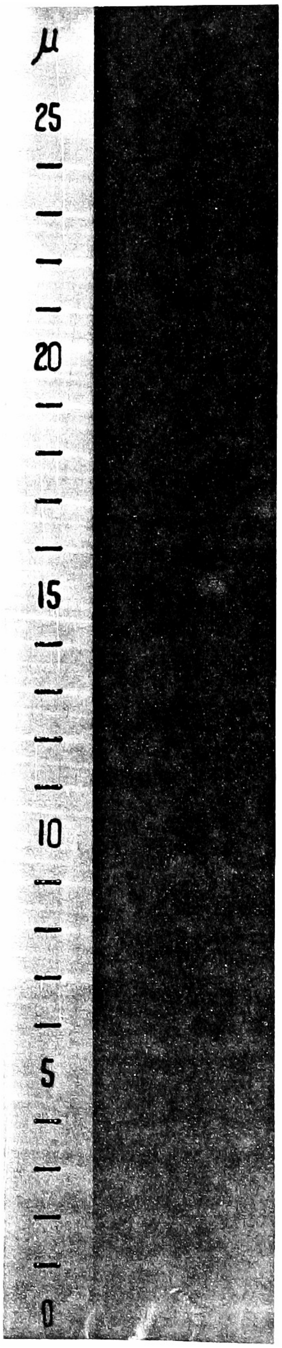
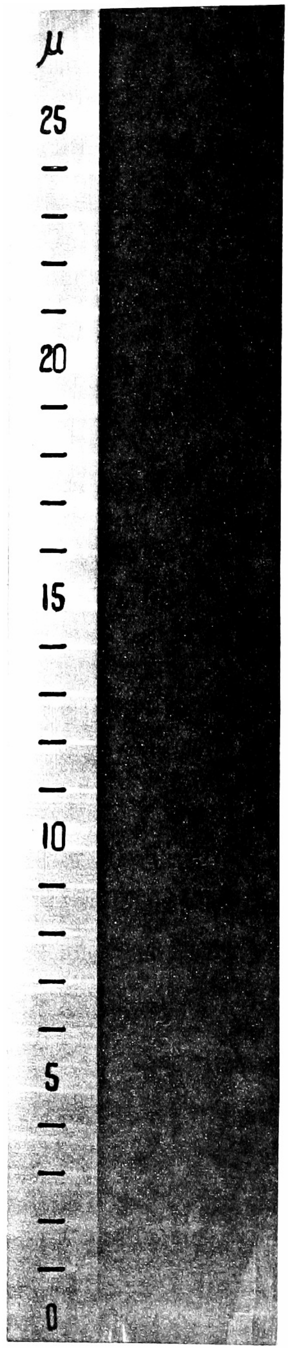
Note: 1. Duplicator:
2. ink: Flint heat-set black ink

sample: K	sample: L	sample: M	sample: P
			

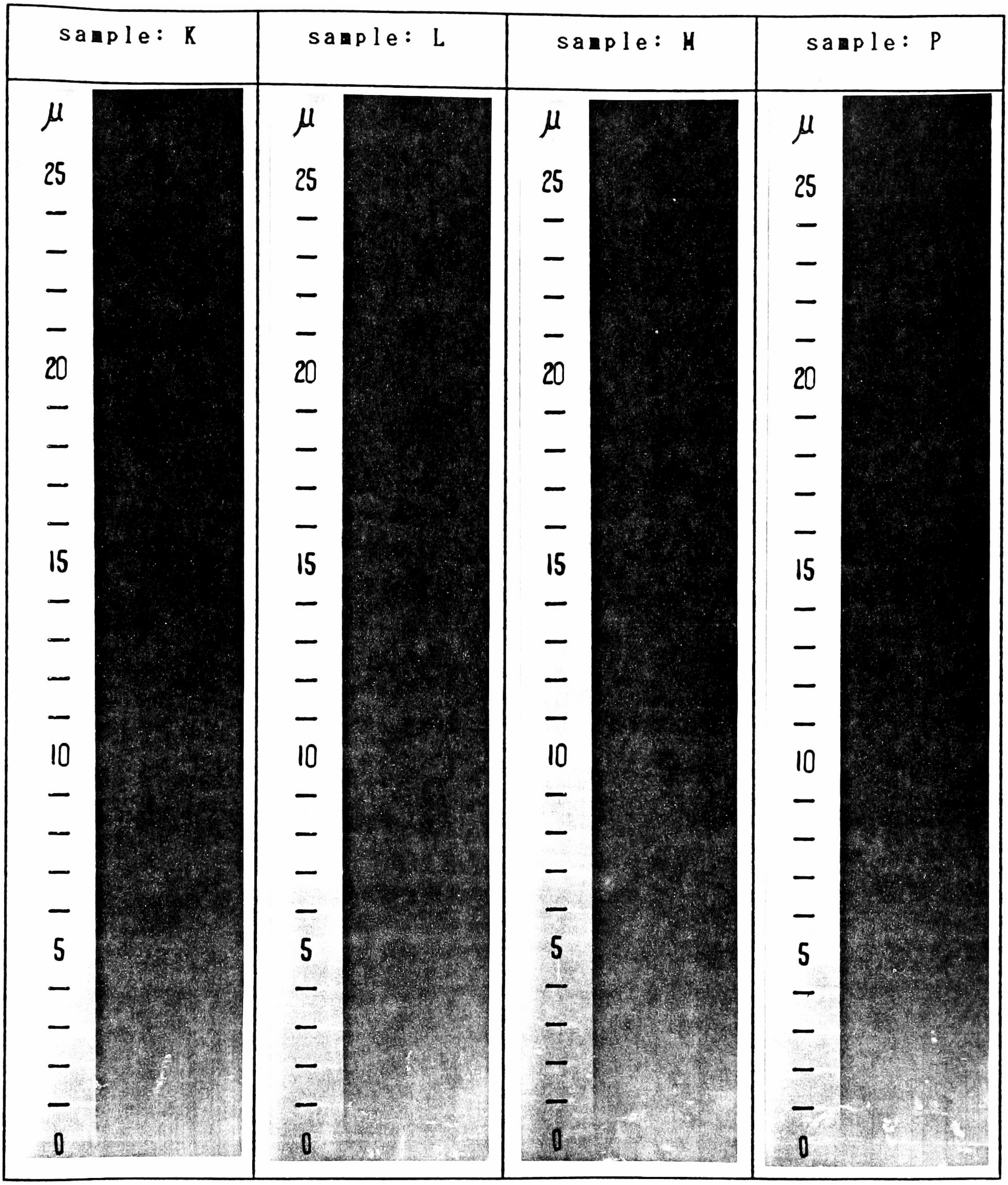
Note: 1. Duplicator:
2. ink: Flint heat-set black ink

Appendix C

Paper Samples Printed from Little Joe Offset Proving Press with Danippon Magenta Linseed Oil Ink

sample: E	sample: F	sample: G	sample: I
			

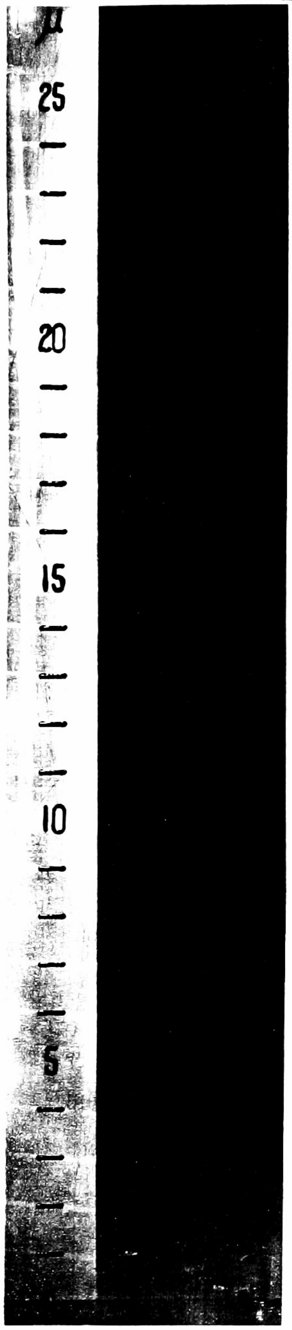
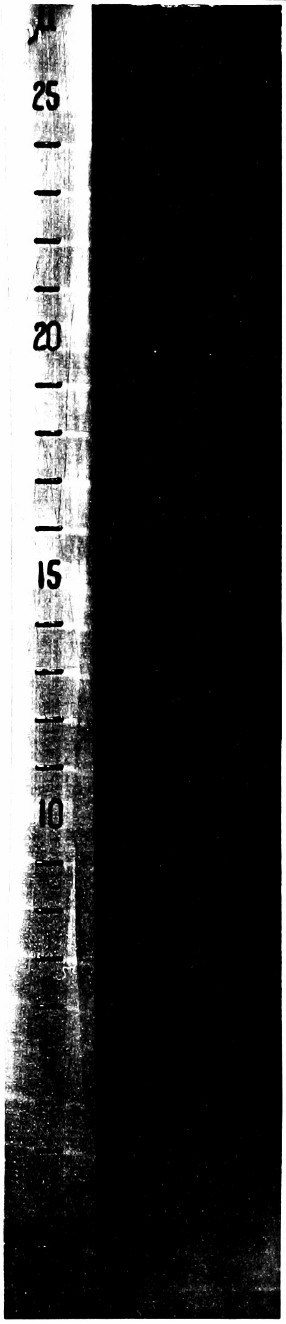
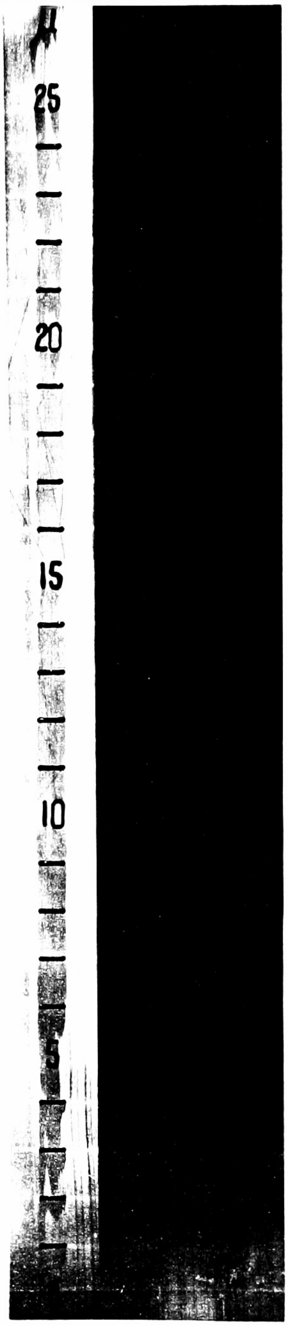
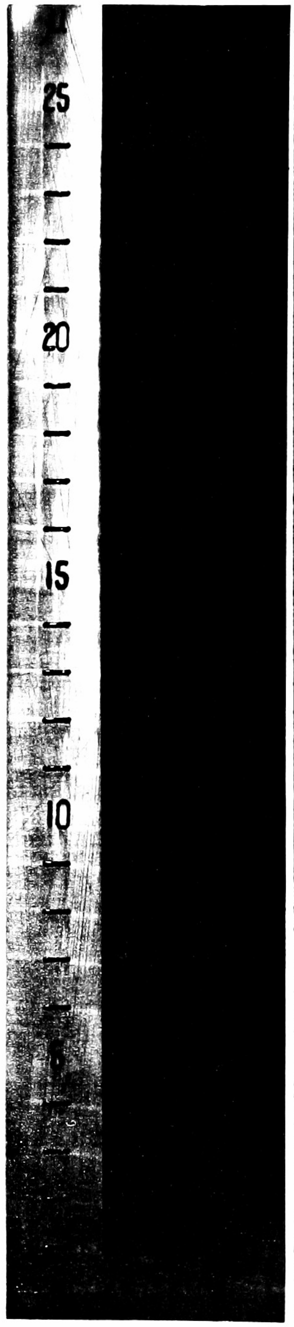
Note: 1. printability tester: little Joe
2. ink: Danippon linseed oil/magenta
3. ink tack value: 14



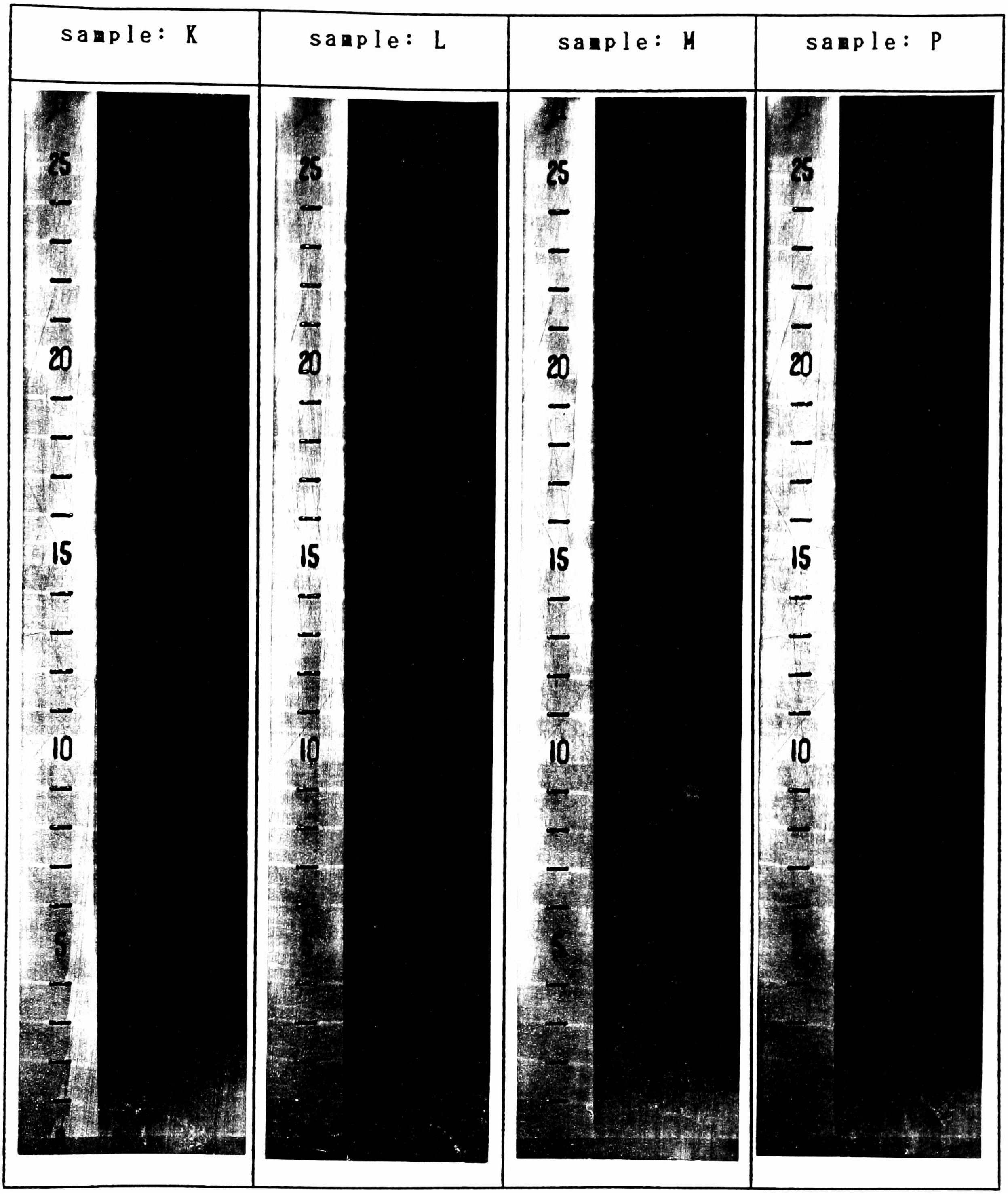
Note: 1. printability tester: little Joe
2. ink: Danippon linseed oil/magenta
3. ink tack value: 14

Appendix D

Paper Samples Printed from Little Joe Offset Proving Press with Morrison Quickset Process Black Ink

sample: E	sample: F	sample: G	sample: I
			

Note: 1. printability tester: little Joe
2. ink: Morrison quick-set black ink



Note: 1. printability tester: little Joe
2. ink: Morrison quick-set black ink