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Effect of Calendaring on Flexographic Print Ability of Linerboard

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EFFECT OF CALENDERING ON FLEXOGRAPHIC PRINTABILITY OF LINERBOARD

by

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Today's corrugated board end user demands a higher quality than ever. Retailing techniques are moving toward so-called "value-added packaging," which consists of high quality printed packaging that works to sell the product from the shelf. To preserve its dominance in the corrugated market, the flexographic printing industry must find new ways to cost effectively satisfy the new demands.

One possibility is the use of an additional calendering step to give the linerboard better printability. This study evaluated two different types of calenders: the shoe (extended nip) calender and the hot/soft nip calender (Appendix A). The test material was commercially produced linerboard, which was on-line gloss calendered.

The objective of this study was to investigate the relationship between the quality of the printed samples and their calendering conditions. The results showed that the linerboard characteristics of water and ink absorption and surface roughness contribute significantly to print quality. The optical properties of delta gloss and print density, and to a lesser extent print mottle and gloss mottle, correlated with the subjective visual ranking of the samples according to print quality.

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CHAPTER I

INTRODUCTION

The printing processes of offset lithography, gravure, and flexography collectively dominate the commercial printing industry. Each has a unique niche; still, there exists heavy competition in many areas. Flexography is the newest of the processes, dating from 1955 *(1)*. In 1996, it comprised about 20% of the worldwide printing market. Throughout its history, flexography has outpaced the other two in market growth. It is perhaps best suited for the packaging industry; as of 1996, it held 50% of the domestic market *(2)*. A more recent estimate puts this figure at about 65% for 1999, which is the result of an 8-10% average annual growth rate during this decade *(3)*. The corrugated board market alone had $184 in sales in 1998 *(4)*.

Corrugated board is a converted board product. It consists of two components. The inner component is called the *corrugating medium.* This is the lightweight, inner ply that is fluted for structural strength. It is glued to two outer layers of *linerboard*, which is lightweight board. Linerboard comprises large North American sales, with total tonnage much greater than that of newsprint *(5)*. The linerboard may be printed by itself before being joined with the corrugating medium in a process called *preprint*, or the corrugated board itself may be printed, which is called *postprint*. The latter is cheaper, but commonly at the cost of lower print quality and loss of corrugated board strength *(6)*.

While flexography is dominant in the corrugated market, there is a new challenge emerging. There is a trend toward high quality graphic art on corrugated board, which is driven by the demands of the end users, who want packages that will sell the product from the shelf *(7)*. Retailers, to cut overhead, are decreasing the ratio of sales staff to customers. This creates the need for the printed package to capture the attention of the consumer. This technique is called *point-of-purchase (POP) retailing*. The packaging itself is referred to as *value added packaging*. It is estimated that the percentage of products retailed in value-added packaging could reach 22% by 2000, as this sector has a current growth rate of 6-7% *(8)*.

CHAPTER II

THEORETICAL BACKGROUND

Printability of Linerboard

Before trying to find correlations between linerboard characteristics and printability, it is necessary to define what is meant by the term *printability*. While it is the consumers' impressions that ultimately count, it is difficult to quantify perceived print quality. The problem is that the consumers' perceptions are subjective; this is compounded by the fact that different people will perceive the images differently. There is little agreement on which parameters accurately quantify print quality; three commonly accepted ones are: *print density*, *print uniformity*, and *gloss*.

Print density is a measure of the difference in *optical density* between the print area and the unprinted substrate surface. *Optical density* is a measure of the amount of incident light of a specified wavelength that is reflected from the ink and substrate. Good print density appears as a sharp, finely detailed image. Print density values are logarithmic. Specifically, they are the negative logarithm of the fraction of incident light that is reflected. For instance, if the relectance is 0.10, the logarithm is –1.00, and the negative of this gives a print density value of 1.00.

The light in densitometers is incident at 45 degrees, and the measurement angle is 90 degrees. Thus, it measures *diffuse reflection,* or the light that is scattered or non-directional *(9)*. Reflection that is directional, or has an angle of reflection equal to its angle of incidence, is called *specular reflection*. The measured quantity of this reflection is called *gloss (10)*. Gloss affects the overall quality of the printed area. Another important factor is the difference in the gloss of the printed area and the unprinted substrate, or *delta gloss*. Typically, a large delta gloss is desirable.

Print uniformity is a measure of the variation of the reflected light of the printed area due to variations in the printed substrate. Poor print uniformity is called *mottle*, an apparent graininess or unevenness in the image. This has been found by some to be the most important factor affecting subjective analysis of print quality *(11)*. Mottle can be of either the print density or gloss type, and can be measured accordingly. Mottle can also occur because of uneven ink transfer. This property is referred to as *print coverage*; this quantity should not be misinterpreted as a measure of print uniformity. Thus, accurate measurements of print uniformity depend on good print coverage.

Substrate Properties That Affect Printability

As the trend towards value-added packaging increases, a thorough understanding of the relationships between the physical characteristics of the linerboard and the print quality is needed. Several factors effect how well linerboard will print, some better understood than others. Zang and Aspler *(12)* attempted to summarize these factors and evaluated the methods currently used to test them. Among factors discussed were roughness of the printing surface, porosity of the substrate, and water absorbency.

The *roughness* of a surface is the deviation from the mean planar surface. For a heterogeneous surface like that of uncoated linerboard, the apparent roughness is due to many different scales of roughness. For example, some roughness may be attributed to fiber formation, while a much smaller scale roughness can be attributed to individual fiber characteristics. Aspler and Zang point out that there is no natural distinction between surface deviations, or "hills and valleys," and the inter-fiber pores. This point can be illustrated by considering the surface created by cutting a sponge. If one were to try to measure the roughness of this surface, it would be difficult to calculate how much of the variation is attributable to the cleanness of the cut, and how much to the porous structure of the sponge. Unfortunately, in practice, roughness is usually inferred from the quality of the printed image itself *(13)*.

The most common method of measuring roughness is by measuring the rate of airflow between the surface of the board and a smooth platen under a known pressure. The rougher the sheet, the more recesses will be present to facilitate the flow. Thus, higher airflow rates indicate higher roughness values. A common instrument for roughness testing for boards in the United States is the Sheffield Instrument, but this instrument has been criticized for showing poor correlation with the printability of linerboard. A much better correlation can be found with the Parker Print Surf because it more sensitive to small differences in surface profile *(14)*.

A more direct way to measure the deviations of the board surface is with a *profilometer*. The advantage of this instrument is that the actual contour of the surface can be mapped. This allows roughness to be calculated directly as the standard deviation of the surface height or by some other means, rather than it being inferred from airflow rate. With airflow type roughness testers, only gross roughness can be measured, while profilometers show the scale profile of the roughness. This is useful because the eye can more easily detect some scales of roughness than others.

Porosity, or the pore volume fraction of the substrate, mainly affects printability by influencing *ink setting* and *ink holdout*. Ink setting is a physical phenomenon, which results from bonds being created and viscosity of the ink increasing upon application. Ink holdout is the tendency for pigment to stay on top of the substrate surface and not flow into the pores with the vehicle.

A substrate's porosity is usually approximated by its *air permeability*. Air permeability is a measure of how easily air can flow through the substrate's pore network. It is theoretically a function of several factors, including porosity (Appendix B). While the two characteristics are uniquely defined, the porosity of a substrate is often identified by the substrate's air permeability.

Unlike roughness testing, there is poor correlation between any air permeability measuring instrument and linerboard printability, because the air permeability is a function of factors other than porosity *(15)*. Also, there is an inherent shortcoming of trying to use airflow to predict the flow behavior of ink into the pores. The Lucas-Washburn equation *(16)* predicts that the ink uptake in paper is a dynamic function of viscosity as well as surface tension (Appendix C).

Løvhaugen, et al. *(17)* found it useful to consider the percent void volume bounded in the z direction by the maximum and minimum heights of the surface. They used a confocal laser scanning microscope to gather height data of the surfaces of their 11 uncoated samples of brown, white top, and laminated linerboard. By evaluating four different fractions of the volume of interest, they found correlation factors between 0.8 and 0.9 with Parker Print Surf roughness values. This suggests that the porosity of the most significant z-direction fraction of the linerboard, that which bounds the surface, is a measure of the roughness of the surface.

This might explain why air permeability correlates poorly with linerboard printability. It might be that air permeability is predicts printability insofar as it is correlated to roughness. Consequently, the thicker the paper or board being measured, the pertinent z-direction fraction comprises a smaller fraction of the total caliper, thus reducing the predictive strength of air permeability. Also, if there are different plies, the porous structure of this fraction may not well represent that of the rest of the sheet.

Water absorbency has a large effect on printability, but the effect is poorly understood. Flexographic inks for linerboard printing are usually water-based, so the major mechanism for drying is absorption of the vehicle, rather than evaporation or some other mechanism. Zang and Aspler *(18)* expressed that there is conflicting evidence as to whether more or less absorption is desired for good printability. They concluded that the relationship between absorption and printability is complex; higher absorption causes better transfer, yet leads to ink waste as excess ink flows into the pores.

Printability analysis for linerboard was conducted by Aspler, et al. *(19)*. They stressed that the correlations depended on exactly which characteristic of the printed image was being studied. They found that the overall subjective quality of halftones was a function of roughness and brightness of the linerboard. They also found that roughness led to problems in print density and ink holdout when considering the spectrum of grades, but had little effect on any single grade.

Effects of Calendering

Calendering is a process by which the web is passed through a high pressure nip, where one or both of the calendering rolls has a very smooth surface. Calendering is used for three purposes: to correct irregularities in sheet formation, to improve sheet surface smoothness, and to compact and densify the sheet *(20)*. One variation of this system is to use a “shoe” as a backing instead of a roll to extend the residence time of the web in the nip; such a calender is called an *extended nip calender*.

The changes imparted to the substrate are primarily functions of the nip characteristics, residence time, and temperature. The make-up of the sheet, initial sheet temperature, and moisture will also have effects. The two primary nip characteristics are the radii of the rolls and the load, measured in units of pounds per linear inch. In actuality, there is a non-uniform (elliptical) pressure profile in the machine direction, with a peak pressure value (Appendix D). Both the peak pressure value and the residence time are functions of the resiliency of the rolls *(20)*.

If the non-finishing roll, or the *back-up roll*, is made with a non-metallic surface, meant to deform under the pressure of the nip, the nip is referred to as a *soft nip*. This resilient surface will typically have a modulus of elasticity that is 50 to 500 times softer than the "hard" roll, i.e., steel *(20)*. The calendering process that employs this type of nip is referred to as *soft nip calendering*. If the calender operates at an elevated temperature, it is called a *hot/soft nip calender*. The net result of using a soft nip calender is a product that undergoes less caliper and density variation reduction, but gains a smoother surface, as compared to a conventional hard nip calender.

There is a price to be paid for calendering linerboard. While roughness, or the variation in the surface height, is decreased by calendering, the density variation and porosity variation are increased. Since a smoother substrate enhances printability, and an increase in the variations of the sheet density and the porosity hinders it, it is unclear what the net effect might be.

Work by Hunger *(21)* suggested that, for coated substrates, the (hard nip) calendering benefits of increased smoothness more than offset the losses due to densification. Characteristics that showed improvement were gloss, smoothness, brightness, and visual print smoothness. It is hoped that these same properties can be improved by use of a soft roll, with the added benefit of reduced increase in the density variation of the linerboard.

CHAPTER III

STATEMENT OF PROBLEM

The role of packaging is changing. Until recently, good corrugated box was defined solely by strength properties. The primary purpose of such packaging was to protect the product during shipping, and the packaging was typically discarded upon arrival to the retail environment. Print was of poor quality and usually monochromatic, displaying little else besides handling instruction or identification information.

The corrugated board used for product packaging today must meet the much more rigorous demands of point-of-purchase retailing. This presents a challenge. Linerboard is typically a cheap, uncoated grade, with a rough surface that is less than ideal for good printing. A new process is required to modify the printing surface without upsetting good bulk properties if these same grades are to be used to meet the new demands.

Qualities that the unprinted linerboard must possess are subjective. Some possibilities include low roughness, low or high absorption, and low or high porosity. Qualities that the printed corrugated board have that might measure printability include print mottle, gloss mottle, and print density.

CHAPTER IV

RESEARCH OBJECTIVES

It was the objective of this study to discover the effects of using two different types of calenders on the printability of water-based flexo printed linerboard. This was done to assess the effectiveness of using one or both of these types of calenders as a secondary process. The linerboard samples were commercially produced and were calendered by Valmet.

It was hoped that calendering would offer significant improvement in the printability of linerboard, as a result of the decreased roughness. Two types of calenders were considered: a hot/soft nip calender and a shoe calender (extended nip). In addition, two levels of loading were considered for each type of calender. These two loading levels for each calender were set by target roughness values, so the lower and higher pressures used on one of the calenders were different from those used on the other.

Variables of the printed linerboard that were measured were: print density, delta gloss, and density and gloss mottle. Image analysis was conducted to measure dot fidelity. Additionally, a visual ranking was conducted to acquire a subjective measure of print quality.

CHAPTER V

EXPERIMENTAL DESIGN AND PROCEDURE

Printing

This research consisted of two parallel studies, each of which considered one of two different types of paperboard machines. The two machines were the *off-line ply* and the *Belbond ply*. The two plies were formed as separate webs on the off-line ply machine and bonded after web formation; with the Belbond fourdrinier, the top stock was laid on top of the bottom stock web to form a ply bond on-line. Within each study, there were two independent variables. These were the calendering type and the calendering pressure. The calendering conditions can be seen in Appendix A.

The linerboard from each machine that was used for this research was marketed as the same grade. This grade is called *normal mottled white*. It consists of a darker 100% virgin softwood Kraft pulp basestock, on top of which is a much thinner top stock made of recycled ledger paper. The grade is uncoated. The name comes from the mottled appearance that results from the darker base stock showing through thinner areas of the top stock. It should be noted that all calendered samples were pre-calendered by on-line gloss calenders.

The printed samples herein will be referred to in the following manner in all figures. The first letter will be either an "O" or a "B," representative of the "Off-line ply" or the "Belbond ply," respectively. The second two letter pair will be either "no," "sn," or "sh," meaning: no calendering (besides the on-line gloss calendering), soft nip calendering, or shoe calendering, respectively. Except when denoting a sample that has not been subjected to either of the two test calendering processes (the controls), the names will have as the final character either the number *one* or *two*. These represent the low and the high levels of calendering pressures, respectively. For example, the sample O-no represents the control linerboard for the off-line ply study, and the sample B-sn-2 represents the linerboard sample that has been subjected to the higher soft nip calendering pressure in the Belbond ply study.

The samples were printed with Ultra Gloss and Rubine (UGL026625) ink on the GMS Proofer. The test image was approximately seventeen inches by thirteen inches. Features of the test plate image include a solid print area and a tone steps series.

Before each print run, the viscosity and pH were measured to determine if the ink remained unchanged from day to day. A Zahn cup number 3 cup was used. Ink was used from the same source container throughout the experiment.

It was of concern whether or not the caliper variation would be significant, so the first few samples were chosen to be representative of the thickest and thinnest samples. A subjective analysis was conducted at this point, to assure that there was full ink transfer to the minimum caliper, and not excessive distortion of the text on the thickest caliper, which would indicate too much pressure. The tolerance of the flexo plate is ± 0.001 inch, allowing for a difference between the minimum and maximum calipers of 0.002 inches.

The GMS Proofer printed at least three images per run. For the sake of consistency, only the second and third prints were considered. Printing was conducted for each sample type until a total of at least five good prints (judged on the spot, subjectively) were acquired. This also negated chances of ink film variation due to position in the print series.

Print Quality Analysis

Mottle was measured by a Tobias Model MTI Mottle Tester. Density measurements were done using an X-Rite 408 densitometer. Print gloss was measured by a BYK-Gardner Glossmeter with 60 degree geometry.

Image analysis was used to quantify image fidelity, i.e., dot gain and dot roundness. The camera used for this was a Hitachi HV-C10. The analysis software used was Image-Pro Plus, Version 3.0.

The survey portion of the analysis was meant to determine the most important criteria in determining print quality. To do this, each sample was assigned a value equal to its average ranking. These values were regressed with the values obtained from the instruments to determine the value of these measurements in quantifying printability.

Twelve subjects with varying technical backgrounds in printing were used for the subjective ranking. Each subject was given no specific guidelines to judge the quality of the prints, just the instruction to rank them in the order of best to worst overall appearance.

While the study considered samples from two machine sources and considered these to comprise parallel studies, all samples from both machines were mixed randomly, with two samples used for each calendering condition, for a total of twenty samples. The ranked samples were then divided into the appropriate group, but their overall ranking out of the total twenty was the value used. This was to allow slightly more flexibility, allowing print qualities to be weighted a bit more as appropriate.

Analysis of Data

Each linerboard parameter was first plotted for each machine with standard deviations of the data. As a general rule, one standard deviation was arbritrarily used to assess significance. Thus, if two means were plotted and their standard deviations "overlapped," then the difference between their means was not considered significant. This was first done to determine which particular measurements responded to the calendering conditions. Correlation coefficients were calculated between different instruments that were used to measure the same parameters. Finally, to determine which linerboard parameters contributed significantly to printability, the correlation coefficients between these measurements and the subjective print quality were calculated. The same was done for the optical properties of the printed samples to determine which properties gave a measure of print quality. All calculations were done using Microsoft Excel 95.

CHAPTER VI

RESULTS AND DISCUSSION

Off-line Ply Substrate Characterization

It is important to understand the physical differences between the different samples in terms of fundamental properties. Caliper was measured using TAPPI Standard T-411. Roughness values were measured using three different instruments: Parker Print Surf (PPS), Sheffield Smoothness, and an Emveco Model 210-R stylus profilometer. Dynamic contact angle was measured using the Fibro 1121 Dynamic Absorption and Contact Angle Tester (DAT). The Cobb test was used to measure the absorbtivity of the samples. The Emtec Penetration Dynamics Analyzer (PDA) was used to characterize dynamic absorption. The Gurley Mercury Porosimeter and the Parker Print Surf were used to measure the air permeability of the samples.

Caliper

It would have been of concern if the difference between the largest caliper (uncalendered sample) and the smallest caliper exceeded twice the tolerance of the flexo print plate (the tolerance of the plate is $\pm$ 1.0 mils). However, as Table 1 indicates, this did not occur. Table 1 also contains the calendering conditions of the samples for reference.

Table 1

Calipers of Off-line Ply Linerboard Samples

Sample	Calendering Type	Pressure Level	Caliper (mils)
O-no	none	NA	10.6
O-sh-1	shoe	low	10.0
O-sh-2	shoe	high	10.2
O-sn-1	hot/soft nip	low	9.0
O-sn-2	hot/soft nip	high	9.6

It is not clear why the caliper actually *increases* at the high pressure level calendering for the hot/soft nip samples. One suggestion might be that the hot/soft nip backing roll was distorted under the higher pressure to the extent that it generated excess heat, which built up and lowered the elastic modulus of the backing material. This in turn may have led to a "softer" nip, with the result of a longer dwell time, but lowered peak pressure.

Roughness

Figures 1 and 2 present the roughness values for the off-line ply samples from the Sheffield Instrument and the Parker Print Surf, respectively. The test procedures used were T-538 and T-555, respectively. The results from both instruments show that each type of calendering reduces the roughness significantly, at least at the low pressure levels. This might indicate, as would be expected, that the reduction in

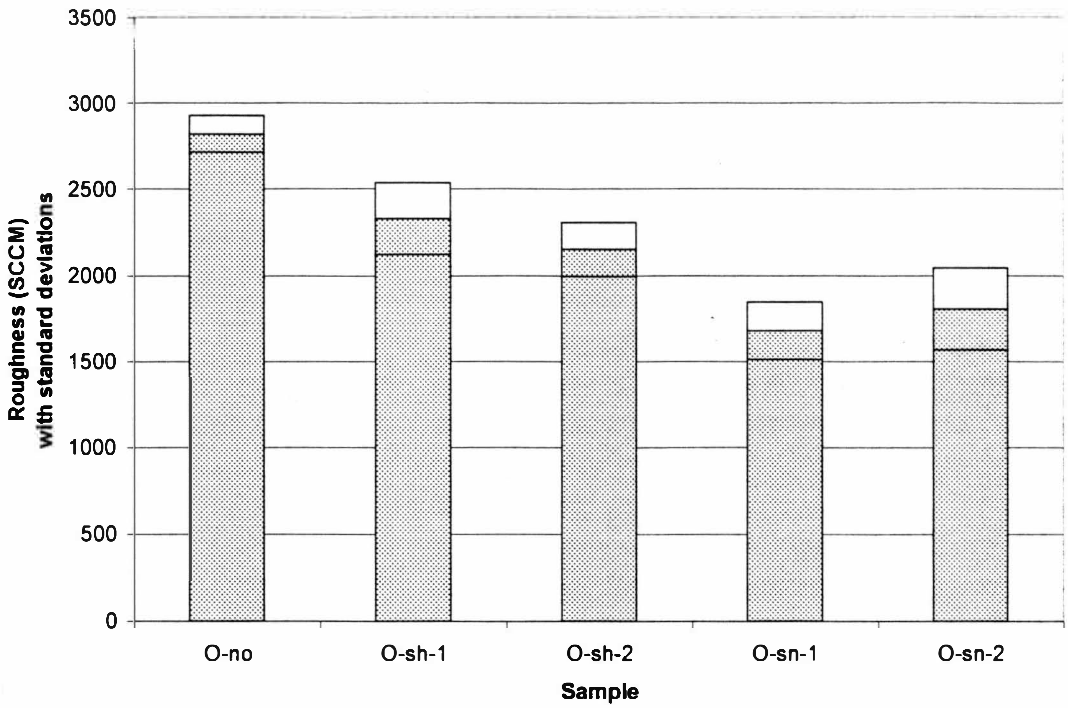

Figure 1. Roughness of Off-line Ply Samples Using Sheffield Instrument.

roughness is a decreasing function of calendering pressure, regardless of the calender type. The two airflow instruments seem to agree with each other well, with r^2 = 89.5%.

Surface Profile

The microdeviations from the Emveco Profilometer for the off-line ply samples are displayed in Figure 3. For each sample, five measurements were made in each the machine direction and the cross direction. The trends shown for both calenders are similar to those which were found using the two airflow roughness measuring devices. When considering the machine direction microdeviation values,

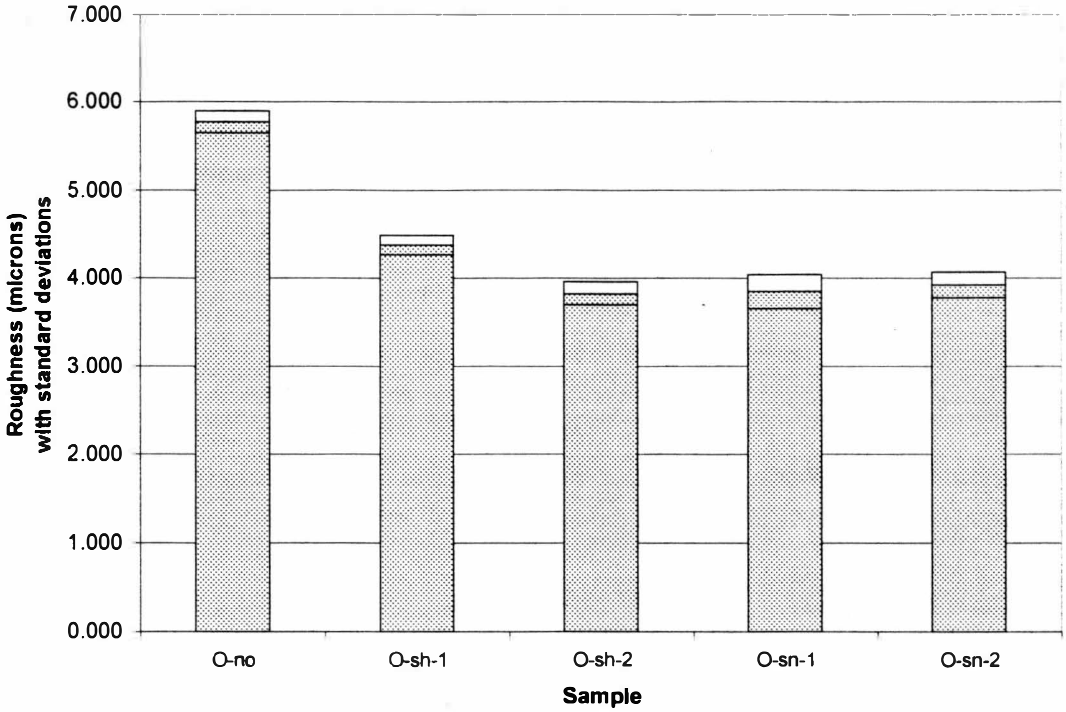

Figure 2. Roughness of Off-line Ply Samples Using Parker Print Surf.

for example, the r^2 value is 87.5% with the Sheffield Instrument, and 73.6% with the Parker Print Surf.

However, unlike the values obtained using the airflow devices, the high pressure levels yield a significant decrease in microdeviations for the shoe calendered samples. This is probably a result of the inherent differences between the profilometer and the airflow instruments. The first uses the variable microdeviation, which weights more heavily the extreme "peaks" of the substrate surface because the z-direction heights are squared. The pressure from the calender distributes more heavily on these "peaks," so the microdeviation would be affected more than the airflow values.

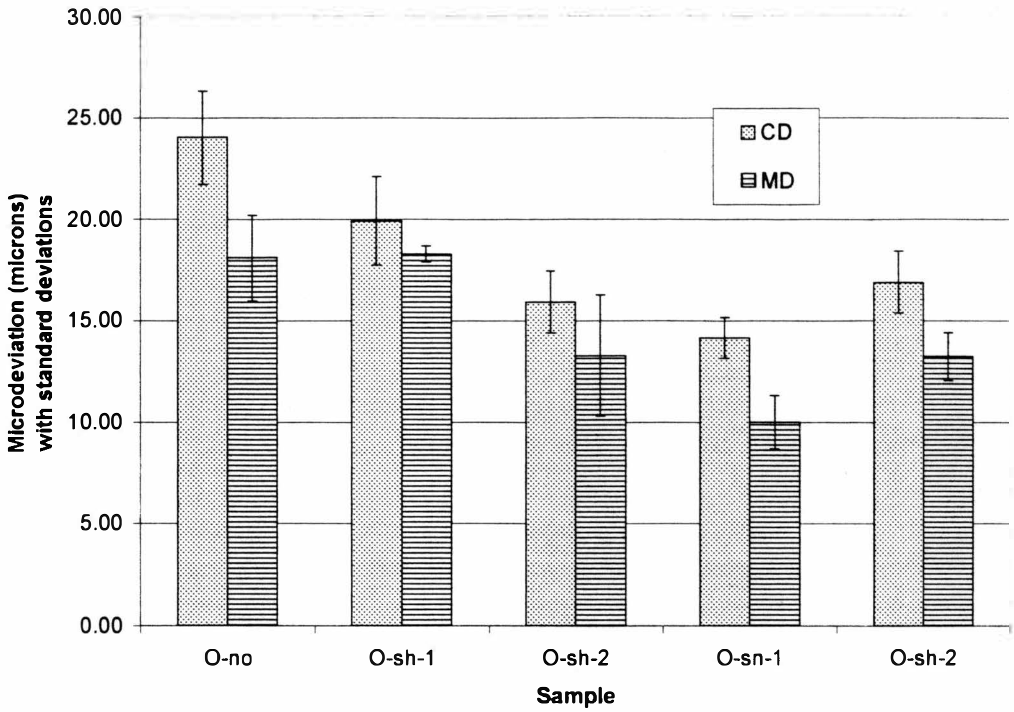

Figure 3. Roughness of Off-line Ply Samples Using Emveco Profilometer.

It is noteworthy that the hot/soft nip shows an increase in the microdeviation value from the low pressure level to the high pressure. This may be due to the softening of the backing roll under the high pressure nip conditions as already discussed.

Dynamic Contact Angle of Penetrating Ink Droplet

Figure 4 shows the dynamic contact angle data. For each sample, ten measurements were made. The contact angle, defined as the angle that subtends the liquid between the liquid/solid interface and the tangent of the liquid/air interface at the point of contact of all three, was measured at 0.10, 0.50, and 1.00 seconds. Apparently, this quantity did not respond significantly to the calendering conditions,

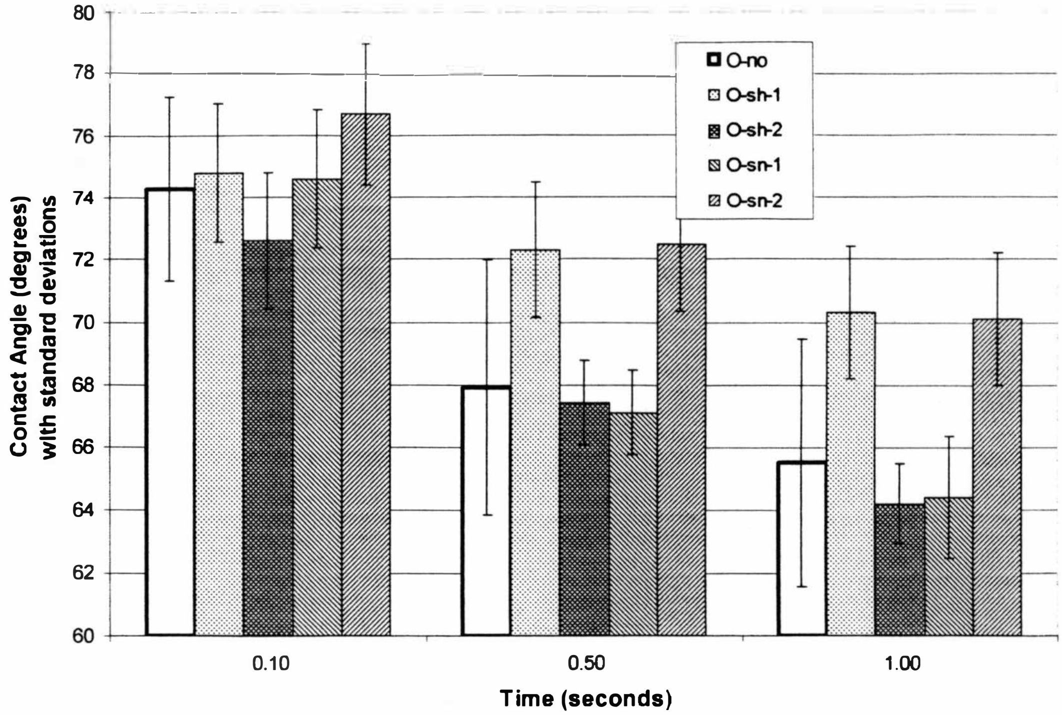

Figure 4. Dynamic Contact Angles of Off-line Ply Samples Using Fibro 1121 Dynamic Absorption and Contact Angle Tester.

as there are no significant differences between any of the values at any measurement time.

These poor results, judged by the relatively large and overlapping standard deviations of the measurements, could be the a reflection of an inadequate instrument, rather than a poor technique. Also, the data might be more useful if it covered a longer time period. This is because only a fraction of the absorption occurs during the first second, the limit of the measurements made by the PDA.

Absorptivity and Wettability

Figure 5 shows the data obtained from the Cobb Test (T-441), performed over a sixty second period. The results indicate that there is significant change in absorptivity imparted to the linerboard upon calendering by either type. The shoe calendering significantly decreases the absorptivity at low pressure, but does not decrease with any further significance at high pressure. In contrast, the low pressure hot/soft nip calender imparts no change to the samples, and the high pressure significantly reduces the absorptivity. This is probably due to the top liner having a smaller porosity than the base stock. The top liner, made of finer furnish, has a relatively low absorbency. Once the test water saturates this layer, it quickly absorbs into the base stock. This explains the appearance of the sudden drop in absorptivity for each calendering type, rather than a gradual decrease.

Table 2 shows the parameters that characterize the PDA plots. The plots themselves may be seen in Appendix E. The PDA measures the percent transmittance of an ultrasonic signal that irradiates the linerboard while it is submerged in the test water. The resultant plot of transmittance vs. time is useful in characterizing the wetting and absorption of the water into the linerboard samples.

The signal may be attenuated by any of three mechanisms: reflection, absorption, or scattering. The change in reflection shapes the response curve during the wetting phase, while it is the change in scattering that is the dominant effect during the absorption phase. The thin air film that exists between the linerboard at time = 0 seconds and the water form an interface that is reflecting to the signal, more

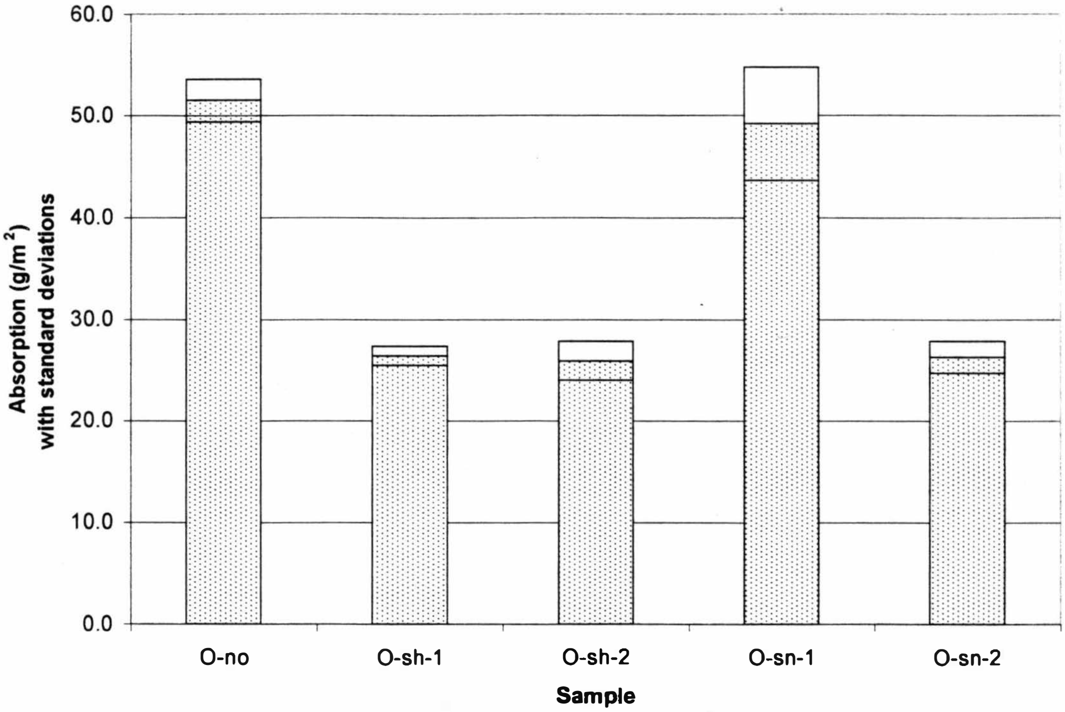

Figure 5. Absorptivity of Off-line Ply Samples Using Cobb Test.

so than the water/fiber interface. Once absorption is initiated, the signal will decrease as a result of signal scattering. This is caused by water penetrating the linerboard and subsequently trapping bubbles of air *(22)*. Therefore, the signal peaks when the linerboard is completely wetted, but hasn't yet started to absorb the water.

The parameters are *W*, *max*, and *A*. *W* is a dimensionless empirical value and is the area above the curve before the maximum value, bounded by the lines *transmittance = maximum transmittance* and *time = 0 seconds*. *Max* is the time in seconds to wet the surface; this corresponds to the point of maximum replacement of water/air with water/fiber interfaces. A_{60} is also an empirical dimensionless value, and is the area above the curve that is bounded by the lines *transmittance = maximum* *transmittance* and *time = 60 seconds*. This value is supposed to linearly correlate well with the Cobb value *(23)*.

The data from Table 2 shows that W is decreased by the low pressure level calendering for both calendering types. There is no significant additional reduction

Table 2

Wetting and Absorption Parameters of Off-line Ply Linerboard Samples

Sample	W	max (sec.)	A_{60}
O-no	3.4	0.876	38.6
O-sh-1	2.9	0.928	27.5
O-sh-2	3.0	0.992	26.6
O-sn-1	1.6	0.685	36.5
O-sn-2	2.4	0.897	25.6

achieved with the use of the high pressure shoe calendering, but the high pressure calendering actually increases the roughness value for the soft nip samples. This is in accord with the other measured values.

It appears as if both the low and high pressure conditions of the shoe calender increased the wetting time slightly. However, the hot/soft nip calendering significantly lowered wetting time for the low pressure sample, yet increased it to about the same value as the uncalendered sample at the high pressure level. A display of the correlations between the roughness measurements of Sheffield Instrument, Parker Print Surf, Emveco microdeviation (in machine direction), and W from the

PDA are displayed in Table 3. These high correlation coefficients suggest that W might be a measure of roughness.

Table 3

Correlation Values of the Roughness Measurements

	PPS	Emveco (MD)	PDA (W)
Sheffield	89.5%	87.5%	90.0%
PPS	-	73.6%	66.7%
Emveco	-	-	84.1%

The parameter A_{60}, unlike the parameters W and max, is a function of the bulk properties of the linerboard. The r^2 value for the correlation between the Cobb data and A_{60} is 99.2%. This excellent agreement suggests that A_{60} is a good measure of absorptivity.

Air Permeability

The air permeability values were obtained using the Gurley Mercury Porosimeter. These results are in Figure 6. The data show that shoe calendering has no effect, while hot/soft nip calendering decreases the permeability. The Parker Print Surf was also used to measure air permeability values. These can be found in Figure 7. It is evident that overall, the calendering of both types decreased permeability. Again, the anomaly of the high pressure hot/soft nip calendered sample appears again. There is excellent correlation between the two instruments (r^2 = 98.1%).

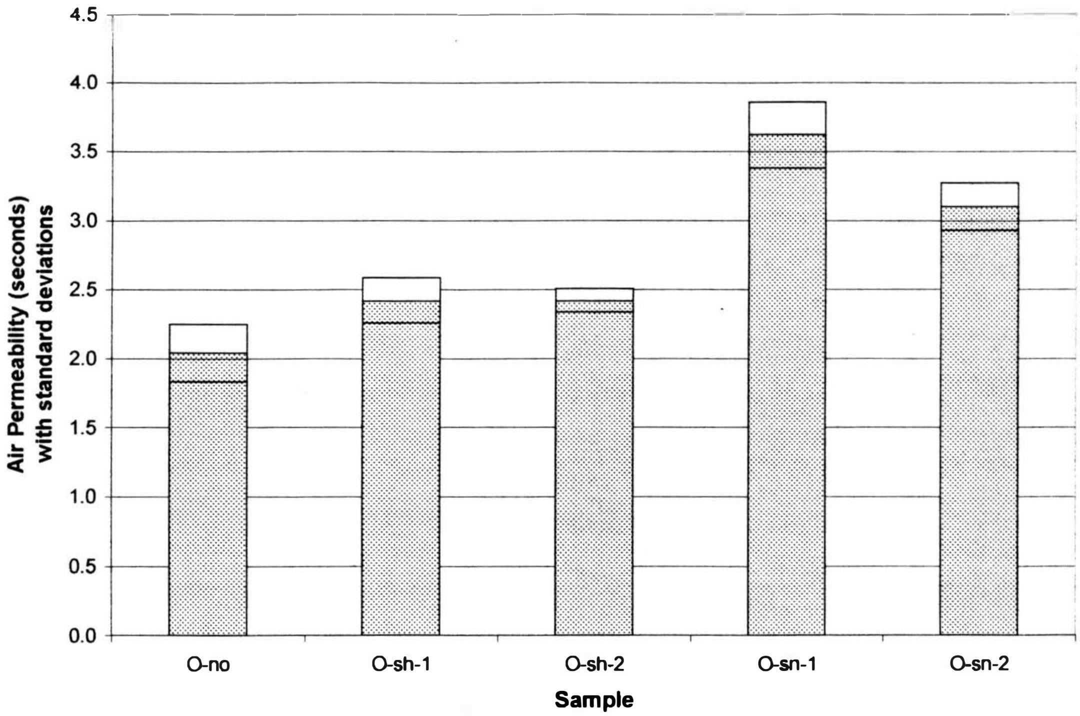

Figure 6. Air Permeability of Off-line Ply Samples Using Gurley Porosimeter.

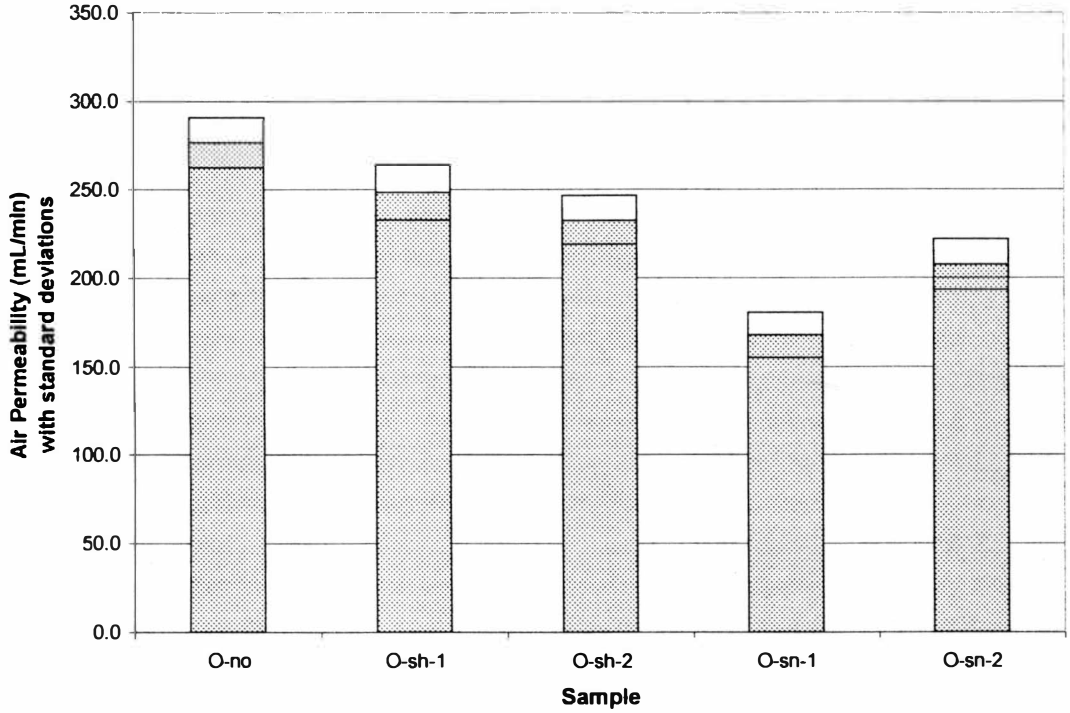

Figure 7. Air Permeability of Off-line Ply Samples Using Parker Print Surf.

Off-line Ply Printability Analysis

Print Density

The print density values for the solid areas are shown in Figure 8, and those for the tone steps are in Figure 9. The shoe calendering increases solid print density significantly, but only at the high level pressure. The hot/soft nip calendering offers no significant improvement in print density.

It is not obvious from Figure 9 what, if any, effect occurs because of the calendering. This is because the data are plotted absolutely. If, however, the *differences* of the print densities of the calendered samples from those of the uncalendered samples are plotted, the effect is more apparent. This is displayed in Figure 10. This plot is not conclusive, but it does suggest that both calendering calenders improve density along the full scale at each pressure level.

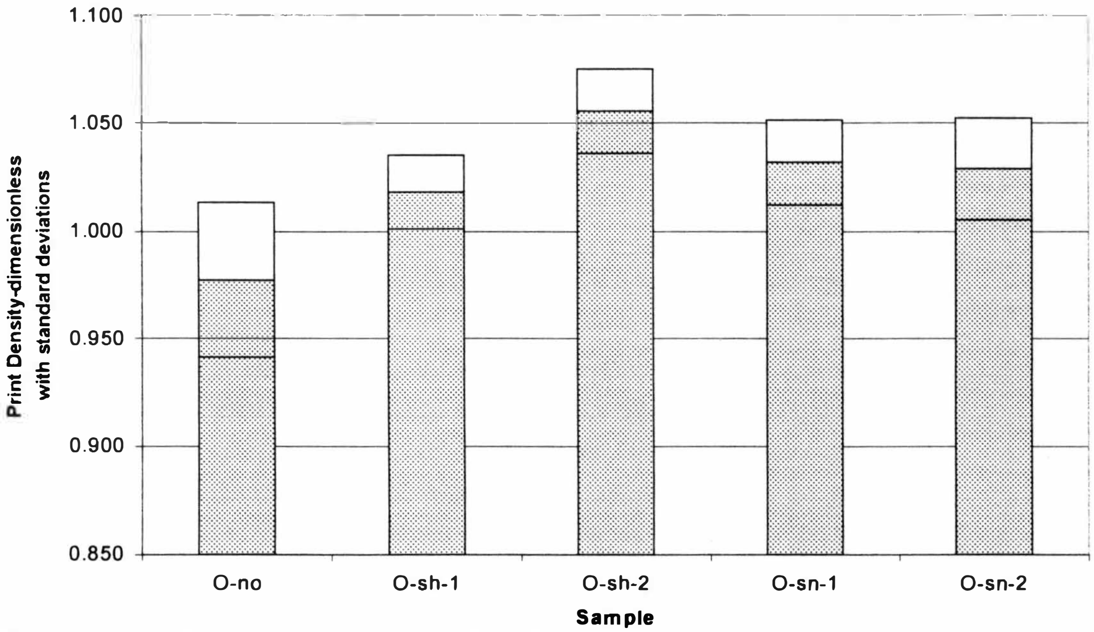

Figure 8. Solid Print Density of Off-line Ply Samples.

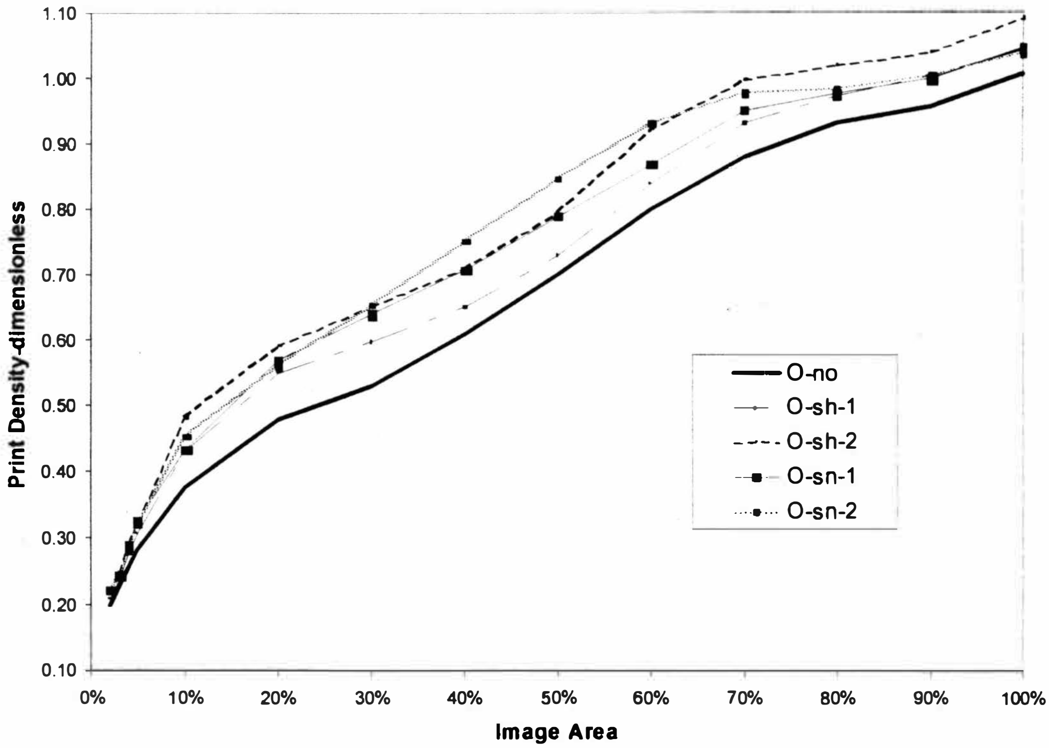

Figure 9. Tone Steps Print Density of Off-line Ply Samples.

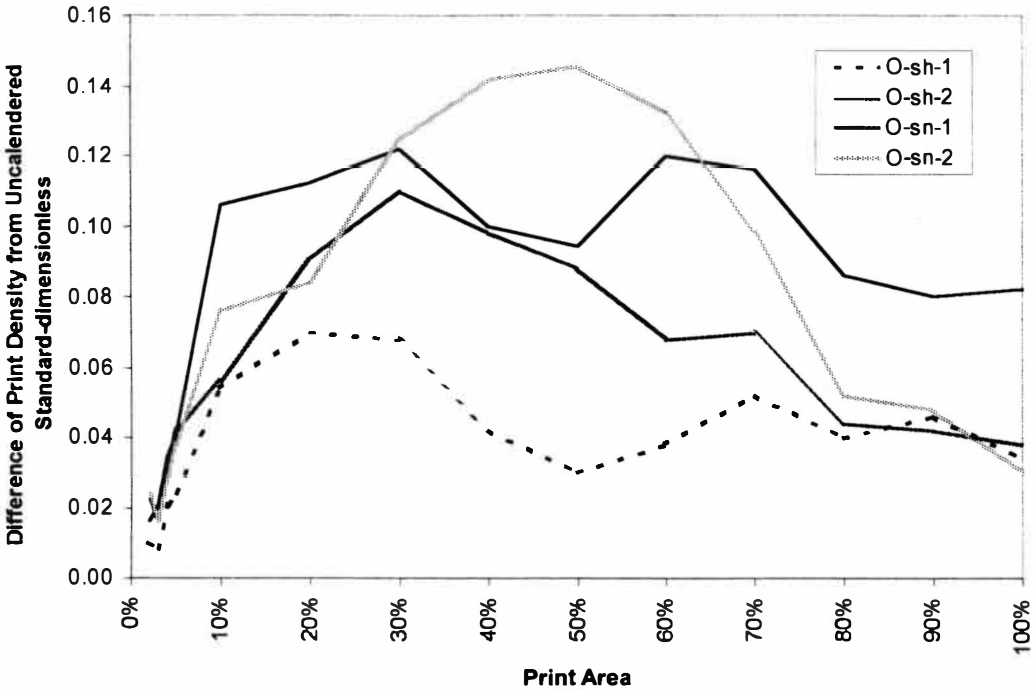

Figure 10. Differences of Print Density of Calendered Samples From Uncalendered Sample for Off-line Ply Samples.

Gloss

The delta gloss data are shown in Figure 11. All values are the result of an average of ten readings. The most evident fact about the data is that the delta gloss values are mostly negative. This is probably due to the fact that the wetting of the fibers by the ink allows them to spring back elastically from the flattened position imposed by the calendering. The greater the smoothening of the surface, the greater potential the surface has to revert and thus the greater delta gloss value.

The low pressure soft nip calendered sample alone increases the delta gloss value. This may be due to the fact that the fibers were compacted mostly by plastic flow, with minimal contributions from mechanical compaction. This would reduce the effect of the fibers springing from the surface.

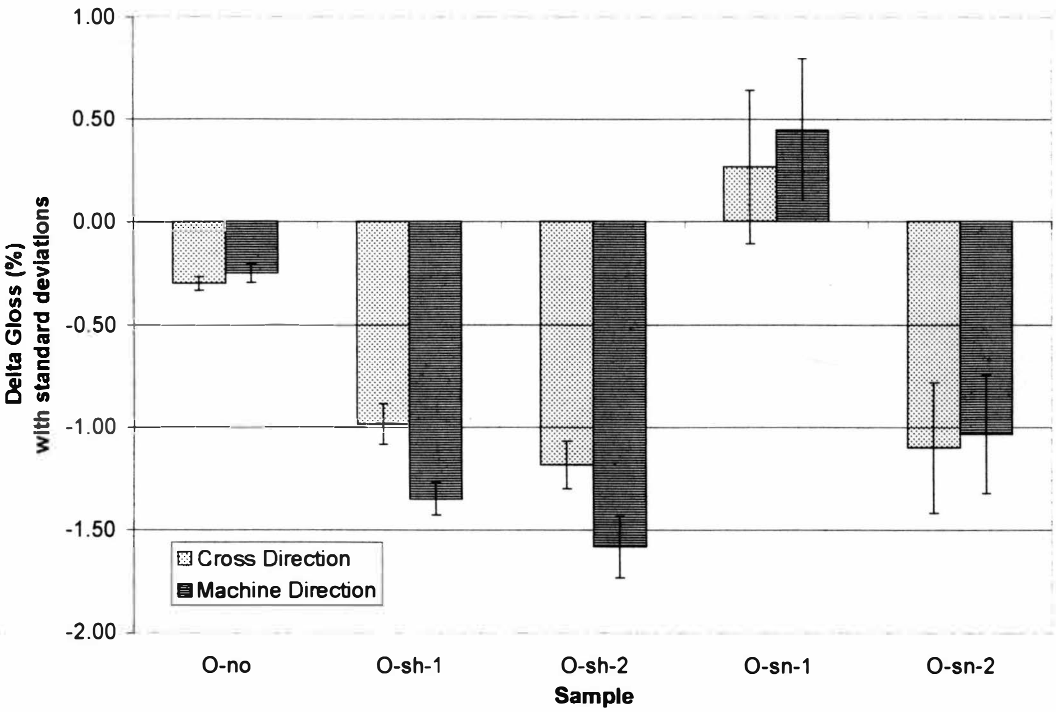

Figure 11. Delta Gloss of Off-line Ply Samples.

Mottle

The previous section discussed the measured quantities of print density and gloss of the printed linerboard samples, which are *mean* quantities. The measured variations of these quantities, mottle, will now be considered. The print density mottle date is presented in Figure 12, and the gloss mottle data is presented in Figure 13. Each value is the average of ten readings.

For the shoe calendered samples, there is a significant reduction in print mottle for the low pressure sample, and no significant additional reduction for the high pressure sample. In contrast, the print mottle is increased for the low pressure soft nip calendered sample, with a reduction in print mottle for the high pressure sample. This is probably due to the inherent difference between the two calendering process. The shoe calender decreases roughness without appreciably increasing the densification variation, with the net effect decreasing print mottle. However, the hot/soft nip calender incurs both effects, with the effect of the densification variation increase being dominant, leading to increased print mottle.

There is even a greater difference between the two calendering processes when considering the gloss mottle values. The shoe calender apparently imparts no change to the gloss mottle, whereas the hot/soft nip calender more than doubles the gloss mottle index. This can probably be best understood using the idea that the linerboard surface roughens from being wetted. As the hot/soft nip calendered

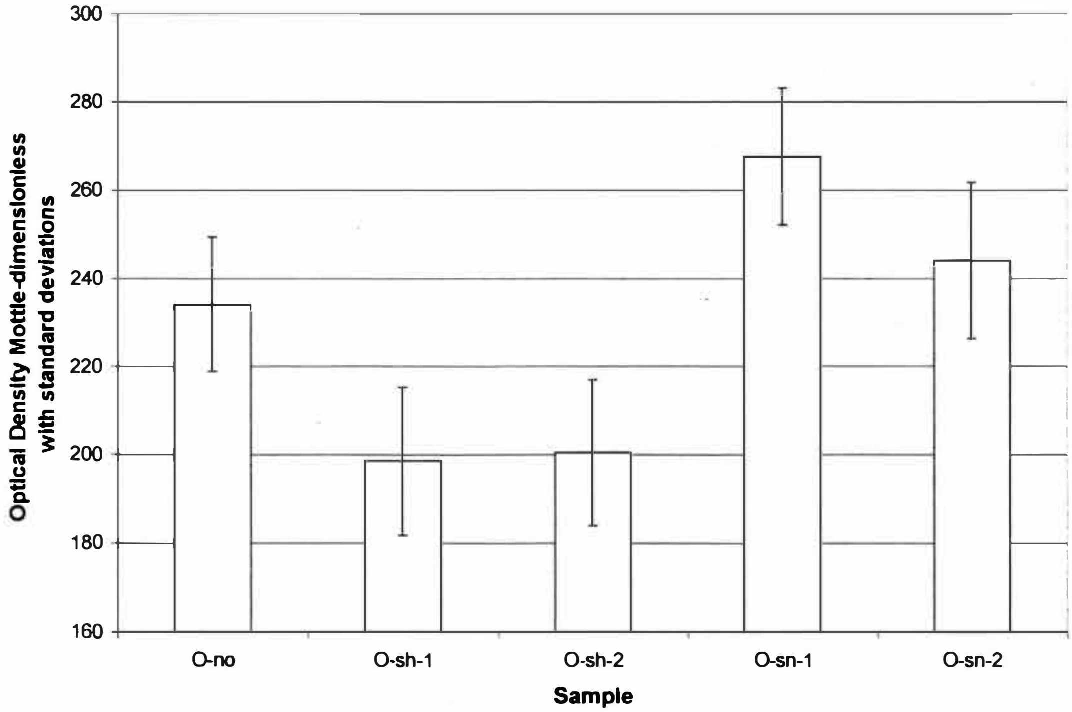

Figure 12. Print Density Mottle of Off-line Ply Samples.

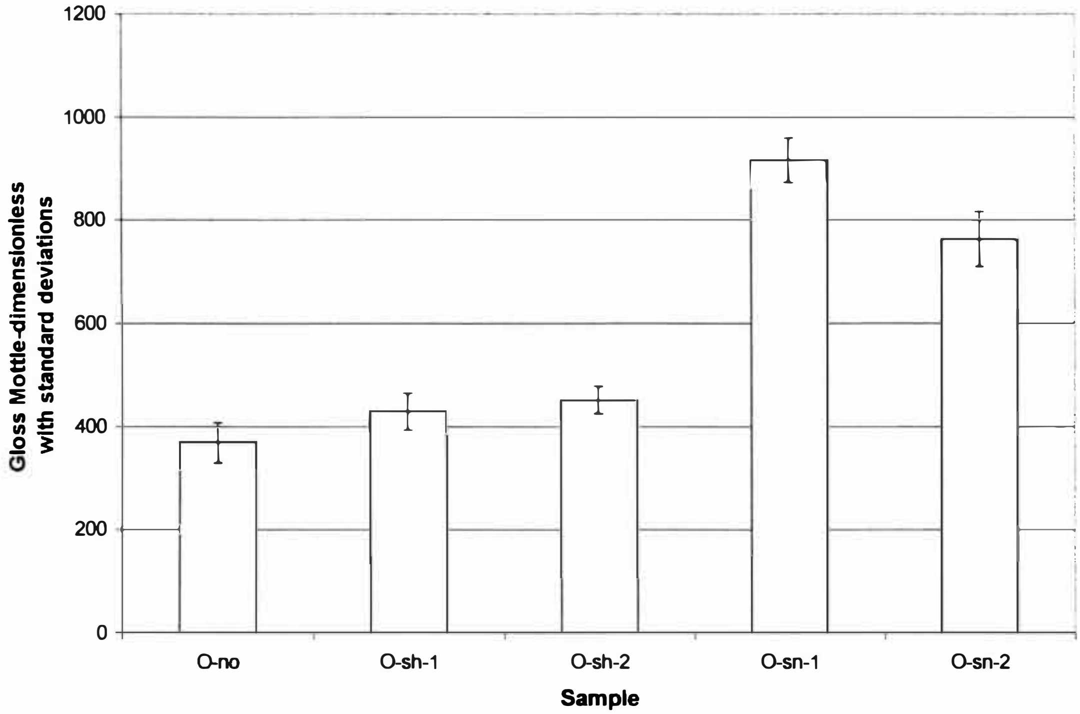

Figure 13. Gloss Mottle of Off-line Ply Samples.

samples are more uniformly reduced in caliper, there will be a subsequent increase in the variation of bulk compaction, resulting in higher printed gloss mottle.

Image Analysis

Three quantities were measured on the 2% coverage areas of the samples. They were dot area, perimeter of the dots, and roundness. Each value is the result of two readings. These are displayed in Figures 14, 15, and 16, respectively. Figure 14 shows that while there may be a slight decrease in dot area, it can't be said that it is significant. A better measure of this property is the tone step plot. A measure of the perimeter and roundness do not appear to be useful, as Figure 15 and 16 do not show any significant changes.

Subjective Ranking

The subjective ranking values for the samples are presented in Figure 17. Because everyone has different criteria by which they judge print quality, there is an expected high variation in the results reported from one individual to another. This is evidenced by the fact that the standard deviations are so large. However, the mean values reveal that the low pressure shoe calendered sample was perceived to be an improvement to the uncalendered linerboard, and that the high pressure sample is even better. In contrast, the hot/soft nip calender lowers the print quality at the low pressure, and increases it for the high pressure. This agrees with the supposition that the low pressure hot/soft nip calendering actually had a higher peak pressure than the

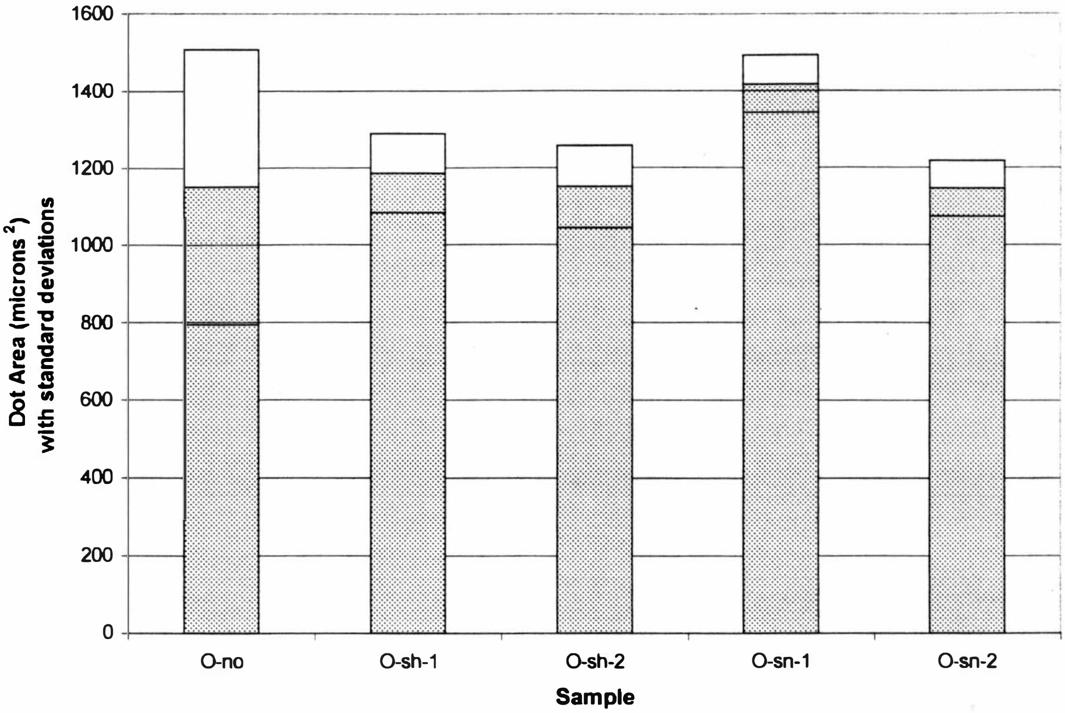

Figure 14. Dot Area of 2% Coverage Area of Off-line Ply Samples.

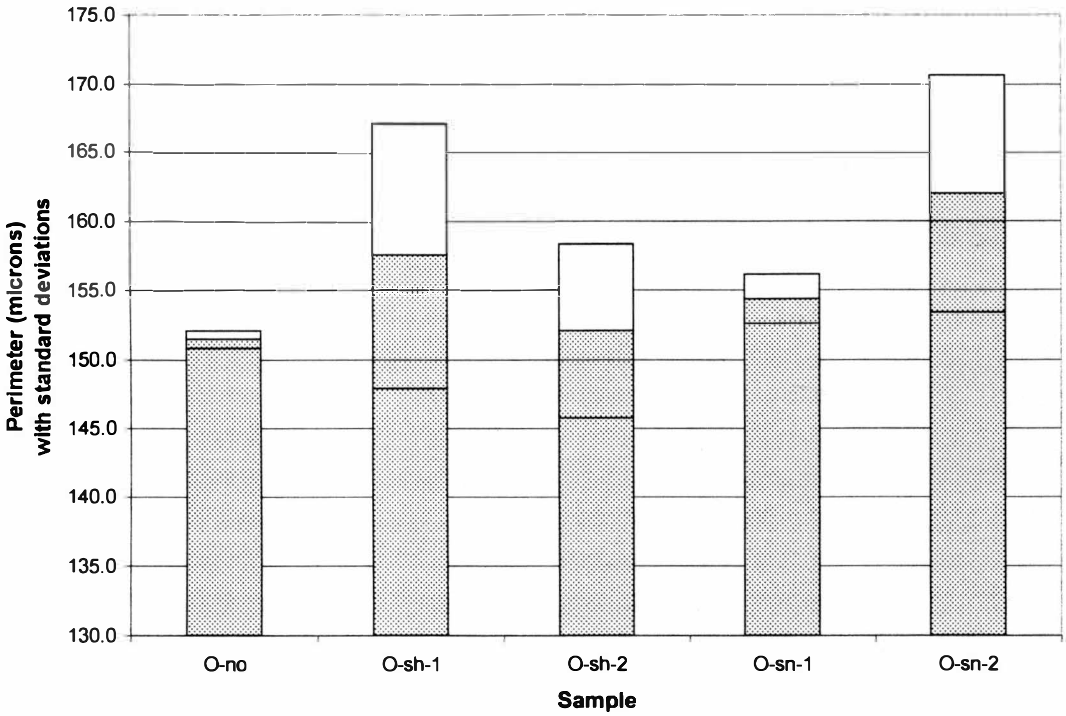

Figure 15. Perimeter of Dots of 2% Coverage Area of Off-line Ply Samples.

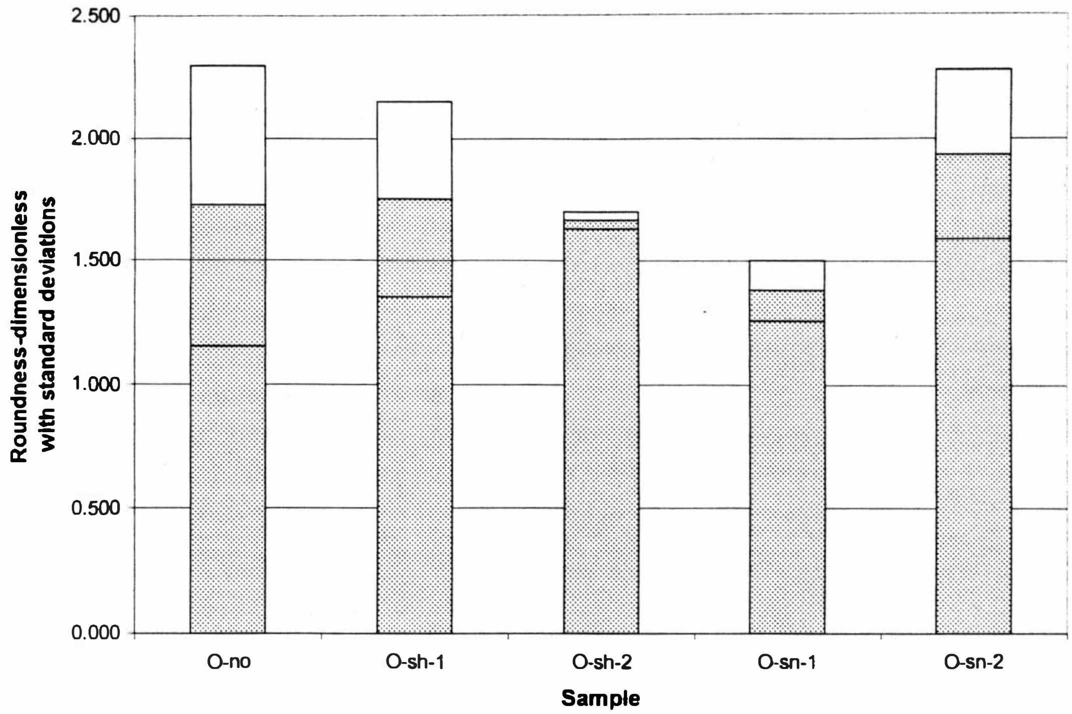

Figure 16. Roundness of Dots of 2% Coverage area of Off-line Ply Samples.

high pressure calendering. The high pressure ranking is only slightly better than the uncalendered sample. Again, this is thought to be attributable to the fact that the elastic modulus of the high pressure sample is reduces because of the higher temperature induced by the higher overall pressure. The lower elastic modulus leads to a broader pressure profile, with a lower overall peak pressure. In other words, the total peak pressure is proportional solely to the area under the pressure profile, while the ratio of the height of this profile to the width of the profile (*eccentricity* of the ellipse) is a function of the elastic modulus. This is only significant if the peak pressure value is of primary importance in affecting the linerboard.

Belbond Ply Substrate Characterization

Caliper

Table 4 shows that the span of the calipers is 2.0 mils, exactly twice that of the tolerance of the plate. This assures that the effects from the caliper are minimal. Table 4 also contains the calendering conditions of the samples for reference.

Roughness

Figure 18 and Figure 19 present the roughness values for the Belbond plies from the Sheffield Instrument and the Parker Print Surf, respectively. The results from both instruments show that each type of calendering reduces the roughness significantly, at least at the low pressure levels. This response is similar to that of the off-line ply samples. There is excellent agreement between the two types of airflow instruments, as they have a correlation value of 95.3%.

Surface Profile

The microdeviations from the Emveco Profilometer for the off-line plies are displayed in Figure 20. As with the off-line samples, the results agree with those from the two airflow roughness measuring devices (r^2 = 92.2% for the Sheffield Instrument, and r^2 = 97.8% for the Parker Print Surf). There is also the appearance of additional roughness reduction from the low to the high level pressure for both calendering types, as with the off-line samples.

Table 4

Calipers of Belbond Ply Linerboard Samples

Sample	Calendering Type	Pressure Level	Caliper (mils)
B-no	none	NA	10.9
B-sh-1	shoe	low	9.0
B-sh-2	shoe	high	8.9
B-sn-1	soft nip	low	9.1
B-sn-2	soft nip	high	9.2

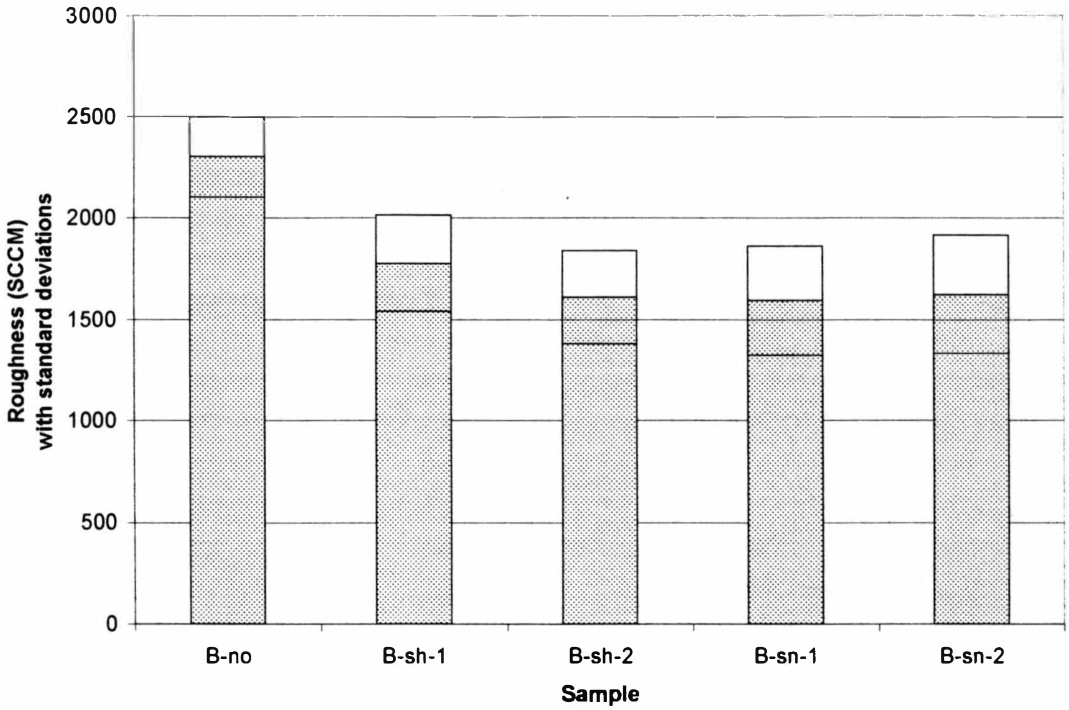

Figure 18. Roughness of Belbond Ply Samples Using Sheffield Instrument.

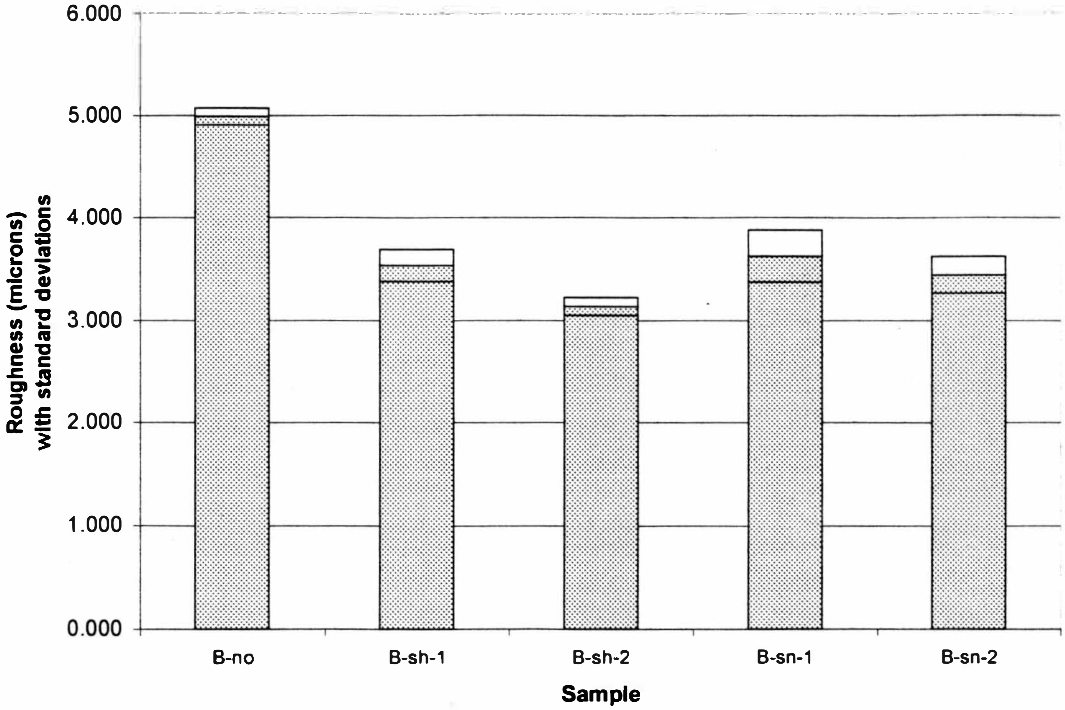

Figure 19. Roughness of Belbond Ply Samples Using Parker Print Surf.

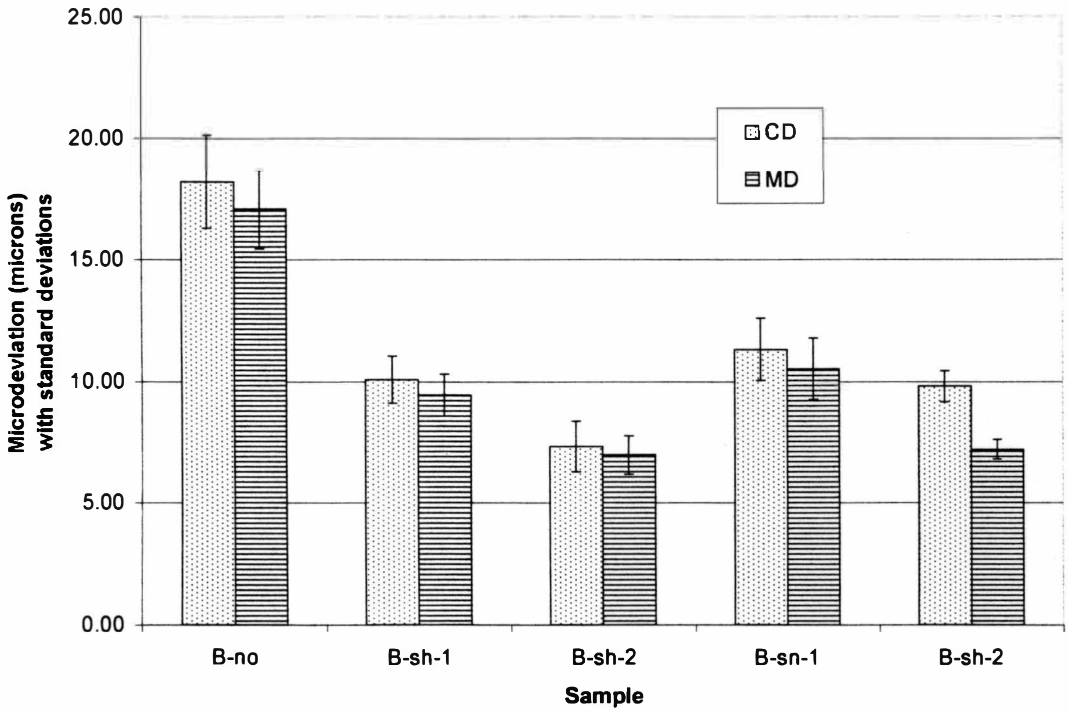

Figure 20. Roughness of Belbond Ply Samples Using Emveco Profilometer.

Dynamic Contact Angle of Penetrating Ink Droplet

Figure 21 shows the dynamic contact angle data. The data suggest that there might be an increase in contact angle of the ink solution from both calender types, but it is not conclusive.

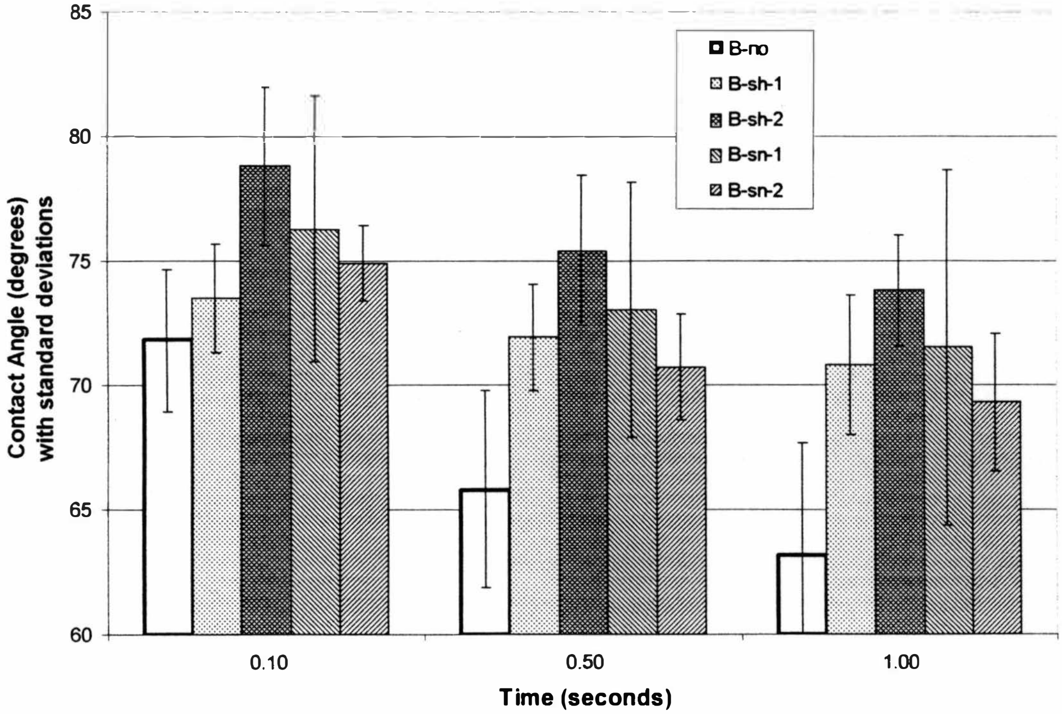

Figure 21. Dynamic Contact Angles of Belbond Ply Samples Using Fibro 1121 Dynamic Absorption and Contact Angle Tester.

Absorptivity and Wettability

Figure 22 shows the Cobb Test results. The results indicate that no significant change in absorptivity is imparted to the linerboard upon calendering by either type. Table 5 shows the parameters W, max, and A from the PDA. The plots themselves may be seen in Appendix E.

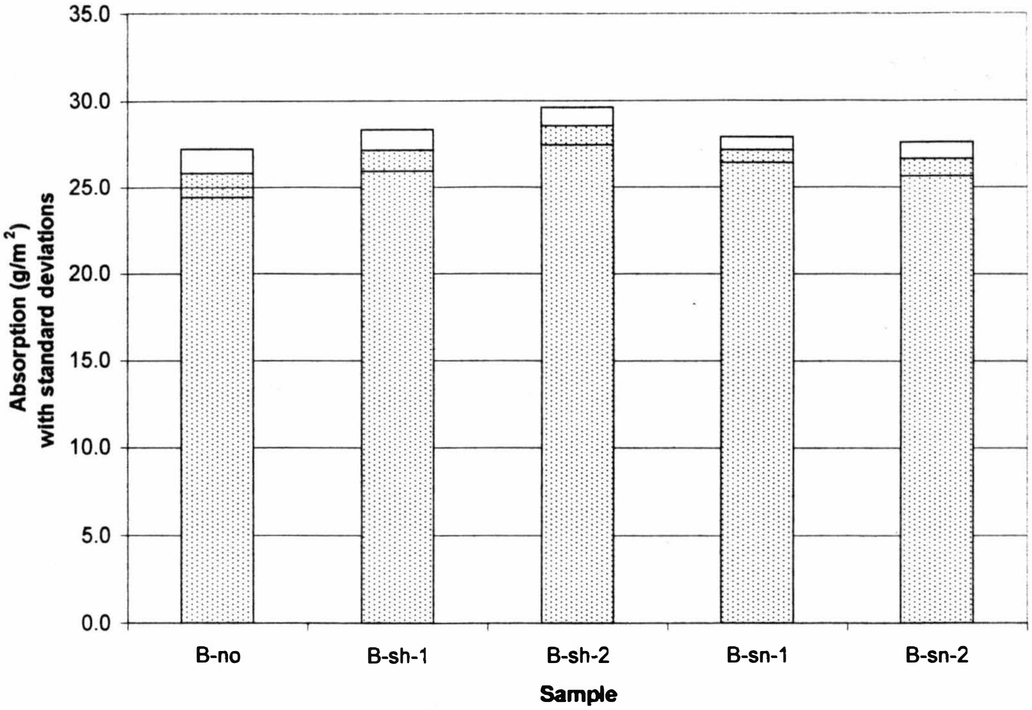

Figure 22. Absorptivity of Belbond Ply Samples Using Cobb Test.

The data from Table 5 suggest that W is decreased by the low pressure level calendering for both calendering types, but the high pressure calendering contributes no additional reduction. Similarly, the low pressure calendered samples wet significantly quicker than the uncalendered sample, yet the high pressure calendered samples do not differ appreciably in wettability from that of the low pressure calendered samples. There doesn't appear to be any significant difference between the A_{60} values. The correlation coefficient with the Cobb values is equal to 53.7%. Table 6 shows the correlation coefficients for the four interpreted roughness measurements.

Table 5

Wetting and Absorption Parameters of Belbond Ply Samples

	W	max (sec.)	A_{60}
O-no	2.9	0.872	26.2
O-sh-1	2.2	0.708	29.3
O-sh-2	2.3	0.724	28.0
O-sn-1	1.9	0.662	27.6
O-sn-2	1.9	0.651	26.9

Table 6

Correlation Values of the Roughness Measurements
for the Belbond Ply Samples

	PPS	Emveco (MD)	PDA (W)
Sheffield	95.3%	92.2%	91.7%
PPS	-	97.8%	79.4%
Emveco	-	-	78.5%

Air Permeability

The Gurley Mercury Porosimeter data is displayed in Figure 23. The data show that each level of calendering for both types decreases the permeability slightly. The Parker Print Surf air permeability data can be found in Figure 24. The results are similar to that of the Gurley results. The correlation coefficient is 84.9% for the two instruments.

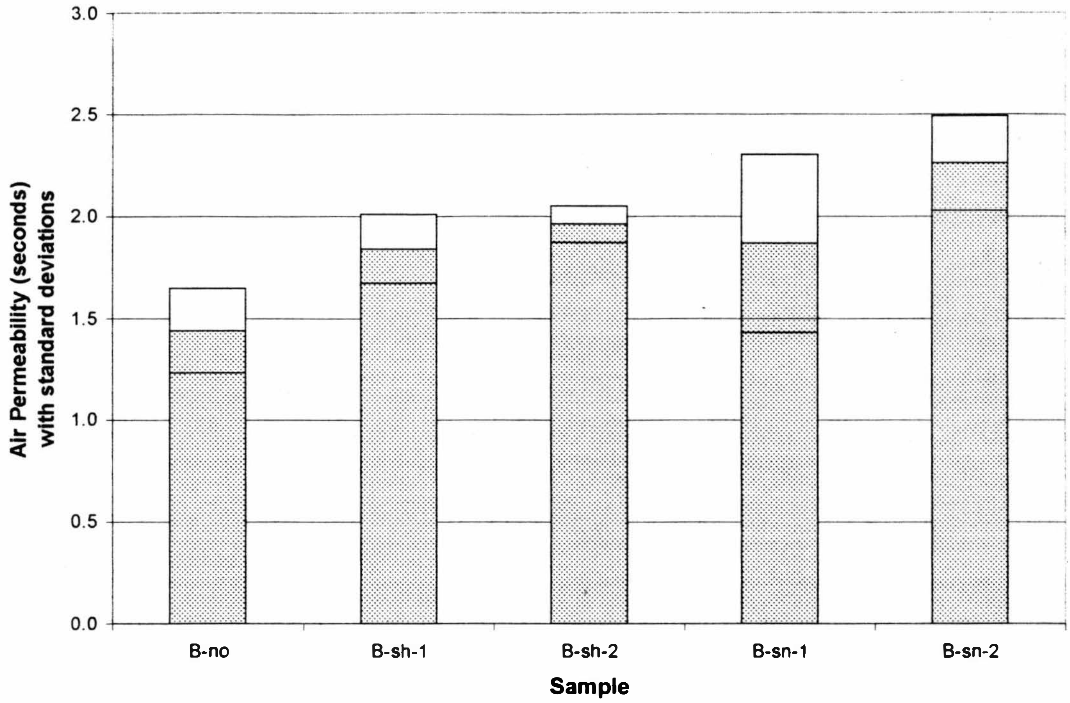

Figure 23. Air Permeability of Belbond Ply Samples Using Gurley Porosimeter.

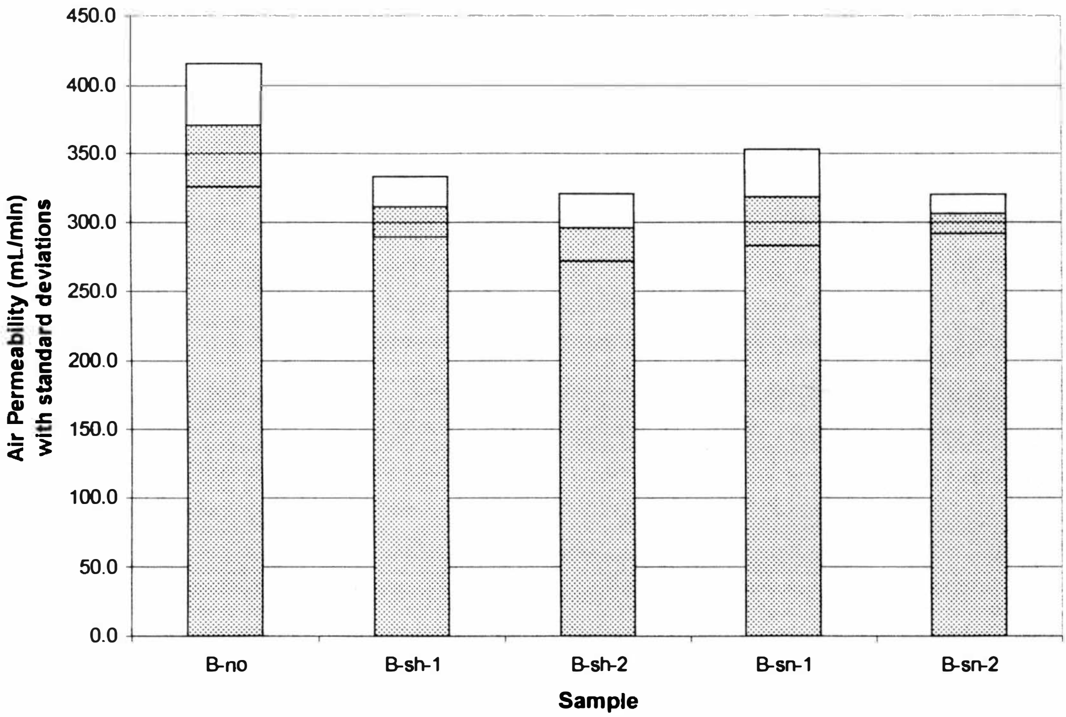

Figure 24. Air Permeability of Belbond Ply Samples Using Parker Print Surf.

Belbond Ply Printability Analysis

Print Density

The print density values for the solid areas are shown in Figure 25, and those for the tone steps are in Figure 26. Both low pressure levels of the two calendering types increase print density, and both high pressure levels seem to cause no additional significant change.

As with the off-line samples, the tone step plot is more useful if the calendered samples are plotted in reference to the uncalendered sample. This is shown in Figure 27. This plot clearly shows that the shoe calender offers significant improvement to the uncalendered linerboard sample, and that there is little difference between the high and low levels. The hot/soft nip calender, however, worsens the print densities of the tone steps. As with the shoe calendered samples, there is little difference between the high and low pressure levels.

Gloss

The delta gloss data are shown in Figure 28. As with the off-line samples, all values are negative. Both calendering types increase the magnitude of the delta gloss values, but only by significant amounts at the low pressure levels.

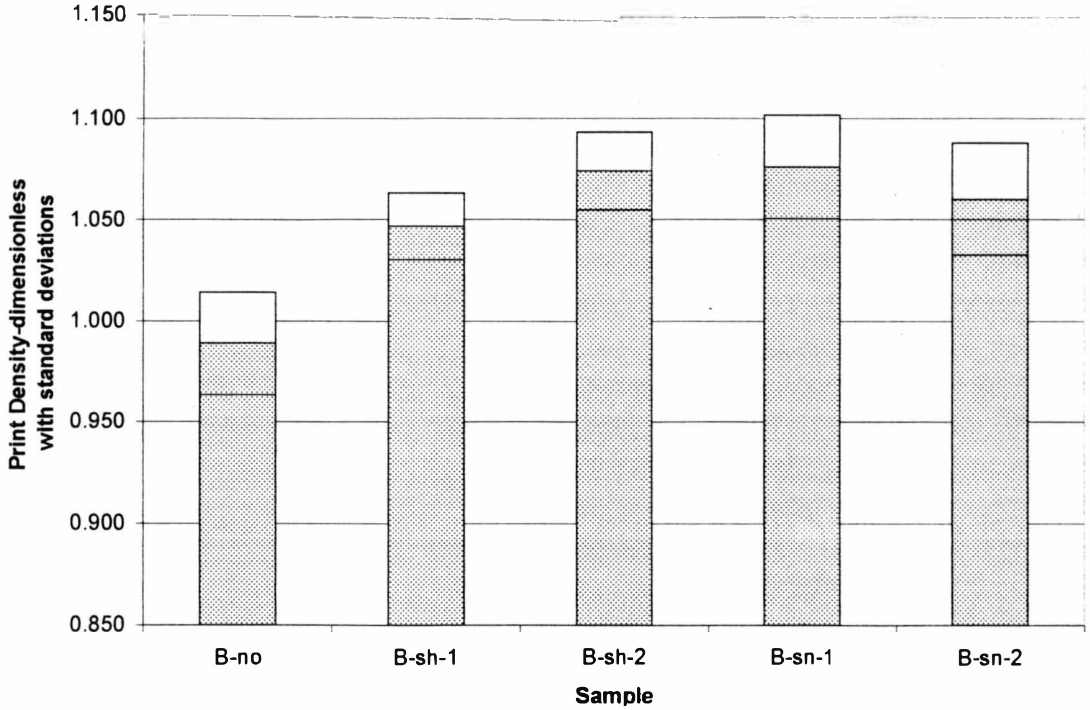

Figure 25. Solid Print Density of Belbond Ply Samples.

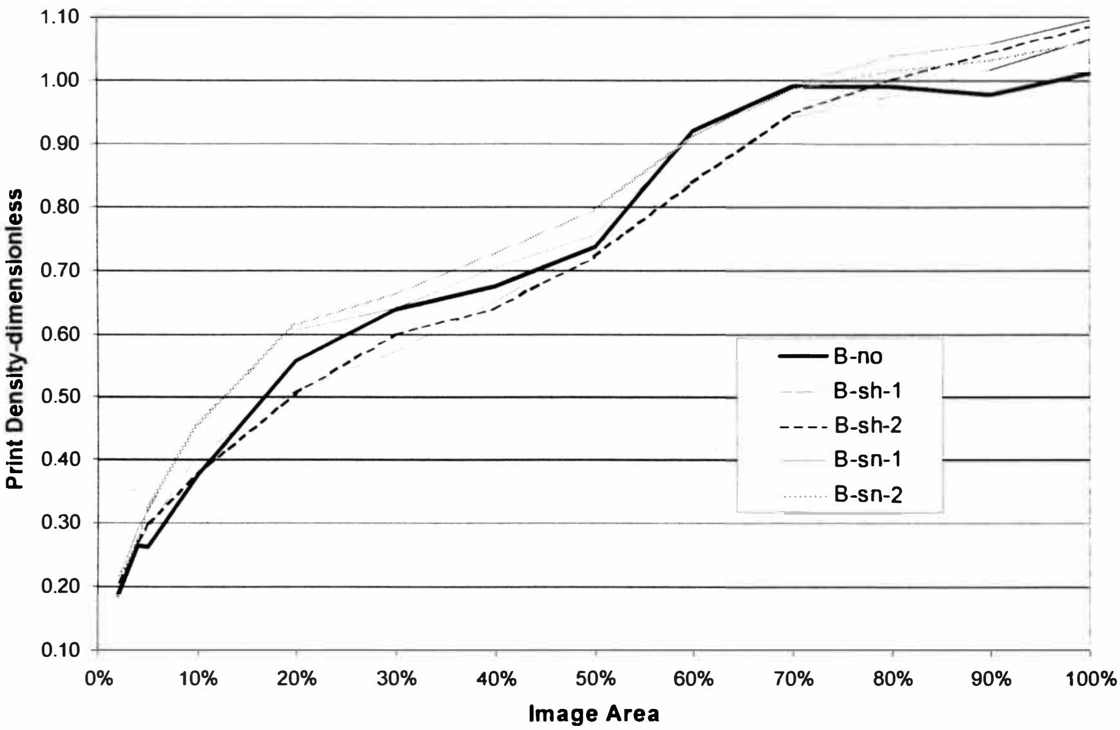

Figure 26. Tone Steps Print Density of Belbond Ply Samples.

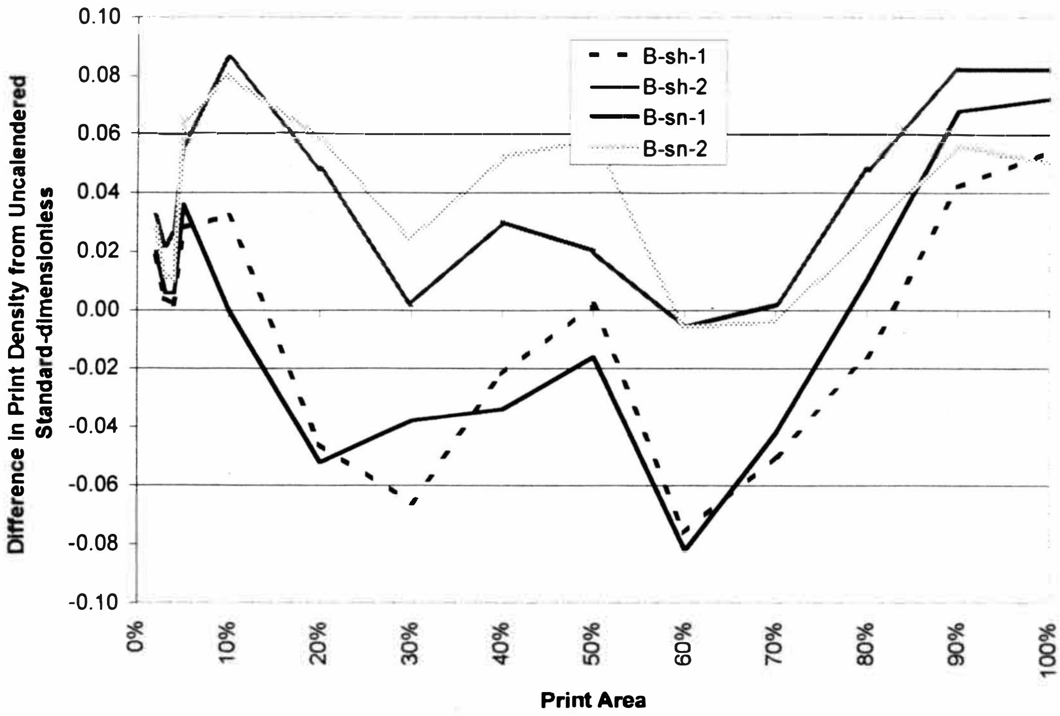

Figure 27. Differences of Print Density of Calendered Samples From Uncalendered Sample for Belbond Ply Samples.

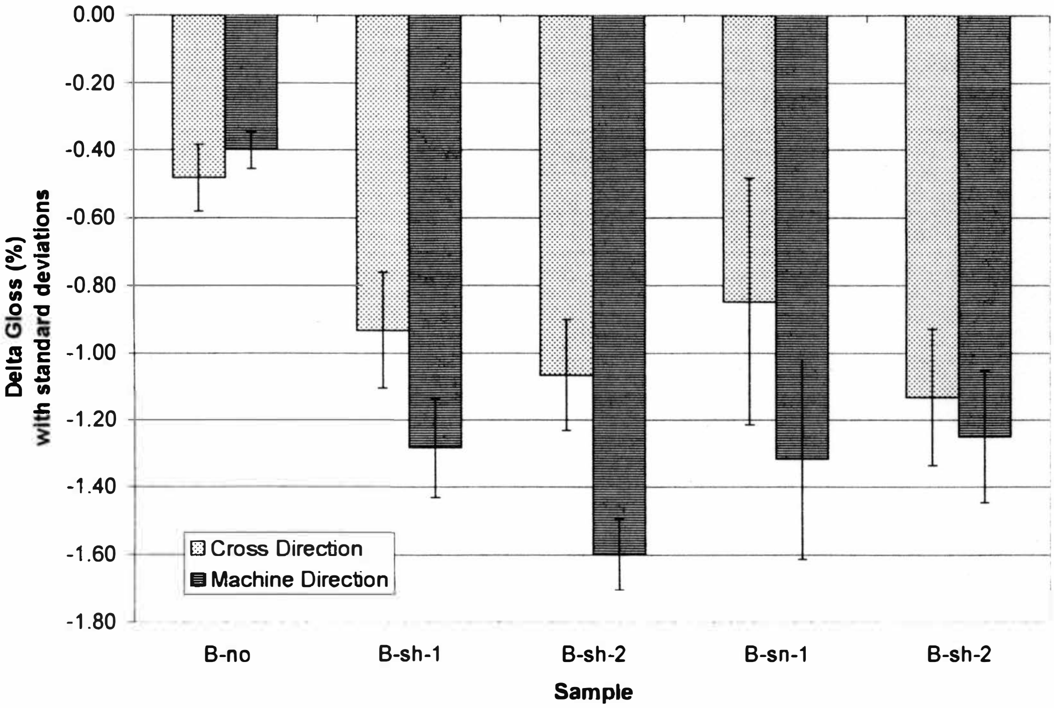

Figure 28. Delta Gloss of Belbond Ply Samples.

Mottle

The print density mottle date is presented in Figure 29, and the gloss mottle data is presented in Figure 30. There is no effect on print mottle from shoe calendering, but the hot/soft nip calendering significantly increases the print mottle. There are similar results with gloss mottle. These results are reasonable. It is to be expected that the hot/soft nip calender causes greater increase in the variation of the densification of the sheet, thereby leading to increased print density. The hot/soft nip calender causes a greater increase in the densification variation than does the shoe calender, which leads to an increase in gloss mottle.

Image Analysis

The dot area, perimeter of the dots, and roundness data are displayed in Figures 31, 32, and 33, respectively. None of these measurements seem to respond significantly to calendering.

Subjective Ranking

Figure 34 shows the results of the subjective ranking of the samples. As with the off-line samples, the mean values suggest an improvement in print quality by calendering, but only by the low pressure calendering. As with the off-line samples, the standard deviations are large.

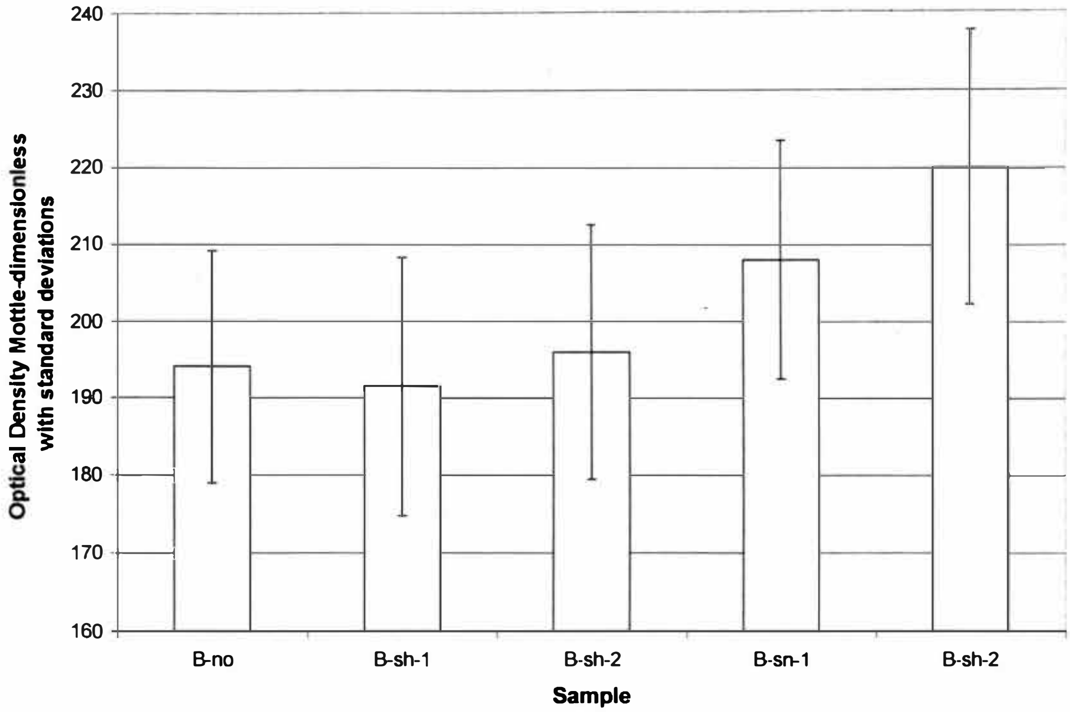

Figure 29. Print Density Mottle of Belbond Ply Samples.

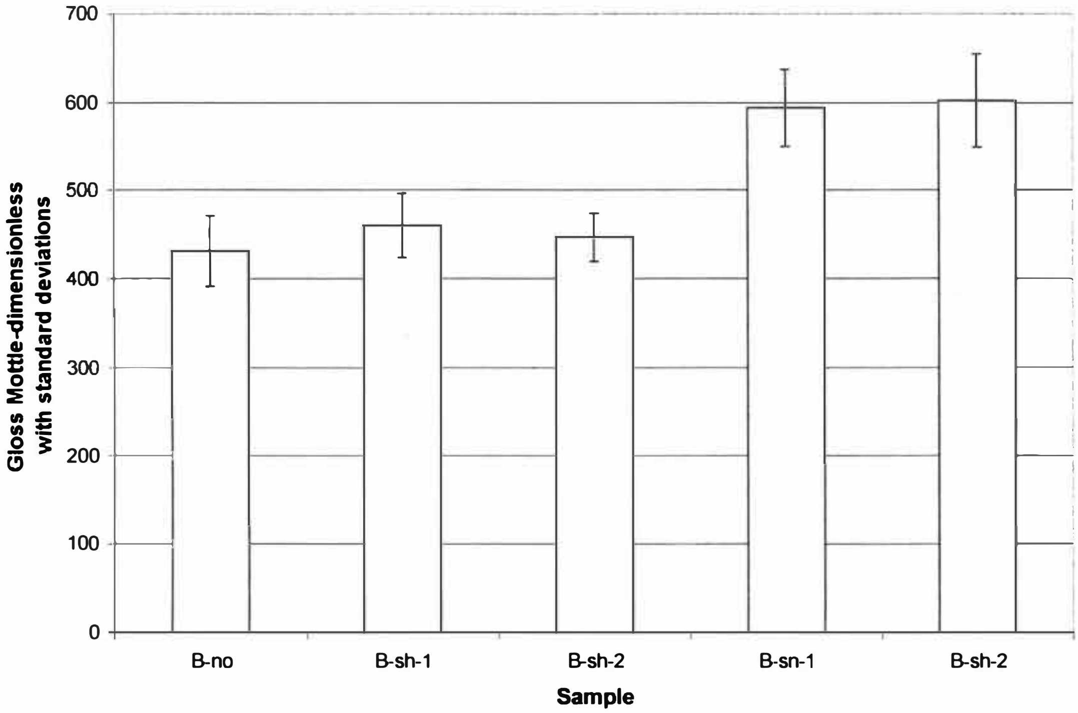

Figure 30. Gloss Mottle of Belbond Ply Samples.

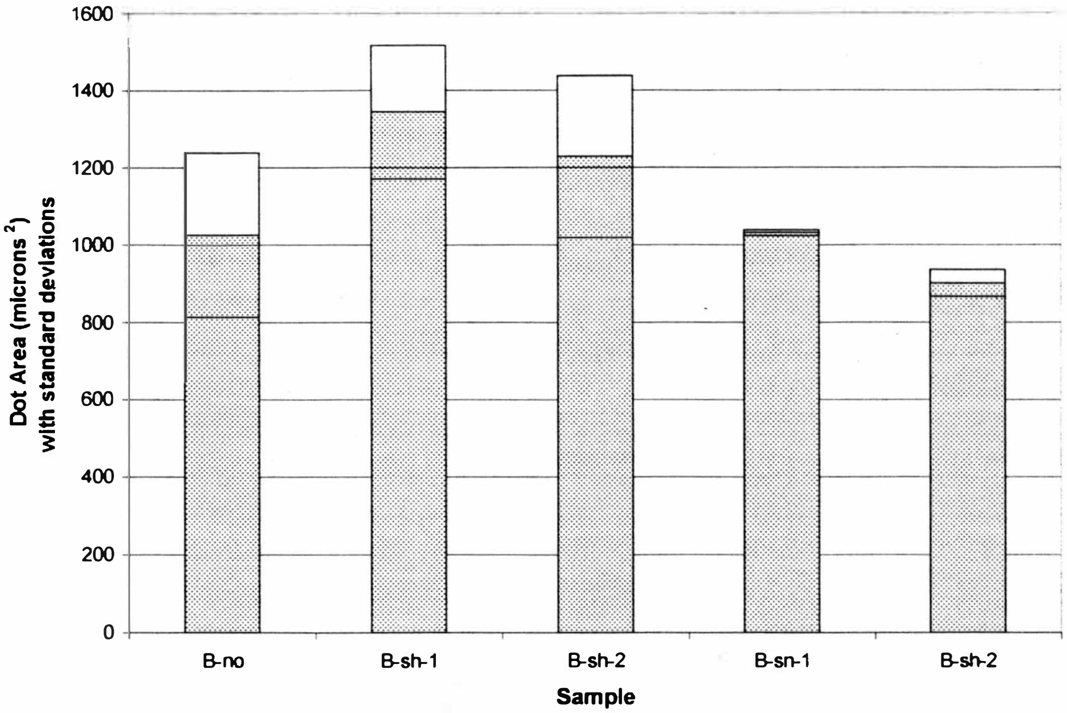

Figure 31. Dot Area of 2% Coverage Area of Belbond Ply Samples.

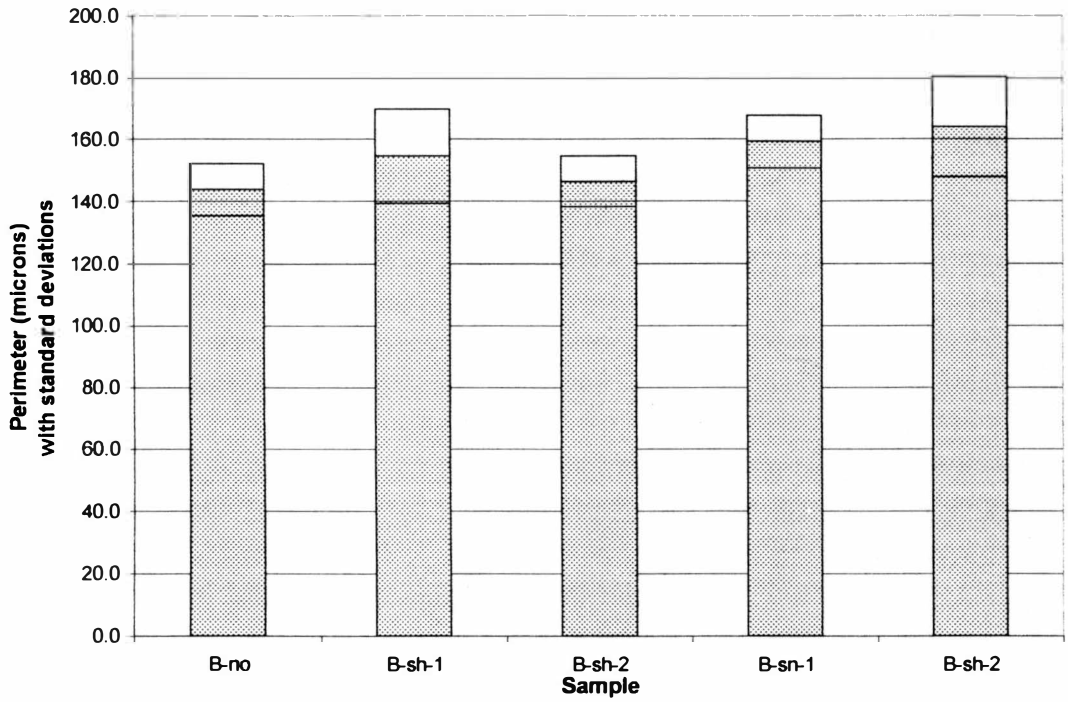

Figure 32. Perimeter of Dots of 2% Coverage Area of Belbond Ply Samples.

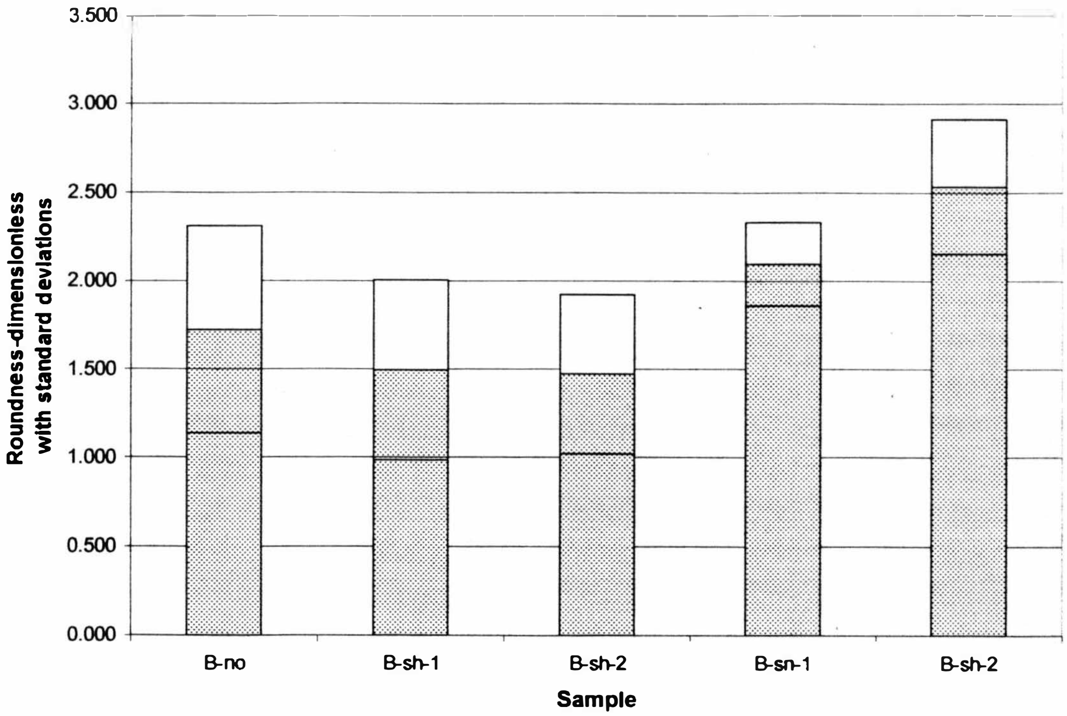

Figure 33. Roundness of 2% Coverage Area of Belbond Ply Samples.

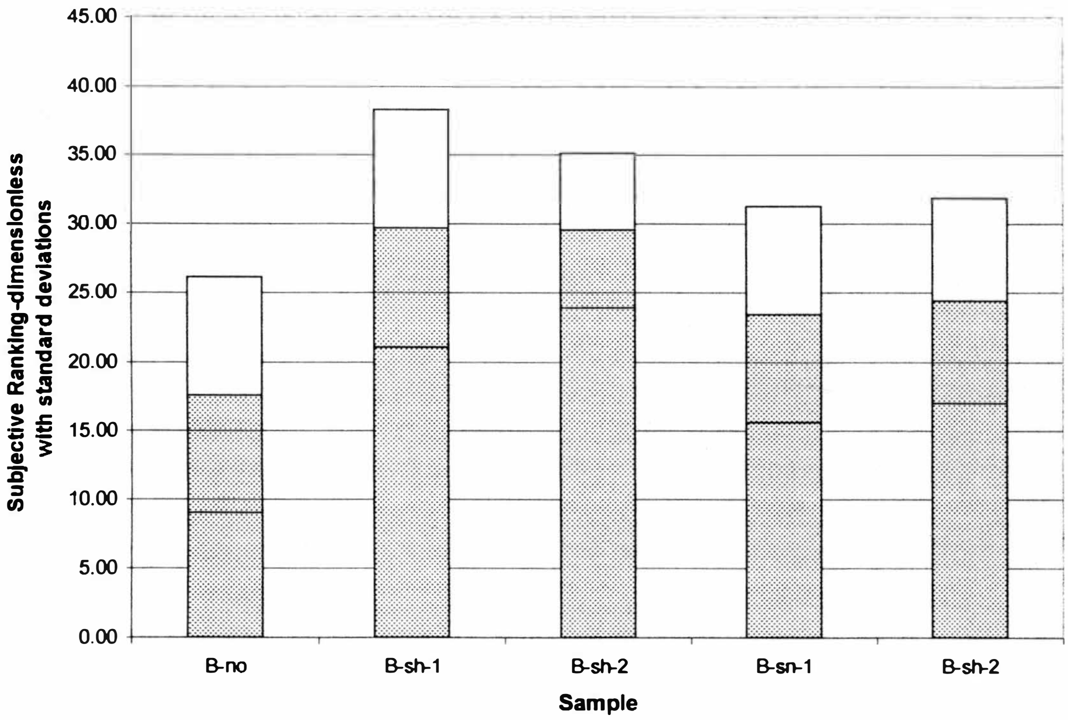

Figure 34. Subjective Visual Ranking of Belbond Ply Samples.

Correlation Coefficients of Measured Quantities With Subjective Ranking

In order to qualify which linerboard characteristics predicted printability, and which quantities measure print quality, the correlation coefficients were calculated and are presented in Table 7. The DAT data were linearly regressed; the intercept value was interpreted as a measure of wetting, and the slope a measure of absorption. As the objective of this study was not to determine response equations of linerboard characteristics and print quality, but to screen out and identify which are significant contributors, all regressions are by default linear. The values in parentheses are judged meaningless. These were chosen if and only if they showed no significant difference for either type of calendering at either pressure level, from the uncalendered sample.

Table 7

Correlation Coefficients of Linerboard Characteristics and Printability Parameters With Subjective Ranking

	Off-line Ply	Belbond Ply
Caliper	37.7%	-87.0%
Sheffield roughness	8.3%	-70.9%
PPS roughness	-36.1%	-87.5%
Emveco microdeviation	24.0%	-82.6%
DAT intercept	-32.3%	60.1%
DAT slope	54.6%	87.7%
Cobb absorbancy	-85.0%	(82.4%)
PDA W	43.0%	-49.7%
PDA max	84.0%	-58.3%
PDA A_{60}	-79.3%	82.9%
Gurley air permeability	-42.8%	54.9%
PPS permeability	29.8%	-87.8%
Print Density	56.1%	69.9%
Delta Gloss	-93.7%	-87.3%
Print Density Mottle	-90.6%	(-15.4%)
Gloss Mottle	-51.6%	-7.0%
Dot Area	(-54.8%)	(70.4%)
Perimeter	(3.1%)	(17.6%)
Roundness	(34.5%)	(-35.4%)

CHAPTER VII

CONCLUSIONS

The results of the optical measurements as measured by print density, density mottle, and gloss mottle show an improvement in print quality due to the shoe calendering. This improvement appears to have a practical limit, as would be expected, as there appeared to be little difference between the high pressure and low pressure calendered samples. Using these same parameters, there appeared to be a worsening of print quality due to the hot/soft nip calendering.

The coefficients of correlation from Table 7 can be used as a rough indicator of which optical properties are useful in measuring print quality. If the data from a particular instrument did not show significant differences between the calendered samples and the uncalendered sample, then its coefficient of correlation with subjective ranking is meaningless. Print density and delta gloss appear to be the most important criteria, with the two mottle indices also contributing. Interestingly, the correlation of delta gloss with subjective ranking was negative, indicating that it is the *contrast*, negative or positive, in the gloss values of the printed and unprinted areas that are desirable.

Similarly, the linerboard parameters can be evaluated as to how well they improve printability. Not surprisingly, the caliper alone is no indicator of printability. It is unclear what effect roughness has on printability. On the one hand, the coefficients of correlation were all high for the Belbond samples for the three roughness measuring devices. On the other hand, the off-line samples showed poor correlation between roughness and subjective ranking. Of the three, the PPS appeared to be the most useful. This is despite the fact that the Sheffield Instrument is the most widely used roughness measuring device for linerboard; it is the sole Tappi test method for linerboard.

The Cobb values appear to be grossly different in Table 7 for the two different types of linerboard. However, the values for the Belbond samples did not show appreciable differences for the different calendering conditions, whereas the values for the off-line ply samples did. Therefore, only the results from the latter need be considered. This indicates that higher absorbency leads to poorer print quality, which can be explained by a decrease in print density (r^2 = -61.3% for the off-line samples). There is confirmation of this with the A_{60} value from PDA for the off-line samples.

The air permeability showed poor correlation with subjective ranking. While there was good correlation between the two instruments, neither showed promise as predictive tools of print quality. This is not surprising, as their measured values are functions of the entire thickness of the linerboard, while it is the z-direction fraction that contributes to printability.

CHAPTER VIII

RECOMMENDATIONS FOR FURTHER STUDY

This study was intended to be a useful, broad-based approach to acquiring an understanding of the factors that influence and ways to measure the print quality of flexographic printed linerboard. The findings of this study could be utilized in a follow-up effort which concentrates on the parameters found to be significant. Namely, the effects of roughness and absorptivity could be further studied.

One limitation of this study was the fact that for each calender type and linerboard type, there were only two levels of calendering. Subsequent studies should include a larger sample size, to quantify the relationship better. This study indicates a non-linear relationship between roughness and absorptivity, but more extensive work needs to be done to confirm this.

There was good evidence from this study to show that delta gloss, print density, print mottle, and gloss mottle all contribute by varying degrees to print quality, as measured by the subjective ranking technique. However, there was too much variability in the rankings to make conclusive statements. Further work with a larger group of rankers could improve upon this.

There is not satisfactory explanation to describe the anomaly of the trends from the low pressure hot/soft nip calendered sample to the high pressure samples. The reasoning offered are pure supposition, and this phenomenon calls for further investigation. A study of the heat build-up characteristics of the backing roll material, and the effects on the elastic modulus, could be conducted. In any case, a study involving these samples calendered under a more thorough set of pressures would validate this effect.

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Appendix A

Calendering Conditions

Calendering Conditions

Sample	Calender Type	Loading (pli)
O-sh-1	shoe	1713
O-sh-2	shoe	2284
O-sn-1	hot/soft nip	800
O-sn-2	hot/soft nip	1200
B-sh-1	shoe	1713
B-sh-2	shoe	2284
B-sn-1	hot/soft nip	800
B-sn-2	hot/soft nip	1200

The temperature for all calendering was held at 400 C. The web speed for all calendering was 1500 feet per minute.

Appendix B

Permeability Equation *(24)*

Darcy's Law:

$$Q / A = K_v \cdot p / m \cdot L$$

Q = volumetric flow rate of fluid (cm^3 / sec)

A = area of porous medium (cm^2)

K_v = "permeability coefficient" (cm^2)

p = pressure differential (dynes / cm^2)

m = viscosity of the fluid (dynes-sec / cm^2)

L = thickness of porous medium (cm)

This law describes how a fluid flows through a thickness of substance with some fluid impedance. This law makes several assumptions. The first is that the fluid flow is laminar. The second is that the fluid is isothermal. The third is that the fluid is negligibly compressed. The Hagen-Poiseuille equation describes how such a fluid flows through a capillary:

$$Q = m \cdot r^4 \cdot p / 8\ m \cdot L$$

r = radius of the capillary (cm)

If the assumption is made that any porous medium consists of a packing of identical capillaries, then the fluid flow per unit area is:

$$Q / A = e \cdot r^2 \cdot p / 8\ b \cdot m \cdot L$$

e = porosity of medium (*dimensionless*)

b = tortuosity ratio = effective length of capillary / L (*dimensionless*)

Combining Darcy's law and the Hagen-Poiseuille equation and solving for K_v gives:

$$K_v = e \cdot r^2 / 8\,b$$

Appendix C

The Lucas-Washburn Equation *(16)*

$$V = (e / b) \cdot [(r \cdot g \cdot t \cdot \cos(a) / 2m]^{1/2}$$

V = volume of liquid absorbed per unit area (cm)

e = porosity (*dimensionless*)

b = tortuosity of pore system (*dimensionless*)

r = average radius of the pores (cm)

a = contact angle between ink surface and substrate surface (degreees)

g = surface tension of ink (dynes / cm)

m = viscosity of ink (dynes-sec / cm^2)

t = time (seconds)

Appendix D

Equation Relating Peak Pressure and Nip Width

$$b = [(\{ 2 F d_1 d_2 \} \{ [1 - v_1^2] / E_1 + [1 - v_2^2] / E_2 \}) / (pi [d_1 + d_2])]^{1/2}$$

and

$$p = (2 F) / (pi\, b)$$

b = half the width of the nip, (m)

F = loading force per unit length, (N / m)

d = diameter of each roll, (m)

v = Poisson ratio of each roll material, (*dimensionless*)

E = elastic modulus of each roll (Pa)

p = maximum pressure (N)

Appendix E

Transmittance of Ultrasonic Signals vs. Time for the Off-line Ply and Belbond Ply Samples

The response variable is the *attenuation coefficient*, or *a*, which is the percent transmittance, with the peak value normalized to 100%.

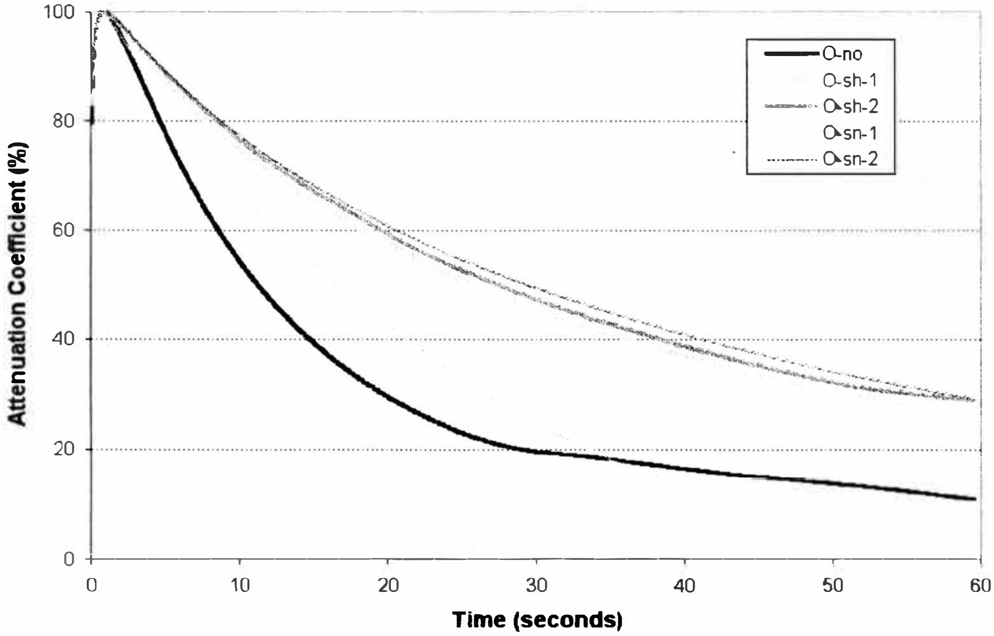

Figure 35. Wetting/Absorption Characterization of Off-line Ply Samples Using PDA.

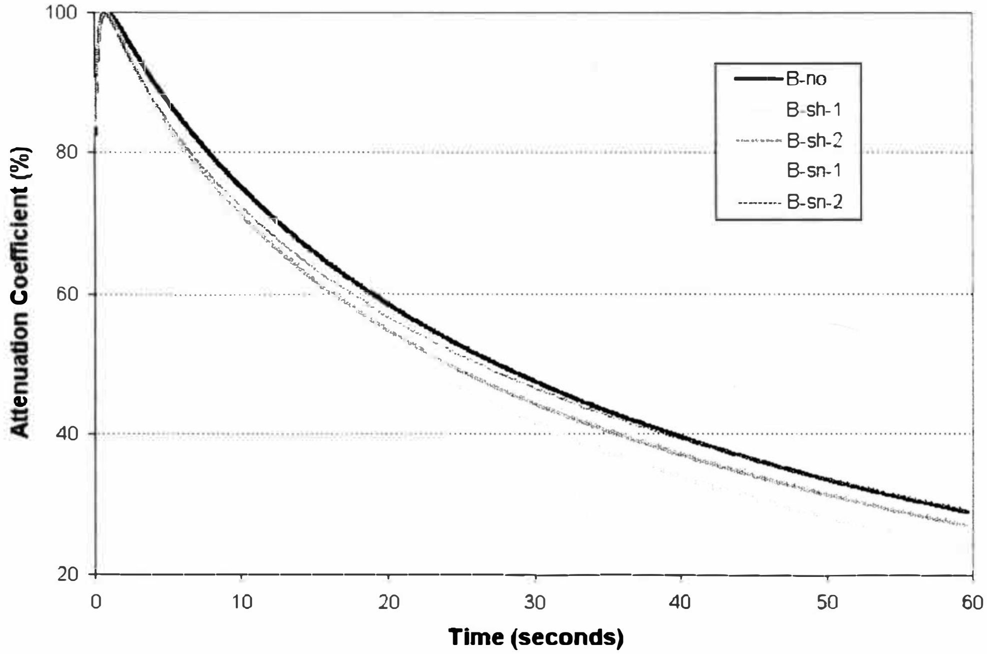

Figure 36. Wetting/Absorption Characterization of Belbond Ply Samples Using PDA.

Appendix F

Raw Data

Individual Density Measurements--Solids

Substrate Type	Subject Number	Lt 1	2	3	4	5	6	AveLt	StDLt	Rt 1
P9	1	1.00	0.99	0.99	1.00	1.02	1.01	1.002	0.012	0.99
	2	1.00	1.00	1.00	0.98	1.02	1.02	1.003	0.015	1.01
	3	0.98	0.99	0.99	0.99	0.99	1.01	0.992	0.010	0.98
	4	0.96	0.96	0.87	0.92	0.92	0.90	0.922	0.035	0.91
	5	0.98	0.97	0.95	0.97	0.95	0.99	0.968	0.016	0.94
650	1	1.00	0.99	0.99	1.01	1.03	1.03	1.008	0.018	1.02
	2							####	####	
	3	0.99	1.00	1.00	1.03	1.03	1.04	1.015	0.021	1.00
	4	1.02	1.02	1.01	1.02	1.05	1.03	1.025	0.014	1.00
	5	1.02	1.01	1.00	1.01	1.04	1.04	1.020	0.017	1.00
	6	1.02	1.01	1.01	1.02	1.02	1.05	1.022	0.015	1.00
652	1	1.04	1.04	1.05	1.06	1.07	1.07	1.055	0.014	1.04
	2	1.05	1.06	1.06	1.08	1.09	1.10	1.073	0.020	1.03
	3	1.05	1.04	1.03	1.03	1.03	1.10	1.047	0.027	1.04
	4	1.05	1.05	1.04	1.06	1.06	1.07	1.055	0.010	1.05
	5	1.04	1.04	1.03	1.04	1.06	1.07	1.047	0.015	1.03
	6							####	####	
655	1							####	####	
	2	1.03	1.03	1.02	1.04	1.06	1.07	1.042	0.019	1.05
	3	1.02	1.02	1.01	1.01	1.04	1.04	1.023	0.014	1.03
	4	1.02	1.02	1.01	1.04	1.03	1.04	1.027	0.012	1.01
	5	1.04	1.04	1.02	1.03	1.05	1.06	1.040	0.014	1.05
	6	1.00	1.00	1.00	1.04	1.05	1.07	1.027	0.031	1.03
656	1	1.00	0.99	0.99	1.02	1.03	1.04	1.012	0.021	1.03
	2	1.00	1.02	1.01	1.03	1.04	1.04	1.023	0.016	1.01
	3	1.05	1.03	1.01	1.05	1.06	1.08	1.047	0.024	1.03
	4	1.03	1.02	1.01	1.05	1.06	1.06	1.038	0.021	1.04
	5							####	####	
	6	1.02	1.00	1.00	1.02	1.04	1.06	1.023	0.023	1.01
P11	1	1.09	1.07	1.04	1.09	1.11	1.11	1.085	0.027	1.07
	2	1.06	1.06	1.07	1.08	1.10	1.12	1.082	0.024	1.07
	3	1.06	1.07	1.04	1.06	1.08	1.08	1.065	0.015	1.05
	4	1.06	1.05	1.04	1.06	1.07	1.08	1.060	0.014	1.04
	5	1.04	1.03	1.02	1.04	1.06	1.07	1.043	0.019	1.02
	6							####	####	
658	1							####	####	
	2	1.10	1.11	1.07	1.11	1.13	1.13	1.108	0.022	1.10
	3	1.09	1.10	1.06	1.08	1.11	1.11	1.092	0.019	1.08
	4	1.11	1.10	1.06	1.09	1.11	1.11	1.097	0.020	1.09
	5	1.07	1.08	1.05	1.09	1.10	1.11	1.083	0.022	1.08
	6	1.10	1.08	1.06	1.08	1.10	1.12	1.090	0.021	1.09
	7							####	####	
659	1	1.07	1.05	1.05	1.06	1.09	1.10	1.070	0.021	1.06
	2	1.07	1.05	1.06	1.09	1.09	1.10	1.077	0.020	1.06

	3	1.12	1.10	1.10	1.11	1.13	1.16	1.120	0.023	1.08
	4							####	####	
	5	1.07	1.05	1.05	1.07	1.08	1.09	1.068	0.016	1.07
	6	1.05	1.05	1.05	1.06	1.07	1.10	1.063	0.020	1.06
P14	1	1.00	0.99	0.95	1.01	1.05	1.05	1.008	0.038	0.99
	2							####	####	
	3	1.02	1.03	1.01	1.06	1.08	1.07	1.045	0.029	1.00
	4	1.04	1.03	1.02	1.06	1.08	1.07	1.050	0.024	1.02
	5	1.04	1.00	1.00	1.07	1.05	1.07	1.038	0.032	1.03
	6	1.01	1.00	0.99	1.04	1.05	1.05	1.023	0.027	1.01
664	1	1.07	1.07	1.06	1.07	1.11	1.11	1.082	0.022	1.08
	2							####	####	
	3	1.10	1.07	1.06	1.09	1.10	1.11	1.088	0.019	1.05
	4	1.07	1.06	1.08	1.11	1.10	1.11	1.088	0.021	1.06
	5	1.11	1.10	1.09	1.11	1.11	1.16	1.113	0.024	1.12
	6	1.01	1.11	1.10	1.13	1.15	1.15	1.109	0.051	1.10
665	1							####	####	
	2							####	####	
	3							####	####	
	4							####	####	
	5							####	####	
	6							####	####	
668	1	1.11	1.09	1.11	1.10	1.11	1.13	1.108	0.013	1.07
	2	1.09	1.07	1.09	1.11	1.11	1.11	1.097	0.016	1.09
	3	1.13	1.11	1.12	1.13	1.13	1.14	1.127	0.010	1.10
	4	1.13	1.09	1.09	1.10	1.13	1.15	1.115	0.025	1.10
	5							####	####	
	6	1.10	1.10	1.08	1.10	1.10	1.11	1.098	0.010	1.10
669	1							####	####	
	2							####	####	
	3							####	####	
	4							####	####	
	5							####	####	
	6							####	####	
P12	1	1.01	1.01	1.01	1.02	1.06	1.02	1.022	0.019	1.00
	2	1.01	1.03	1.03	1.06	1.10	1.05	1.047	0.031	1.02
	3							####	####	
	4	1.01	1.01	1.01	1.02	1.04	1.07	1.027	0.024	1.05
	5	1.00	1.02	1.02	1.05	1.06	1.05	1.033	0.023	1.05
	6	1.02	1.02	1.02	1.06	1.06	1.05	1.038	0.020	1.05
660	1	1.06	1.05	1.06	1.09	1.07	1.09	1.070	0.017	1.07
	2	1.06	1.03	1.07	1.08	1.09	1.10	1.072	0.025	1.06
	3	1.08	1.07	1.06	1.09	1.08	1.10	1.080	0.014	1.05
	4	1.07	1.05	1.05	1.08	1.08	1.10	1.072	0.019	1.05
	5	1.04	1.05	1.05	1.06	1.07	1.05	1.053	0.010	1.06
	6							####	####	
661	1	1.06	1.05	1.06	1.07	1.08	1.08	1.067	0.012	1.04
	2	1.07	1.06	1.06	1.08	1.08	1.09	1.073	0.012	1.06
	3							####	####	

	4	1.06	1.02	1.05	1.09	1.07	1.11	1.067	0.031	1.08
	5	1.07	1.08	1.07	1.08	1.09	1.09	1.080	0.009	1.07
	6	1.06	1.06	1.05	1.08	1.08	1.08	1.068	0.013	1.06
P15	1							####	####	
	2	0.97	0.95	0.97	1.02	1.01	1.01	0.988	0.029	0.98
	3	0.98	0.96	0.96	0.98	1.01	1.02	0.985	0.025	0.99
	4	1.01	0.97	0.98	1.01	1.02	1.02	1.002	0.021	1.00
	5	0.96	0.98	0.97	1.00	1.01	0.99	0.985	0.019	0.99
	6	0.95	0.95	0.96	1.01	1.03	1.00	0.983	0.034	0.97
662	1							####	####	
	2							####	####	
	3							####	####	
	4							####	####	
	5	1.04	1.03	1.04	1.04	1.07	1.05	1.045	0.014	1.03
	6							####	####	
	7	1.03	1.03	1.02	1.05	1.07	1.07	1.045	0.022	1.02
	8	1.05	1.04	1.04	1.05	1.07	1.08	1.055	0.016	1.03
	9	1.04	1.03	1.03	1.05	1.06	1.07	1.047	0.016	1.05
	10	1.04	1.02	1.03	1.05	1.05	1.06	1.042	0.015	1.05
663	1							####	####	
	2	1.08	1.06	1.07	1.08	1.10	1.10	1.082	0.016	1.07
	3	1.08	1.07	1.06	1.06	1.10	1.11	1.080	0.021	1.05
	4	1.07	1.05	1.04	1.05	1.09	1.09	1.065	0.022	1.06
	5	1.07	1.06	1.05	1.07	1.10	1.10	1.075	0.021	1.06
	6	1.06	1.06	1.05	1.06	1.09	1.09	1.068	0.017	1.07
666	1	1.09	1.07	1.07	1.09	1.11	1.11	1.090	0.018	1.07
	2	1.06	1.06	1.05	1.10	1.11	1.12	1.083	0.030	1.06
	3	1.06	1.05	1.03	1.07	1.09	1.10	1.067	0.026	1.05
	4	1.04	1.04	1.04	1.06	1.09	1.08	1.058	0.022	1.05
	5	1.08	1.06	1.05	1.08	1.11	1.11	1.082	0.025	1.06
	6							####	####	
667	1	1.06	1.06	1.04	1.09	1.10	1.11	1.077	0.027	1.06
	2	1.09	1.06	1.06	1.08	1.10	1.11	1.083	0.021	1.06
	3	1.03	1.03	1.02	1.05	1.07	1.07	1.045	0.022	1.04
	4	1.03	1.02	1.01	1.06	1.06	1.06	1.040	0.023	1.04
	5	1.05	1.02	1.04	1.07	1.07	1.08	1.055	0.023	1.04
	6							####	####	
657	1	0.97	1.00	0.98	1.01	1.04	1.06	1.010	0.035	1.01
	2							####	####	
	3	1.03	1.03	1.01	1.02	1.06	1.05	1.033	0.019	1.04
	4	1.01	1.01	1.01	1.05	1.03	1.05	1.027	0.020	1.02
	5	1.02	1.01	0.99	1.02	1.07	1.05	1.027	0.029	1.00
	6	1.02	1.00	1.02	1.03	1.03	1.06	1.027	0.020	1.01
651	1	0.99	0.99	0.99	1.01	1.02	1.01	1.002	0.013	1.00
	2							####	####	
	3	0.99	0.99	0.99	1.00	1.01	1.00	0.997	0.008	1.01
	4	0.99	0.99	0.99	1.00	1.01	1.01	0.998	0.010	1.00
	5	0.98	0.96	0.98	0.99	1.01	1.01	0.988	0.019	0.99
	6	0.97	0.97	0.97	0.99	1.01	1.00	0.985	0.018	0.98

654	1							####	####	
	2	0.99	0.99	0.98	1.00	1.01	1.01	0.997	0.012	0.99
	3	0.99	0.97	0.98	0.99	0.99	1.02	0.990	0.017	1.00
	4	0.99	0.98	0.98	1.01	1.01	1.00	0.995	0.014	1.00
	5	0.99	0.99	0.98	0.99	1.01	1.02	0.997	0.015	0.99
	6	0.99	0.96	0.98	1.00	1.01	1.00	0.990	0.018	0.99

							Individual Density Measurements--Tone Steps				
					AveRt	StDRt					
2	3	4	5	6			2%	3%	4%	5%	10%
1.00	0.98	0.96	0.93	0.98	0.973	0.025	0.22	0.25	0.29	0.31	0.40
0.99	0.98	0.99	0.97	0.96	0.983	0.018	0.20	0.21	0.24	0.27	0.36
0.97	0.97	0.98	0.97	0.94	0.968	0.015	0.20	0.24	0.27	0.30	0.41
0.92	0.87	0.83	0.87	0.86	0.877	0.033	0.18	0.20	0.22	0.25	0.32
0.94	0.90	0.92	0.95	0.84	0.915	0.041	0.19	0.23	0.26	0.28	0.39
1.03	1.02	1.01	1.01	1.01	1.017	0.008	0.18	0.20	0.24	0.26	0.37
					####	####					
0.99	1.00	1.02	1.01	1.04	1.010	0.018	0.21	0.25	0.29	0.33	0.47
0.99	1.00	0.99	1.00	1.03	1.002	0.015	0.21	0.23	0.26	0.30	0.41
0.99	1.01	1.01	1.01	1.02	1.007	0.010	0.21	0.23	0.28	0.31	0.44
1.01	1.00	1.00	1.01	1.00	1.003	0.005	0.23	0.26	0.31	0.33	0.46
1.05	1.04	1.04	1.04	1.05	1.043	0.005	0.20	0.25	0.30	0.33	0.49
1.05	1.04	1.04	1.06	1.05	1.045	0.010	0.20	0.23	0.28	0.30	0.44
1.03	1.02	1.03	1.03	1.05	1.033	0.010	0.23	0.26	0.31	0.33	0.52
1.04	1.04	1.04	1.04	1.05	1.043	0.005	0.21	0.23	0.27	0.31	0.46
1.03	1.03	1.02	1.02	1.02	1.025	0.005	0.23	0.26	0.29	0.34	0.50
					####	####					
					####	####					
1.03	1.05	1.05	1.06	1.05	1.048	0.010	0.21	0.21	0.27	0.31	0.39
1.01	1.04	1.06	1.04	1.07	1.042	0.021	0.23	0.26	0.30	0.34	0.48
1.06	1.04	1.03	1.04	1.04	1.037	0.016	0.21	0.23	0.28	0.30	0.41
1.06	1.05	1.05	1.06	1.12	1.065	0.027	0.21	0.24	0.28	0.30	0.40
1.03	1.03	1.04	1.04	1.02	1.032	0.008	0.24	0.27	0.31	0.37	0.48
1.01	1.01	1.04	0.98	1.02	1.015	0.021	0.22	0.25	0.28	0.33	0.46
1.00	1.00	1.01	1.00	1.02	1.007	0.008	0.23	0.26	0.31	0.35	0.49
1.02	1.03	1.03	1.02	1.02	1.025	0.005	0.20	0.21	0.25	0.28	0.38
1.02	1.02	1.03	1.04	1.05	1.033	0.012	0.22	0.23	0.28	0.30	0.44
					####	####					
1.02	1.00	1.02	1.00	1.04	1.015	0.015	0.24	0.26	0.30	0.34	0.49
1.08	1.04	1.07	1.05	1.03	1.057	0.020	0.21	0.23	0.27	0.28	0.39
1.04	1.08	1.06	0.99	1.06	1.050	0.032	0.24	0.26	0.27	0.29	0.40
1.03	0.99	1.07	1.07	1.01	1.037	0.033	0.20	0.24	0.26	0.28	0.36
1.00	1.04	1.00	1.04	1.00	1.020	0.022	0.18	0.22	0.25	0.25	0.31
1.00	1.05	1.01	1.02	0.98	1.013	0.023	0.21	0.24	0.26	0.30	0.40
					####	####					
					####	####					
1.09	1.09	1.09	1.07	1.07	1.085	0.012	0.19	0.19	0.24	0.24	0.36
1.09	1.07	1.08	1.09	1.10	1.085	0.010	0.22	0.26	0.30	0.30	0.41
1.09	1.09	1.06	1.07	1.10	1.083	0.015	0.20	0.22	0.25	0.26	0.39
1.08	1.07	1.09	1.08	1.06	1.077	0.010	0.22	0.25	0.29	0.29	0.43
1.10	1.09	1.08	1.10	1.09	1.092	0.008	0.20	0.22	0.25	0.28	0.37
					####	####					
1.06	1.07	1.07	1.08	1.10	1.073	0.015	0.21	0.25	0.29	0.31	0.46

1.06	1.05	1.04	1.06	1.07	1.057	0.010	0.23	0.26	0.31	0.35	0.52
1.09	1.11	1.09	1.10	1.10	1.095	0.010	0.23	0.26	0.31	0.33	0.49
					####	####					
1.08	1.07	1.07	1.06	1.09	1.073	0.010	0.23	0.25	0.31	0.32	0.47
1.06	1.09	1.06	1.07	1.08	1.070	0.013	0.24	0.27	0.33	0.34	0.51
1.01	1.01	1.02	0.98	1.01	1.003	0.015	0.19	0.23	0.28	0.31	0.45
					####	####					
1.03	1.04	1.04	1.00	1.00	1.018	0.020	0.16	0.20	0.25	0.30	0.42
1.03	1.04	1.04	1.06	1.02	1.035	0.015	0.19	0.22	0.30	0.32	0.46
1.05	1.06	1.00	1.01	0.97	1.020	0.033	0.21	0.25	0.32	0.35	0.47
1.04	1.04	1.02	0.99	0.97	1.012	0.028	0.18	0.21	0.28	0.31	0.42
1.06	1.06	1.07	1.06	1.04	1.062	0.013	0.21	0.22	0.27	0.30	0.42
					####	####					
1.05	1.06	1.06	1.06	1.06	1.057	0.005	0.19	0.23	0.27	0.30	0.39
1.07	1.07	1.07	1.05	1.07	1.065	0.008	0.20	0.23	0.29	0.32	0.44
1.11	1.10	1.12	1.11	1.11	1.112	0.008	0.16	0.18	0.21	0.21	0.27
1.10	1.10	1.09	1.10	1.10	1.098	0.004	0.23	0.25	0.28	0.32	0.44
					####	####					
					####	####					
					####	####					
					####	####					
					####	####					
					####	####					
1.08	1.08	1.08	1.05	1.06	1.070	0.013	0.19	0.22	0.27	0.29	0.45
1.10	1.09	1.10	1.05	1.08	1.085	0.019	0.19	0.21	0.27	0.30	0.51
1.12	1.10	1.11	1.10	1.12	1.108	0.010	0.17	0.17	0.24	0.26	0.38
1.10	1.11	1.12	1.07	1.08	1.097	0.019	0.20	0.20	0.26	0.26	0.46
					####	####					
1.07	1.10	1.07	1.08	1.10	1.087	0.015	0.24	0.23	0.30	0.34	0.50
					####	####					
					####	####					
					####	####					
					####	####					
					####	####					
					####	####					
1.04	1.02	1.02	1.01	1.01	1.017	0.014	0.20	0.24	0.31	0.37	0.47
1.05	1.08	1.05	1.05	1.00	1.042	0.028	0.23	0.26	0.35	0.36	0.49
					####	####					
1.07	1.08	1.05	1.08	1.01	1.057	0.027	0.20	0.26	0.31	0.33	0.48
1.06	1.06	1.06	1.03	1.02	1.047	0.018	0.18	0.21	0.27	0.30	0.41
1.06	1.07	1.04	1.05	1.01	1.047	0.021	0.21	0.25	0.32	0.35	0.49
1.05	1.05	1.05	1.07	1.05	1.057	0.010	0.22	0.23	0.27	0.35	0.50
1.06	1.04	1.03	1.03	1.04	1.043	0.014	0.24	0.26	0.32	0.37	0.52
1.06	1.06	1.05	1.05	1.05	1.053	0.005	0.22	0.25	0.29	0.33	0.49
1.06	1.05	1.04	1.06	1.04	1.050	0.009	0.25	0.27	0.33	0.37	0.53
1.05	1.05	1.05	1.03	1.05	1.048	0.010	0.22	0.27	0.31	0.35	0.49
					####	####					
1.05	1.05	1.06	1.05	1.05	1.050	0.006	0.21	0.24	0.28	0.32	0.47
1.07	1.05	1.05	1.05	1.06	1.057	0.008	0.24	0.26	0.31	0.38	0.51

					####	####					
1.07	1.11	1.05	1.07	1.04	1.070	0.024	0.25	0.27	0.32	0.37	0.53
1.08	1.06	1.06	1.06	1.06	1.065	0.008	0.21	0.22	0.28	0.32	0.46
1.07	1.05	1.07	1.06	1.07	1.063	0.008	0.22	0.25	0.30	0.35	0.51
					####	####					
1.00	1.01	1.03	0.98	0.96	0.993	0.025	0.19	0.27	0.30	0.32	0.45
1.02	1.00	0.98	0.97	0.97	0.988	0.019	0.18	0.19	0.21	0.21	0.27
0.99	1.01	1.02	0.99	0.93	0.990	0.032	0.19	0.22	0.29	0.23	0.31
1.00	1.01	1.01	0.99	0.95	0.992	0.022	0.19	0.21	0.24	0.26	0.42
0.98	1.02	0.99	0.98	0.93	0.978	0.029	0.18	0.23	0.28	0.29	0.43
					####	####					
					####	####					
					####	####					
					####	####					
1.03	1.04	1.04	1.04	1.05	1.038	0.008	0.21	0.25	0.28	0.33	0.42
					####	####					
1.04	1.03	1.04	1.02	1.05	1.033	0.012	0.21	0.24	0.28	0.30	0.46
1.04	1.05	1.03	1.03	1.06	1.040	0.013	0.20	0.21	0.28	0.28	0.44
1.05	1.04	1.04	1.05	1.06	1.048	0.008	0.21	0.22	0.26	0.28	0.38
1.03	1.04	1.05	1.05	1.06	1.047	0.010	0.19	0.22	0.23	0.26	0.34
					####	####					
1.08	1.07	1.07	1.07	1.05	1.068	0.010	0.19	0.21	0.26	0.27	0.35
1.07	1.06	1.07	1.06	1.07	1.063	0.008	0.21	0.24	0.27	0.32	0.42
1.07	1.07	1.08	1.07	1.09	1.073	0.010	0.19	0.21	0.24	0.27	0.37
1.06	1.06	1.08	1.07	1.09	1.070	0.013	0.23	0.26	0.31	0.33	0.33
1.07	1.07	1.07	1.06	1.09	1.072	0.010	0.21	0.23	0.27	0.30	0.41
1.05	1.07	1.06	1.05	1.07	1.062	0.010	0.21	0.23	0.26	0.30	0.41
1.05	1.04	1.05	1.06	1.04	1.050	0.009	0.24	0.27	0.30	0.32	0.46
1.05	1.05	1.06	1.05	1.04	1.050	0.006	0.23	0.27	0.32	0.38	0.51
1.04	1.02	1.04	0.99	1.05	1.032	0.023	0.20	0.23	0.29	0.29	0.44
1.06	1.06	1.04	1.05	1.01	1.047	0.020	0.21	0.23	0.28	0.30	0.49
					####	####					
1.07	1.07	1.07	1.06	1.05	1.063	0.008	0.19	0.21	0.23	0.31	0.40
1.03	1.05	1.07	1.07	1.05	1.055	0.015	0.20	0.23	0.27	0.30	0.43
1.04	1.03	1.04	1.04	1.06	1.042	0.010	0.23	0.26	0.32	0.35	0.48
1.04	1.04	1.04	1.06	1.04	1.043	0.008	0.26	0.27	0.30	0.38	0.52
1.04	1.04	1.03	1.03	1.05	1.038	0.008	0.19	0.21	0.25	0.29	0.45
					####	####					
1.02	1.07	1.02	1.01	1.10	1.038	0.038	0.21	0.24	0.28	0.32	0.47
					####	####					
1.09	1.01	1.06	1.04	1.02	1.043	0.029	0.21	0.23	0.27	0.30	0.44
1.00	1.01	1.00	1.05	1.04	1.020	0.021	0.20	0.23	0.29	0.33	0.49
1.03	1.02	1.02	1.03	1.08	1.030	0.027	0.22	0.24	0.29	0.33	0.48
1.01	1.04	1.04	1.02	1.04	1.027	0.015	0.23	0.26	0.30	0.35	0.50
1.00	1.00	1.00	0.99	1.01	1.000	0.006	0.21	0.24	0.27	0.31	0.46
					####	####					
0.99	1.00	1.00	0.99	1.00	0.998	0.008	0.20	0.22	0.26	0.29	0.34
0.98	0.97	0.98	1.00	0.99	0.987	0.012	0.21	0.26	0.29	0.33	0.50
0.99	0.99	0.98	0.99	0.99	0.988	0.004	0.22	0.23	0.29	0.33	0.46

0.98	0.97	0.98	0.99	1.01	0.985	0.014	0.25	0.26	0.31	0.38	0.48
					####	####					
0.98	0.98	0.98	0.98	1.00	0.985	0.008	0.23	0.24	0.28	0.31	0.46
0.99	0.99	0.98	0.98	0.98	0.987	0.008	0.19	0.21	0.27	0.31	0.43
0.99	0.99	0.99	0.99	1.00	0.993	0.005	0.22	0.22	0.28	0.33	0.48
0.99	1.00	0.99	0.98	0.99	0.990	0.006	0.23	0.25	0.28	0.33	0.45
0.99	0.94	0.99	0.97	0.99	0.978	0.020	0.24	0.28	0.30	0.38	0.50

Gloss, MD and CD

CD

20%	30%	40%	50%	60%	70%	80%	90%	100%
0.48	0.55	0.61	0.74	0.86	0.93	0.96	0.97	1.02
0.52	0.55	0.64	0.69	0.79	0.88	0.95	0.99	1.02
0.53	0.58	0.64	0.74	0.82	0.90	0.95	0.96	1.01
0.40	0.46	0.53	0.60	0.73	0.82	0.86	0.89	0.99
0.46	0.51	0.63	0.74	0.81	0.88	0.95	0.98	1.00
0.52	0.57	0.64	0.73	0.79	0.90	0.96	1.01	1.06
0.57	0.62	0.66	0.73	0.87	0.96	0.99	1.00	1.04
0.53	0.59	0.63	0.72	0.84	0.93	0.97	1.00	1.04
0.57	0.61	0.64	0.72	0.83	0.93	0.97	1.00	1.04
0.55	0.60	0.69	0.76	0.87	0.95	0.98	1.01	1.03
0.62	0.68	0.69	0.80	0.94	1.03	1.04	1.05	1.10
0.58	0.63	0.68	0.76	0.90	0.97	1.03	1.06	1.10
0.63	0.67	0.76	0.88	0.97	1.02	1.02	1.02	1.08
0.59	0.61	0.70	0.80	0.92	0.99	1.02	1.03	1.08
0.53	0.67	0.72	0.74	0.88	0.98	0.99	1.03	1.09
0.54	0.64	0.69	0.74	0.85	0.93	0.99	1.00	1.06
0.62	0.68	0.75	0.83	0.91	0.99	1.00	1.01	1.03
0.58	0.63	0.70	0.78	0.80	0.93	0.93	0.97	1.03
0.50	0.60	0.68	0.79	0.85	0.95	0.98	1.01	1.04
0.60	0.65	0.72	0.81	0.94	0.96	0.99	1.01	1.07
0.54	0.60	0.72	0.81	0.91	0.96	0.97	1.00	1.02
0.59	0.66	0.78	0.85	0.95	0.98	0.98	1.00	1.04
0.50	0.61	0.70	0.82	0.90	0.97	0.99	1.01	1.06
0.53	0.65	0.77	0.90	0.95	1.00	1.02	1.02	1.03
0.65	0.75	0.79	0.86	0.96	0.99	0.97	1.00	1.04
0.46	0.58	0.70	0.74	0.89	0.98	1.00	1.03	1.08
0.51	0.60	0.69	0.79	0.90	1.00	1.02	1.08	1.11
0.50	0.59	0.65	0.77	0.88	1.00	1.05	1.04	1.09
0.45	0.55	0.64	0.73	0.86	0.95	0.99	1.04	1.09
0.50	0.56	0.62	0.76	0.87	0.94	0.97	1.03	1.07
0.45	0.57	0.70	0.79	0.86	0.98	1.02	1.05	1.12
0.57	0.64	0.73	0.81	0.91	1.05	1.06	1.09	1.13
0.52	0.60	0.68	0.78	0.89	0.99	1.03	1.07	1.11
0.51	0.62	0.69	0.81	0.90	1.02	1.05	1.06	1.12
0.50	0.58	0.72	0.80	0.91	0.99	1.05	1.06	1.11

0.62	0.67	0.69	0.8	0.94	1.02	1.03	1.04	1.08
0.67	0.75	0.75	0.85	0.99	1.04	1.05	1.06	1.10
0.61	0.67	0.74	0.83	0.89	0.99	1.05	1.08	1.13

0.53	0.62	0.74	0.86	0.94	1.00	0.93	1.05	1.09
0.58	0.68	0.79	0.90	0.98	1.02	1.05	1.06	1.11
0.60	0.65	0.73	0.74	0.86	0.99	0.99	1.00	1.04

0.56	0.65	0.71	0.63	0.76	1.01	1.00	1.02	1.03
0.60	0.71	0.75	0.67	0.79	1.05	1.04	1.04	1.08
0.66	0.72	0.76	0.76	0.90	1.03	1.00	1.01	1.07
0.58	0.63	0.70	0.71	0.82	1.00	1.02	1.01	1.08
0.53	0.58	0.67	0.74	0.81	0.93	0.99	1.01	1.09

0.55	0.55	0.61	0.68	0.80	0.95	0.99	1.04	1.10
0.56	0.59	0.64	0.71	0.83	0.98	1.01	1.05	1.09
0.39	0.52	0.60	0.69	0.80	0.92	0.99	1.06	1.15
0.55	0.60	0.65	0.75	0.84	0.92	1.01	1.04	1.11

0.54	0.60	0.62	0.77	0.87	0.95	1.03	1.04	1.13
0.58	0.63	0.75	0.78	0.91	0.98	1.05	1.07	1.13
0.46	0.56	0.65	0.76	0.90	1.00	1.02	1.05	1.13
0.52	0.66	0.72	0.83	0.91	1.02	1.05	1.09	1.13

0.58	0.63	0.71	0.87	0.92	0.99	1.03	1.05	1.09

0.63	0.70	0.78	0.80	0.95	0.98	1.00	0.99	1.02
0.65	0.72	0.83	0.89	0.98	1.06	1.04	1.02	1.05

0.56	0.68	0.80	0.86	0.93	1.05	1.06	1.05	1.05
0.57	0.68	0.74	0.81	0.92	0.98	1.00	1.02	1.06
0.63	0.74	0.79	0.86	0.96	1.06	1.03	1.05	1.07
0.60	0.69	0.76	0.85	0.93	1.00	1.02	1.04	1.09
0.67	0.71	0.77	0.88	0.97	1.04	1.04	1.06	1.10
0.63	0.67	0.75	0.84	0.91	1.01	1.02	1.04	1.09
0.67	0.74	0.81	0.92	1.00	1.04	1.05	1.05	1.09
0.63	0.67	0.75	0.82	0.90	1.00	0.99	1.00	1.06

0.64	0.69	0.77	0.84	0.92	0.99	1.01	1.01	1.09

0.67	0.72	0.77	0.90	1.00	1.04	1.06	1.06	1.11
0.68	0.70	0.76	0.90	1.01	1.05	1.05	1.04	1.11
0.64	0.67	0.72	0.85	0.94	1.03	1.03	1.06	1.08
0.64	0.72	0.77	0.93	1.00	1.06	1.06	1.06	1.09
0.63	0.66	0.71	0.74	0.94	1.02	1.02	0.99	1.02
0.46	0.57	0.69	0.76	0.87	0.94	0.97	0.98	1.01
0.53	0.64	0.78	0.78	0.93	1.00	0.99	0.97	1.01
0.56	0.63	0.53	0.63	0.89	0.99	1.00	0.97	1.01
0.60	0.69	0.66	0.77	0.96	1.00	0.97	0.97	1.01
0.50	0.54	0.66	0.72	0.87	0.93	0.96	1.01	1.05
0.57	0.63	0.69	0.77	0.86	0.96	1.01	1.02	1.07
0.56	0.57	0.60	0.72	0.78	0.93	0.96	1.04	1.09
0.48	0.58	0.66	0.76	0.86	0.96	0.97	1.02	1.07
0.44	0.54	0.65	0.72	0.84	0.92	0.97	1.00	1.05
0.43	0.57	0.65	0.73	0.81	0.94	1.01	1.05	1.10
0.57	0.64	0.66	0.75	0.88	0.99	1.01	1.05	1.10
0.51	0.56	0.61	0.70	0.85	0.91	0.99	1.03	1.08
0.47	0.64	0.64	0.73	0.83	0.96	0.99	1.04	1.05
0.54	0.59	0.64	0.69	0.81	0.94	1.00	1.05	1.09
0.53	0.59	0.64	0.65	0.91	0.98	1.03	1.07	1.13
0.62	0.63	0.69	0.77	0.93	1.01	1.06	1.07	1.10
0.65	0.68	0.77	0.82	0.97	0.98	1.02	1.04	1.08
0.59	0.64	0.67	0.73	0.87	0.98	1.03	1.04	1.05
0.63	0.66	0.75	0.81	0.88	1.01	1.05	1.07	1.11
0.57	0.63	0.71	0.75	0.88	0.97	1.02	1.06	1.09
0.62	0.66	0.72	0.82	0.93	1.01	1.03	1.04	1.08
0.66	0.69	0.74	0.79	0.90	0.97	1.02	1.02	1.05
0.67	0.72	0.75	0.82	0.93	1.00	1.02	1.03	1.05
0.55	0.61	0.71	0.79	0.92	0.98	0.99	1.01	1.04
0.66	0.71	0.80	0.90	0.95	0.96	0.96	1.00	1.06
0.60	0.66	0.76	0.82	0.93	0.95	0.99	1.00	1.03
0.66	0.71	0.80	0.93	0.98	0.99	0.99	1.01	1.07
0.66	0.71	0.77	0.82	0.92	0.95	0.97	1.00	1.05
0.71	0.77	0.82	0.88	0.96	0.97	0.99	1.00	1.08
0.58	0.67	0.71	0.79	0.92	0.96	0.95	0.97	1.00
0.59	0.65	0.70	0.82	0.93	0.96	0.97	0.98	1.02
0.63	0.70	0.74	0.87	0.95	1.00	0.98	0.99	1.02

0.61	0.68	0.76	0.81	0.90	0.95	0.96	0.96	0.98
0.63	0.69	0.78	0.87	0.95	0.98	0.97	1.00	1.01
0.58	0.67	0.69	0.82	0.86	0.95	0.98	0.98	1.02
0.58	0.65	0.67	0.78	0.89	0.96	0.96	0.96	1.01
0.62	0.65	0.70	0.79	0.91	0.99	0.98	0.96	1.03
0.58	0.62	0.72	0.79	0.86	0.95	0.96	0.97	1.01
0.62	0.70	0.76	0.84	0.95	0.97	0.98	0.98	1.00

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