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EFFECT OF PRECALENDERING ON SURFACE AND PRINTING PROPERTIES OF COATED SHEETS

by

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A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Paper and Printing Science and Engineering

Western Michigan University
Kalamazoo, Michigan
April 1998

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1998

EFFECT OF PRECALENDERING ON SURFACE AND PRINTING PROPERTIES OF COATED SHEETS

Hariharan Venkata-Chinnaswamy, M.S.

Western Michigan University, 1998

This study focuses on the effect of different types of precalendering on coated woodfree paper for surface and printing properties as well as coat weight distribution and binder migration.

Precalendering enhanced the gloss and reduced the roughness of the coated paper at all coat weights. In the case of post-calendered papers, any differential effect achieved through various types of precalendering was recovered during post calendering. The final porosity values of precalendered and uncalendered sheets were more dependent on the coat weight at the high coat weights (10-18 g/m^2). At low coat weights the type of precalendering influences the final porosity values.

Precalendering also increased the delta gloss and print density values of the final product. This was observed for the papers that had been subjected to the post-calendering, as well as for those that were not. In the case of print density the type of calendering did not have any specific influence on the final print density values. The data also indicate that the surface latex distribution was not dependent on the type of precalendering and calendering intensity. The latex distribution is found to be more uniform at higher surface latex content.

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CHAPTER I

INTRODUCTION

As it stands today, the much accomplished revolution in surface and printing properties of paper would not have been possible without calendering. The surface characteristics of paper control a variety of end uses like printing and coating of paper. A clear understanding of the processes and interactions involved is essential to achieve a paper with superior quality. The factors controlling the surface properties of calendered paper are very complex as a result of interactions between basestock, coating color, type of calendering and calendering variables.

Machine calendering (MC), supercalendering (SC) and soft nip calendering (SNC) are the three major types of calendering used widely in the industry for improving the surface and printing properties of paper. In this study an attempt is made to define the differences in quality produced by these calendering processes and to quantify their effects on surface and printing properties, surface binder migration and surface mass distribution of the coated sheet. A clear understanding of the interaction between the base stock, calendering operation and coating color are of great importance in obtaining a sheet with good surface and printing properties. This study will assist in gaining a better understanding of the influence of precalendering and the interaction between the base paper and the coating color on the properties of coated paper.

CHAPTER II

REVIEW OF RELATED LITERATURE

Producing high quality images from a printing press requires paper with a smooth and uniform surface. Surface and printing properties of paper are usually improved by a combination of coating and calendering. Coating helps to fill in non-uniformities in the paper surface, provide small uniform pores for ink absorption and provide gloss enhancement. The calendering operation reduces caliper, smooths the surface, reduces the average pore size, and orients the pigment particles in the coated sheet (1-3).

Coating Process Interaction

A common property that mars the print quality of paper is surface roughness. During the coating process a coating color that consists of pigment and binder dispersed in water is applied on the paper. The interactions between the coating color and the base stock influence the structure of the paper in a negative sense, that is, increasing roughness, thickness, swelling and debonding (4-7).

The gloss, rotogravure printability, print gloss and print density of coated paper are greatly influenced by the roughness of coated sheet. Coated paper quality is controlled by the coating mass distribution along the surface of the paper. It has been shown that the measurement of coating mass distribution can be used for studying the printing problem like mottle. A definite relationship between print mottle and coating mass distribution has been confirmed (8, 9). The coating mass distribution of paper is affected by a number of factors, such as the coating process (10, 11), type of base paper (12-14), coating color (14, 15), and drying conditions (12).

The consolidation of coating color on the base paper is governed by a number of factors related to the composition of coating color, the base paper, and the conditions in the coating process. All these factors influence the structure of the dry coating layer and redistribution of the binder. The binder redistribution is generally accepted to occur in two directions: (1) towards the surface with the water that is evaporated at the coating surface, and (2) toward the base paper with the water that is absorbed (16). A coated sheet with optimal smoothness, gloss, and print quality could be obtained if the increase in surface roughness of the base sheet is kept at a minimum during the coating of the paper (8, 16).

Calendering Techniques

Calendering is the mechanical process of subjecting a viscoelastic paper web to the nip pressure of two or more adjacent and revolving rolls with resulting changes in paper properties. Calendering consists of three elements: pressure, temperature and plastic flow of the paper. In this process the caliper of the sheet is reduced, density is increased and improvement in surface levelness on macro-scale and micro-scale due to compaction occurring in the nip.

A calender that uses metal rolls is termed machine calender (MC) and is usually used on-line in the paper making process, with or without on machine coating. Rolls are very hard and non-resilient (18). MC operates in the range of 400 - 1000 pounds per linear inch nip pressure. The number of rolls in the MC can range from five to nine arranged in vertical stack.

Supercalendering (SC) is usually an off-machine method of obtaining superior gloss and smoothness for both coated and uncoated printing papers by using two rolls of different hardness. The number of rolls in the supercalender can range from nine to twelve. Operating nip pressures is generally in the 1000 - 4000 pounds per linear inch range for coated paper. The steel roll can be heated to temperatures ranging from 100 - 200°F. The speed range of the SC is about 1000 - 3000 ft/min. When the rolls are rotating, the metal roll causes depression in the filled roll causing it to creep to obtain its original shape that results in a difference in the surface speed of the metal roll and filled roll. This difference in speed causes friction and a polishing action, leading to a smooth and glossy surface. Most filled rolls are made of cotton (1).

The soft nip calender consists of a smooth highly polished steel roll and a resilient roll. Operating nip pressure ranges from 500 - 4000 pounds per linear inch. The steel roll can be heated by steam, oil, or other controllable means to temperature ranging from 200 to 600°F. Increased levels of smoothness and gloss are obtained without materially densifying the web. Some advantages of soft nip calender are, lower cost than a supercalender, less capital investment, fewer operating problems, less bulk reduction, higher strength retention at equal gloss and smoothness, in both coated and uncoated sheets. Most modern soft nip calenders use synthetic rolls (3).

Effect of Precalendering

In an extensive work done by Skowronski et al. (6), it is shown that surface deformation in paper is due to fiber swelling, debonding and internal stresses in the fiber trying to recover to original shape upon wetting. The paper thickness increases during wetting and decreases during drying; but the recovery is not complete. The results also indicate that the swelling of the fibers is dependent on the type of pulp fiber used and is more pronounced in the case of mechanical fibers.

Skowronski (17) also reported, in a later work, that the effect of water during coating of paper on precalendered handsheets made from thermo mechanical pulps and kraft pulps. The additional variables that were included are yield, bleaching and degree of beating. The results show that changes in the surface roughness of paper, due to precalendering are not permanent due to the presence of intrafiber stresses. Surface changes due to temperature gradient calendering had more permanent effect than a conventional calendering. The surface roughening upon wetting was higher in the case of precalendered sheets, when compared to uncalendered sheets. Surface roughness and gloss were also affected by the kind of wood, pulping method, degree of delignification and the method of drying. Irreversible increase in the surface roughness for a freely dried sheet (wood-containing) and uncalendered sheet was close to zero for sheets made from mechanical pulp, and marginally greater when produced from chemical pulp. Thus, the effects for precalendered paper differ from those of uncalendered papers.

Engström and Lafaye (4) studied the effect of precalendering the base paper (LWC) and its interaction with the coating color on coating mass distribution and print mottle. Precalendered and uncalendered base paper was blade coated in the in a pilot coater. Results indicate that precalendering primarily condensed the fiber flocs in the base paper. Precalendered sheets expanded the most when in contact with the coating color. They showed that the coating layer on the precalendered base sheet had a non-uniform coating layer that affected the coating mass distribution and the print mottle, negatively. The reason suggested was that the internal stresses formed in the base paper because of the calendering operation. It was presumed that these stresses were released when the coating color comes in contact with the base sheet, thus deforming the fiber surface. This surface deformation was not significant in the case of uncalendered sheets.

Steffner et al. (18) blade coated woodfree base paper to investigate the influence of the precalendering on surface properties and the covering ability of the coating. Machine calender and soft nip calendered was used for precalendering. Precalendering had a positive influence on the surface properties and uniformity of the final coating layer. Results indicate that when the paper was more densified during the precalendering it had improved surface properties and a more uniform coating layer. The reason for this difference from earlier work (4) is that irreversible deformation of the base sheet was less pronounced in the case of woodfree sheets.

They showed that the final roughness and gloss and uniformity of the coating layer were not influenced by the calendering conditions like machine speed, roll temperature, and roll material. The reason for this is that the degree of densification achieved during precalendering is more important than the calendering variables.

CHAPTER III

STATEMENT OF THE PROBLEM AND OBJECTIVE

The surface structure of the paper can be improved by calendering and coating. During coating the liquid phase in coating color comes in contact with the base sheet, and an increase in thickness and roughening of the surface of the base sheet occurs (4-7, 17). This increase in surface roughness of the base sheet may affect the coating mass distribution. In the case of calendered sheets before coating the entire effect of calendering was lost due to the presence of intrafiber stresses (6, 17). When the fibers come in contact with the water in the coating color they show a tendency to recover to their original shape and the fiber surface tends to become rougher. The increase in surface roughness should be kept to a minimum to achieve a uniform coating layer. It has been shown that in the case of blade coated material, a uniform coating layer with a narrow mass distribution resulted in an offset print with low print mottle (16). In this project the influence of precalendering on woodfree base sheets and its interaction with the water in the coating color with regards to surface and printing properties, binder migration and coating mass distribution are studied.

The objectives of this project are : (a) to study the effect of precalendering, using a MC, SC and SNC on the surface properties of coated (woodfree) sheets as given by roughness, gloss and porosity; (b) to study the effect of precalendering using MC, SC and SNC on the printing properties of coated sheets as given by print gloss and print density; and (c) to study the effect of precalendering using MC, SC and SNC on the surface latex content at the surface of coated-calendered sheets and on the mass distribution of coated sheets.

CHAPTER IV

EXPERIMENTAL PROCEDURE

This project is divided into five phases: (1) pre-calendering of the base sheet by machine calender, supercalender and soft nip calender; (2) application of coating using a cylindrical laboratory blade coater (CLC-6000) on the calendered (MC, SC and SNC) and uncalendered base sheet; (3) soft nip calendering all the coated sheets; (4) printing of coated, soft nip calendering paper on a Moser Gravure Proof Press with water-based ink; and (5) measurement of the surface and printing properties, mass distribution and surface latex concentration. Experimental schematic of this study is shown in Figure 1.

Material

The base paper used in this project was an uncalendered woodfree paper with a fiber furnish of 50% Canadian softwood and 50% eucalyptus. The basis weight of the paper was 58 g/m^2. The base paper had a roughness value of 6.75 μm on the felt side measured with Parker Print Surf.

No. 2 kaolin clay was used as the pigment (specific surface area of 10.5 m^2/g), of which 80% had an equivalent spherical diameter less of than 2 μm. The binder used in the coating color was a styrene-butadiene copolymer, with a particle size of 0.15 μm and a glass transition temperature of 25°C. Carboxymethycellulose (CMC) was used as a cobinder. Coating colors were prepared to a solids content of 59%, and adjusted to a pH of 8. The coating color had 100 parts of No 2. kaolin clay, 12 parts of binder and 2.5 parts of CMC.

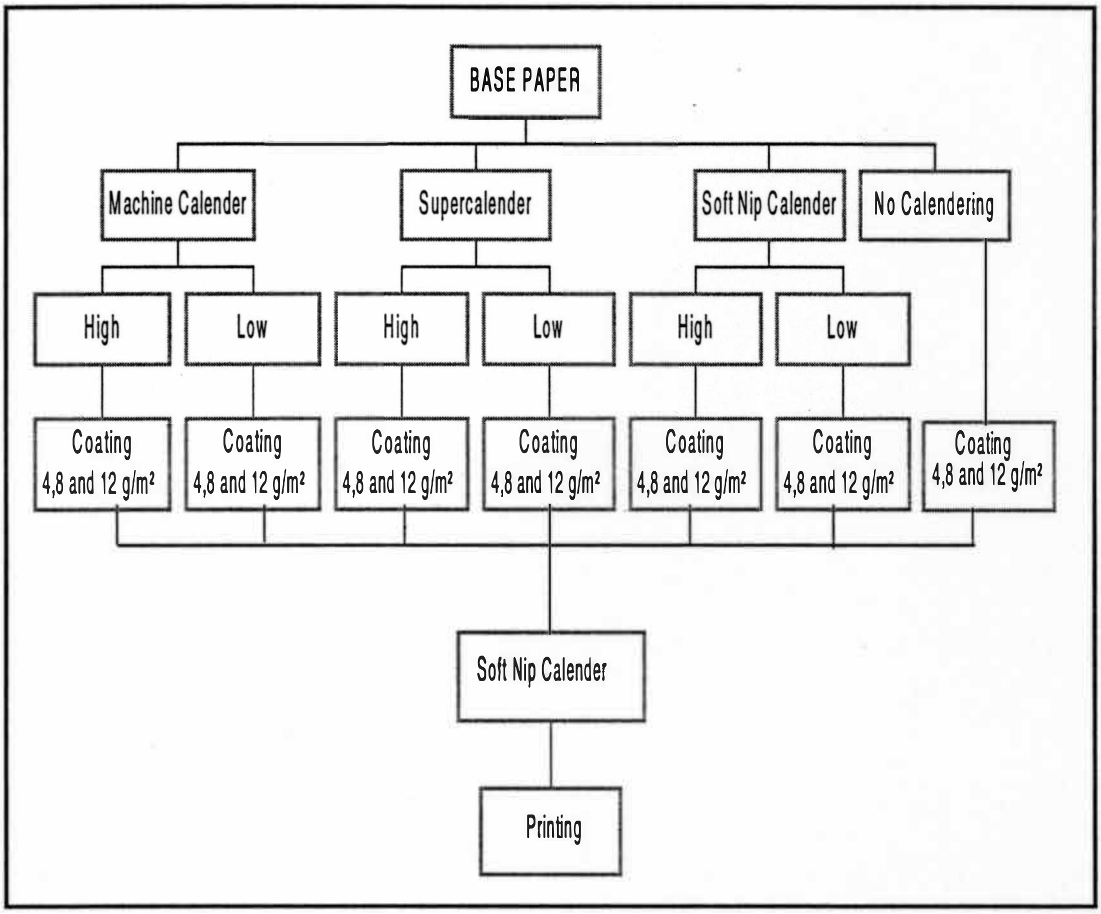

Figure 1. Schematic Experimental Design of Calendering and Coating Operation.

Water based ink was used for printing the paper. The volumetric components of the ink were 24.7% phthalocyanine red pigment, 50.0% acrylic emulsion, 3.0% polyethylene wax, 0.3 % organic defoamer and 22% water.

Methods

Pre-Calendering

The base paper was pre-calendered using a MC, SNC and SC. Base paper was pre-calendered to two different roughness levels (high and low). For the sake of simplicity the high roughness level will be referred to as low intensity calendering and the low roughness level will be referred to as high intensity calendering. The high surface roughness value was in the range of 5.00 to 5.15 μm. The low surface roughness value was in the range of 4.35 to 4.66 μm. The roughness of the sheets was measured using Parker Print Surf.

Coating

The uncalendered and pre-calendered base papers were blade coated using a Cylindrical Laboratory Coater (CLC) at a speed of 1000 fpm. The base paper was pre-dried at 25% power for 10 seconds and post-dried at 100% power for 40 seconds. Uncalendered and pre-calendered (MC, SC and SNC) sheets were coated to achieve three different coat weights (low, medium and high). The three different coat weights were approximately 3.5, 7.5 and 12.5 g/m^2.

Post-Calendering

Part of the coated sheets were calendered in a soft nip calender in order to evaluate the response, if any, of post-calendering on the surface properties.

Printing

Part of the coated and post-calendered sheets were printed in a Moser Gravure-Proof Press at a speed of 100 fpm with a printing pressure of 90 pli and a blade pressure of 20 psi. The angle of the doctor blade was set at 40° and the hot air dryer was set at 100°F.

Measuring Methods

Surface roughness and porosity of the sheets were measured using Parker Print Surf (PPS). This instrument measures the rate of flow of air between a platten and paper under a clamping pressure (19). Gloss was measured according to the standard TAPPI procedure T 480 om-92.

Ultraviolet (UV) absorption was used to measure the surface latex content and distribution (20). This testing is done using a Shimadzu dual wavelength TLC scanner model CS-930 driven by an IBM PC clone using a computer program supplied by H. Fujiwara. This instrument is equipped with a scanning X-Y stage as shown in Figure 2. Light from the deuterium lamp is directed onto the surface of the test specimen at 90° angle and the reflected light at 45° angle is measured using a detector. The spot area and wavelength can be varied. The scanning area for each sample was approximately 60 mm × 63 mm in lines separated by 4 mm from each other. The size of the light beam used in this study was 1.2 mm × 1.2 mm. The coated sheets were scanned with monochromatic light at three different wave lengths, i.e., 235, 260 and 285 nm. The SB latex reflection-absorption spectrum for the Ultraviolet region is shown in Figure 3. It shows peaks at 220 and 260 nm. The absorption band at 260 nm was selected as the best to use. Two wavelengths (235 and 285) at equal distances on either side were selected to obtain a base line value at 260 nm. The absorption in Figure 3 is shown in optical density, the values obtained in the computer controlled analysis were in related units ranging from 20,000 to 50,000. The mean of all measuring points gives the surface latex content in the coating surface while the variance gives the latex distribution.

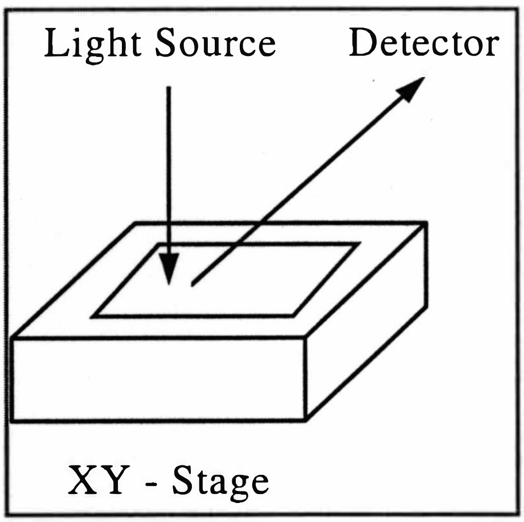

Figure 2. Scanner Measuring System.

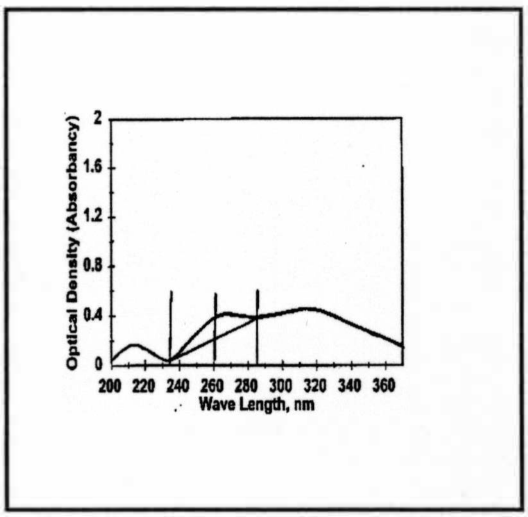

Figure 3. Ultraviolet Absorption of Coated Layer.

The coating mass distribution of the sheet was determined using a burn-out test (23). It is achieved by immersing the sample in a solution containing 25 g/L of NH_4Cl in a mixture of equal parts of water and ethanol. The sample is soaked in the solution for one minute, is withdrawn and any excess solution is allowed to drip off. The sample is then dried and transferred to an oven at a temperature of 225°C, the fiber material in the base paper carbonizes and turns black. Against this background, the unevenness in the mass of the coated layer is revealed. The variance in blackening is a measure of coating mass distribution. The variance was measured using an Shimadzu Dual-Wavelength Thin-Layer Chromato Scanner (Model CS-930), which makes it possible to obtain the unevenness in the coating layer (Figure 4).

The scanning area for each sample was approximately 60 mm × 63 mm in lines separated by 4 mm from each. The size of the high intensity visible light beam used in this study was 1.2 mm × 1.2 mm. The absorption of the coated layer showed a peak at 520 nm. Hence, the burnt-out sheets were scanned with visible light three times at an absorption wavelength of 520 nm. The light scattered at the sample surface is detected by the reflection photomultiplier, while a part of the incident light is detected by the monitoring photomultiplier. The ratio between outputs of the two detectors are converted logarithmically to provide an absorbance signal. The mass distribution is represented by the coefficient of variation in blackening.

The print gloss and print density were measured using standard procedures (24). Print gloss was measured using Micro-Gloss Gardener 60°. Light is directed onto the surface of the test specimen at 60° angle and the reflected light at 60° angle is measured photoelectrically. Print density was measured using a densitometer. The print density was measured using the following formula:

Print Density (D) = $\text{Log}_{10}\,(1/R)$

$$\text{Where } R = \frac{\text{Reflected Light Intensity } (R_i)}{\text{Intensity of Light Reflected by the white paper } (R_w)}$$

$$\text{Therefore } D = \text{Log}_{10}\,(R_w/R_i)$$

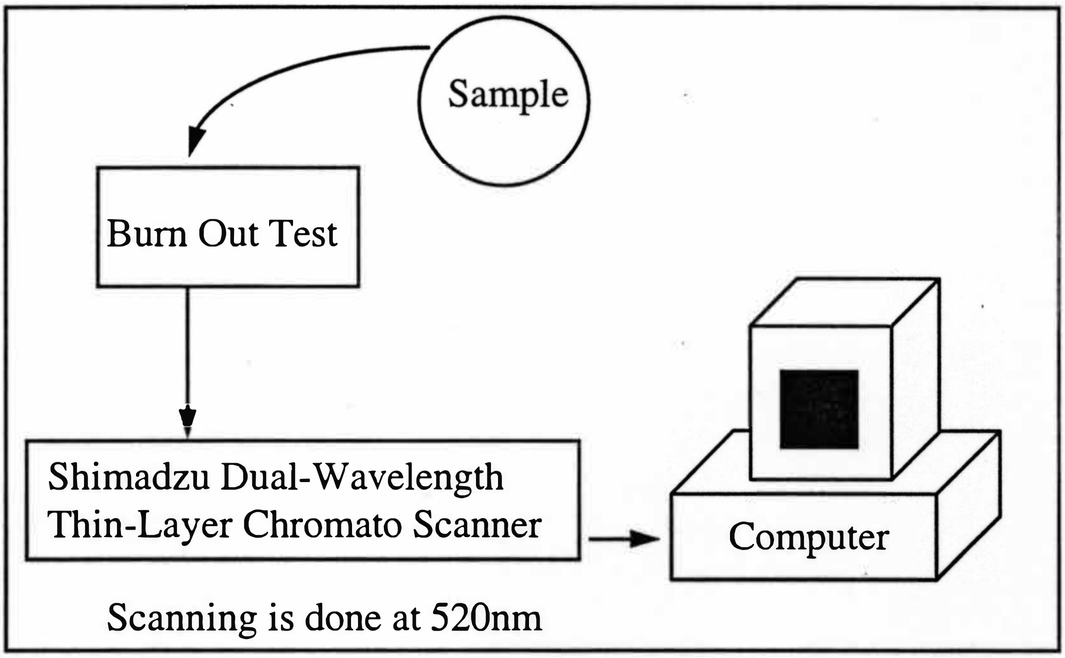

Figure 4. Flow Chart for Coating Mass Distribution Test.

Experimental Runs and Their Associated Measurments

Uncalendered, pre-calendered, coated, post-calendered and printed sheets were conditioned according to TAPPI standard procedure (T 402 om-88). Ten measurements were made for gloss on both machine-direction and cross-direction. Ten measurements were made for roughness, porosity, print gloss and print density. Three scans were made for surface latex concentration and mass distribution. At each scan 1024 data points were measured. Table 1 shows various properties that were tested at different process conditions.

Table 1

Properties of the Sheets That Were Tested

	Properties						
Conditions	Gloss	Roughness	Porosity	Print Gloss	Print Density	Surface Latex Concentration	Mass Distribution
Uncalendered	Yes	Yes	Yes	No	No	No	No
Pre-Calendered	Yes	Yes	Yes	No	No	No	No
Coated-Uncalendered	Yes	Yes	Yes	Yes	Yes	No	Yes
Post-Calendered	Yes	Yes	Yes	Yes	Yes	Yes	No

CHAPTER V

RESULTS AND DISCUSSION

Roughness of Coated Sheets

The surface roughness of the coated-uncalendered sheet was affected by precalendering. The roughness values as a function of coat weight are presented at varying coat weights for coated sheets both before and after post-calendering at different precalendering conditions in Figures 5-7. It is evident that the surface roughness of the sheets decreased with increasing coat weight in all cases. Precalendered (MC, SC and SNC) sheets had lower surface roughness than uncalendered sheets at all coat weights. At lower coat weights (approximately 2-5 g/m^2), the coated paper was rougher than the uncoated sheets for precalendered sheets. It can be concluded that the roughness increase of the precalendered base paper is due to the fact that it expanded more than uncalendered base paper when it was exposed to coating color. With increasing coat weights the coated sheets were smoother than the uncoated sheets. Hence, the influence of coating color on surface roughness was greater at lower coat weights for precalendered sheets.

Coated-uncalendered paper had the highest roughness at all coat weights. When the roughness of the base paper before coating was low due to precalendering, i.e. at high intensity calendering, the smoothening effect of the coating color was

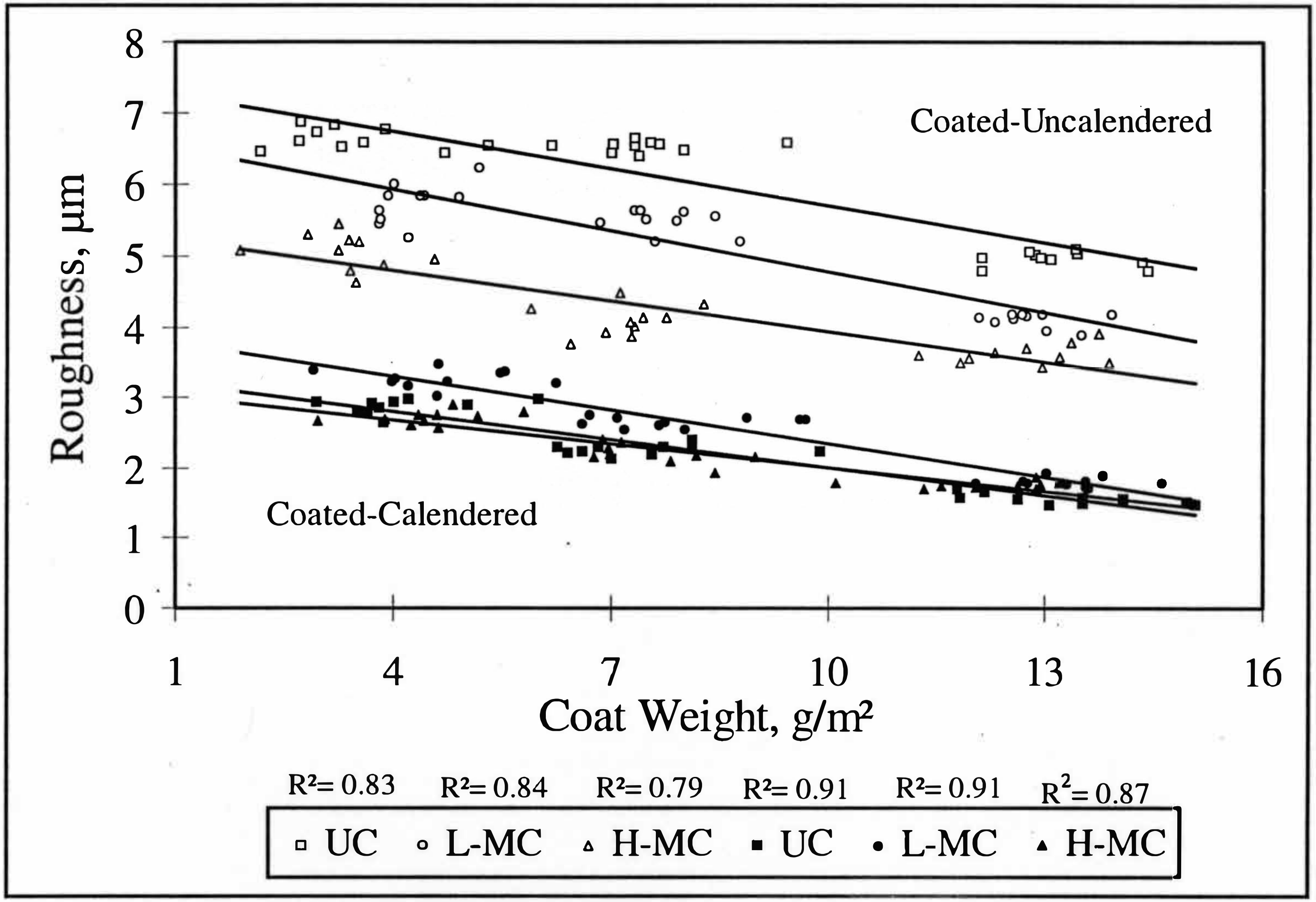

Figure 5. Effect of MC-Precalendering on the Roughness of Coated Sheets.

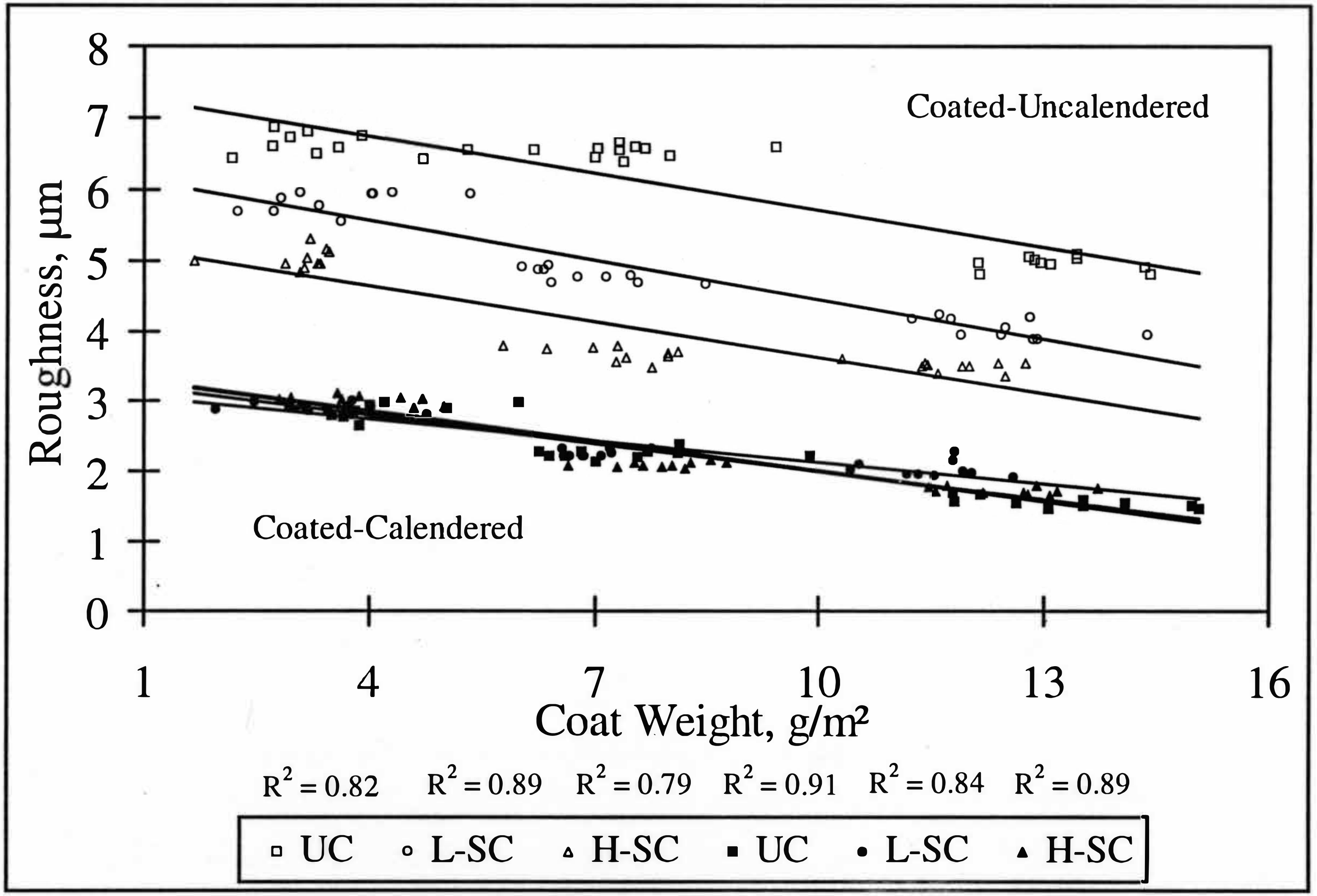

Figure 6. Effect of SC-Precalendering on the Roughness of Coated Sheets.

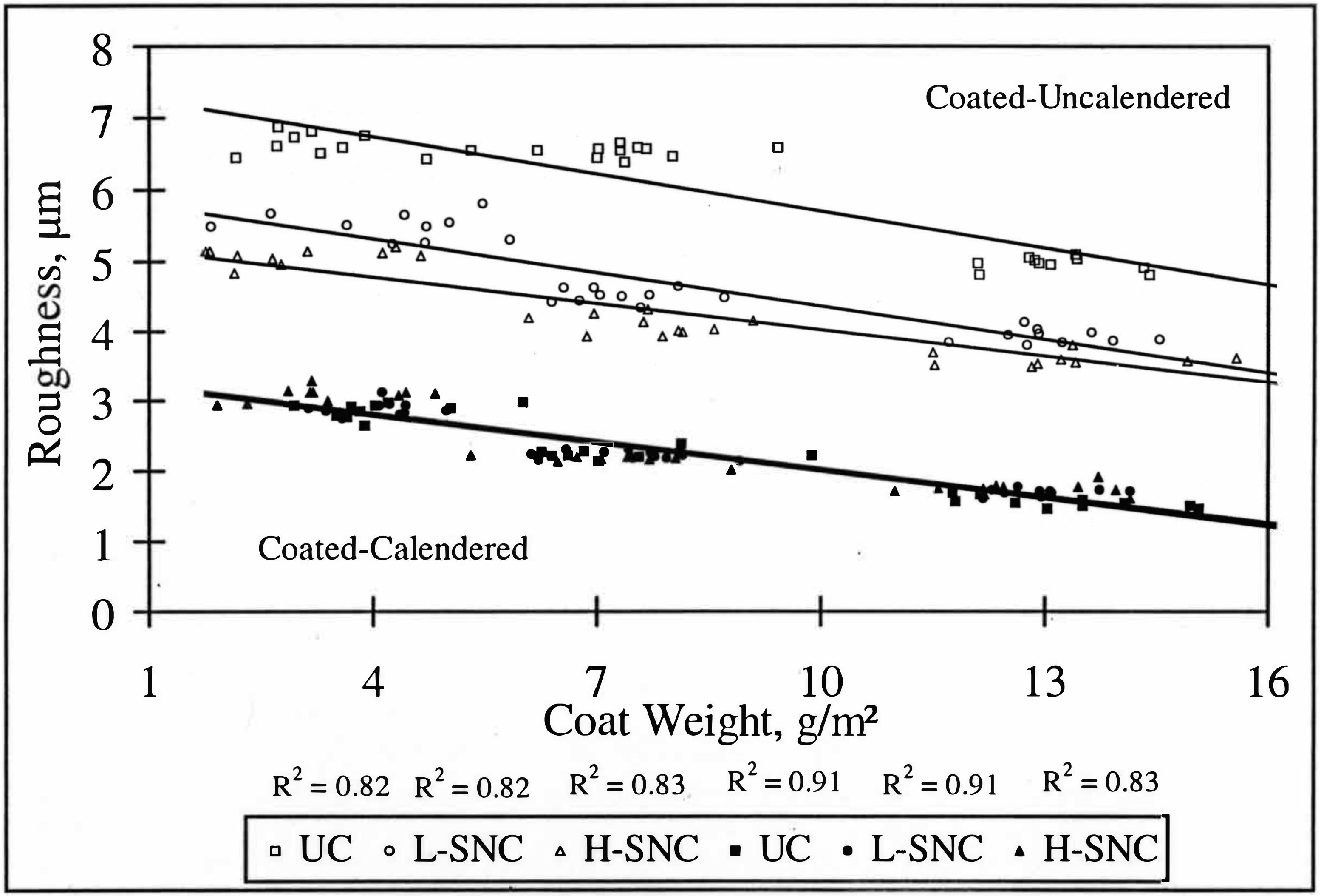

Figure 7. Effect of SNC-Precalendering on the Roughness of Coated Sheets.

high in all cases as shown in Figures 5-7. When the base paper before coating was calendered to low intensity, the smoothening effect of coating was less. The final roughness achieved due to different calendering methods (MC, SC and SNC) at all coat weights was not significantly different. Table 2 summarizes the final roughness values and slope of the base sheet subjected to different precalendering conditions. Linear regression lines were drawn and R^2 values are shown in the figures.

To see whether the observed effect is preserved after coating and calendering, some of the samples were calendered using a SNC. Such post-calendering of the coated sheets reduced the surface roughness of the sheets significantly as shown in Figures 5-7. The data obtained in this experiment indicate that when the uncalendered and precalendered (MC, SC, SNC) sheets were coated and subsequently calendered, the final roughness values was not significantly different, except for the low intensity machine calendered sheets. Different types of precalendering did not exert any significant influence on the relation between the surface roughness and the coat weights. The differential effects of precalendering (MC, SC and SNC) were lost when coated sheets were post-calendered.

Gloss of Coated Sheets

The gloss values as a function of coat weight are presented at varying coat weights for coated sheets both before and after post-calendering at different pre-calendering conditions in Figures 8-10. Table 3 shows the gloss values and slope of coated sheets subjected to different pre-calendering conditions. The gloss of the

Table 2

Change in Roughness (μm) With Coat Weight (g/m²) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered		Supercalendered		Soft Nip Calendered	
		Low	High	Low	High	Low	High
Roughness Before Coating, μm	6.75	5.44	4.66	5.12	4.35	5.00	4.52
Coated-Uncalendered							
Coat Weight (4 g/m²)	6.63	5.74	5.06	5.83	5.02	5.49	5.07
Coat Weight (8 g/m²)	6.54	5.49	4.10	4.80	3.50	4.51	4.10
Coat Weight (12 g/m²)	4.96	4.10	3.62	4.05	3.50	3.93	3.62
Slope, μm/g	-0.17	-0.19	-0.14	-0.19	-0.17	-0.16	-0.12
Coated-Calendered							
Coat Weight (4 g/m²)	2.88	3.27	2.72	2.91	3.01	2.90	3.10
Coat Weight (8 g/m²)	2.26	2.66	2.19	2.27	2.10	2.23	2.19
Coat Weight (12 g/m²)	1.56	1.80	1.76	2.04	1.73	1.70	1.76
Slope, μm/g	-0.13	-0.16	-0.11	-0.10	-0.14	-0.13	-0.13

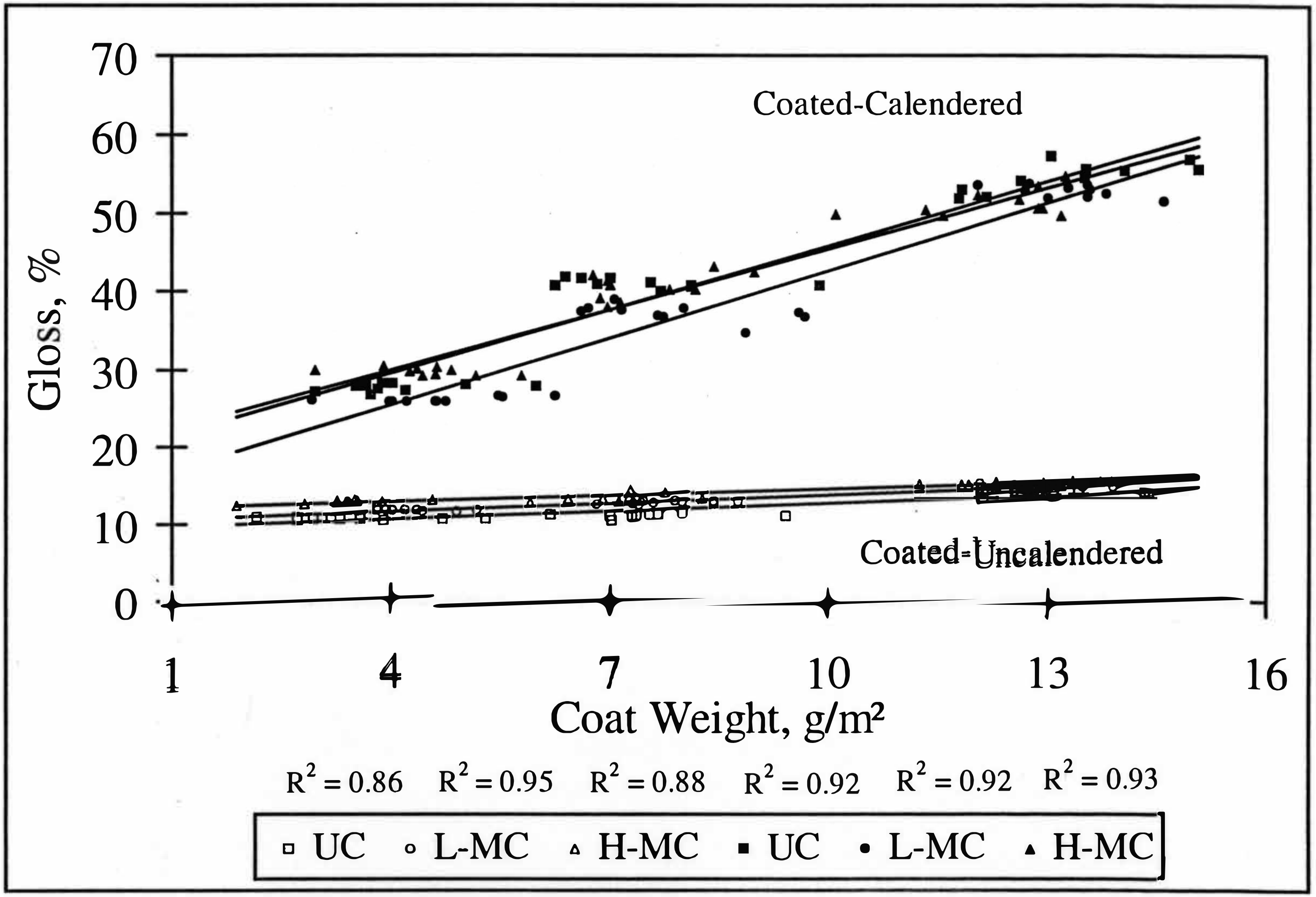

Figure 8. Effect of MC-Precalendering on the Gloss of Coated Sheets.

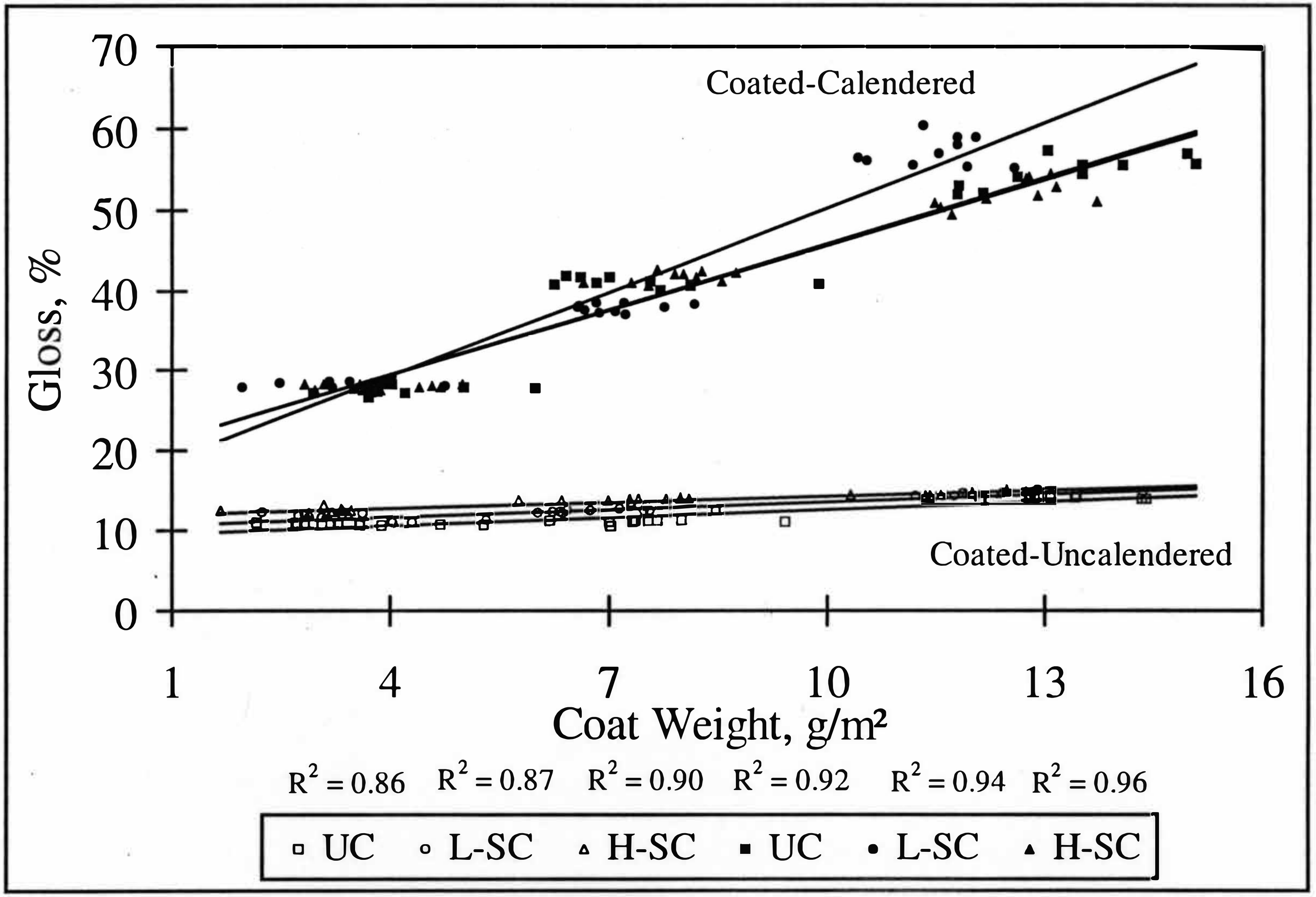

Figure 9. Effect of SC-Precalendering on the Gloss of Coated Sheets.

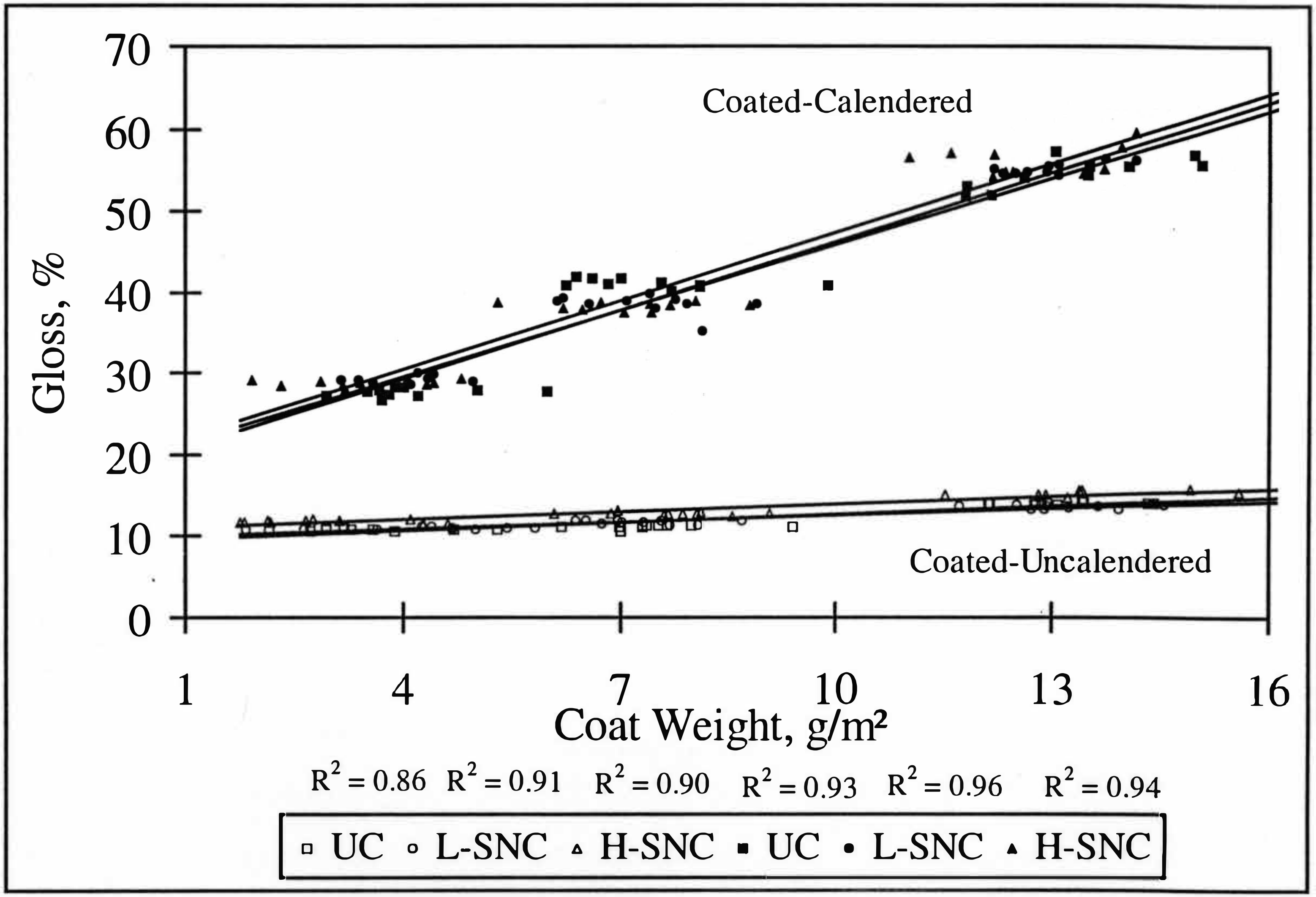

Figure 10. Effect of SNC-Precalendering on the Gloss of Coated Sheets.

Table 3

Change in Gloss (%)With Coat Weight (g/m²)for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered		Supercalendered		Soft Nip Calendered	
		Low	High	Low	High	Low	High
Gloss Before Coating, %	6.30	7.80	10.5	8.90	10.30	7.80	9.30
Coated-Uncalendered							
Coat Weight (4 g/m²)	10.8	11.8	12.9	11.6	12.5	10.9	11.7
Coat Weight (8 g/m²)	11.2	12.8	13.4	12.4	13.9	11.7	12.8
Coat Weight (12 g/m²)	14.0	14.8	15.3	14.5	14.7	13.6	15.3
Slope, %/g	0.33	0.35	0.26	0.32	0.25	0.29	0.32
Coated-Calendered							
Coat Weight (4 g/m²)	27.7	26.1	29.8	28.3	28.0	29.3	28.6
Coat Weight (8 g/m²)	41.1	37.3	40.7	37.9	41.7	38.5	38.2
Coat Weight (12 g/m²)	54.6	52.8	51.3	57.1	52.0	55.2	56.2
Slope, %/g	2.72	2.87	2.59	3.47	2.68	2.83	2.81

sheets increased with increasing coat weight in all cases, which is also indicated by the positive slope shown in Table 3. Both the uncalendered and precalendered sheets did not show any significant difference in the final gloss development in the case of coated-uncalendered sheets. The results indicate the type of calendering method seemed to have no significant impact on the gloss value obtained. However, the gloss of coated sheets at any coat weight were higher than the gloss of uncoated sheets (Table 3).

Post-calendering of the sheets increased the gloss of the sheets in all cases as expected. The data obtained in this experiment indicate that when the uncalendered and precalendered (MC, SC, SNC) sheets were coated and subsequently calendered, the final gloss values was not different, except for the low intensity MC and SC sheets. Different types of precalendering did not exert any significant influence on the relation between the gloss and the coat weights.

Porosity of Coated Sheets

Figures 11-13 show the porosity results of the coated-uncalendered sheets as a function of coat weight due to precalendering. Table 4 summarizes the final porosity values of the base sheets subjected to different precalendering and coating conditions. It is evident that the porosity of the coated sheet decreased when compared to uncoated sheets. With an increase in coat weight the porosity of the sheet decreased in all cases. Precalendered (MC, SC and SNC) and uncalendered sheets had the same porosity values at higher coat weights for coated-uncalendered sheets. It appears that

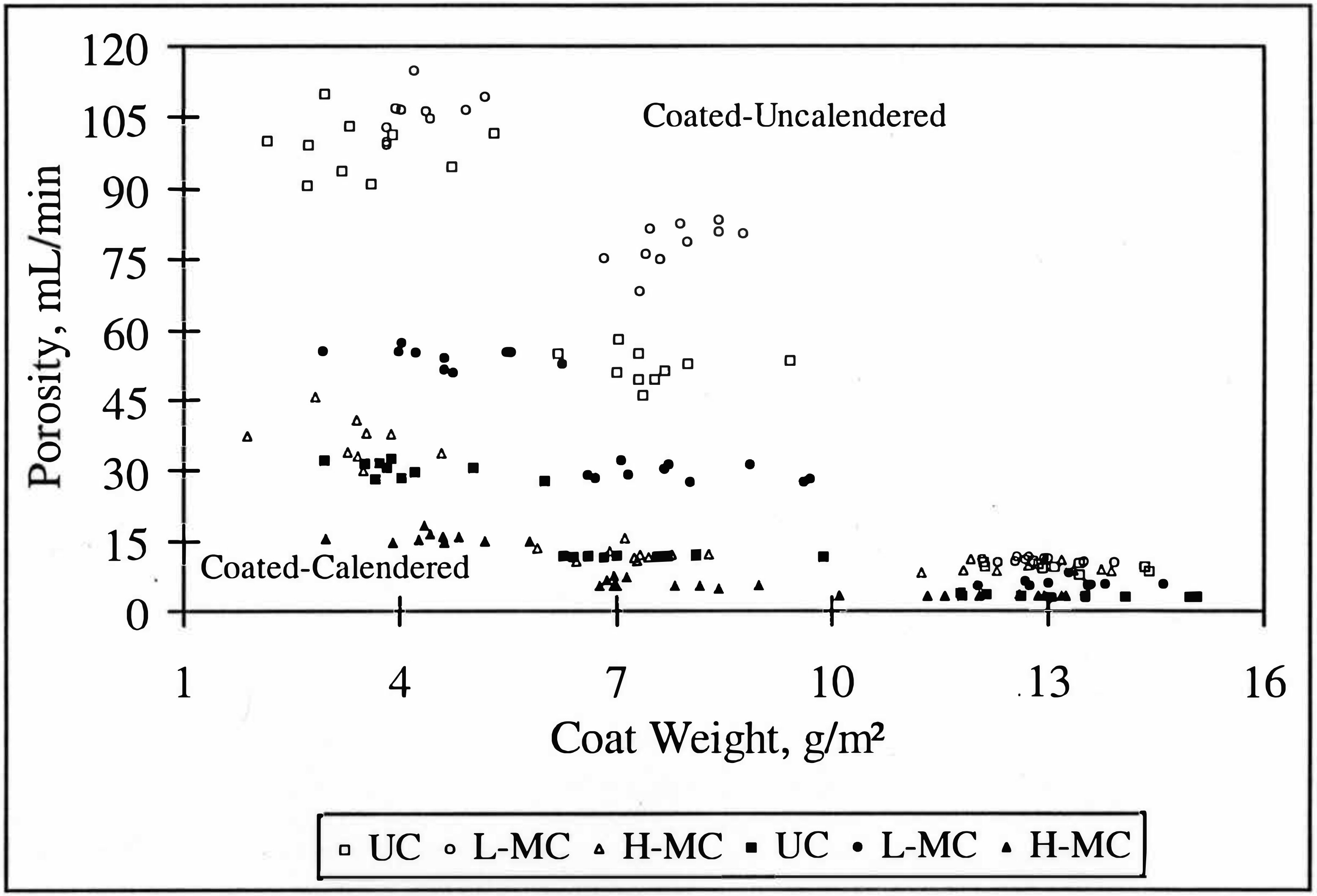

Figure 11. Effect of MC-Precalendering on the Porosity of Coated Sheets.

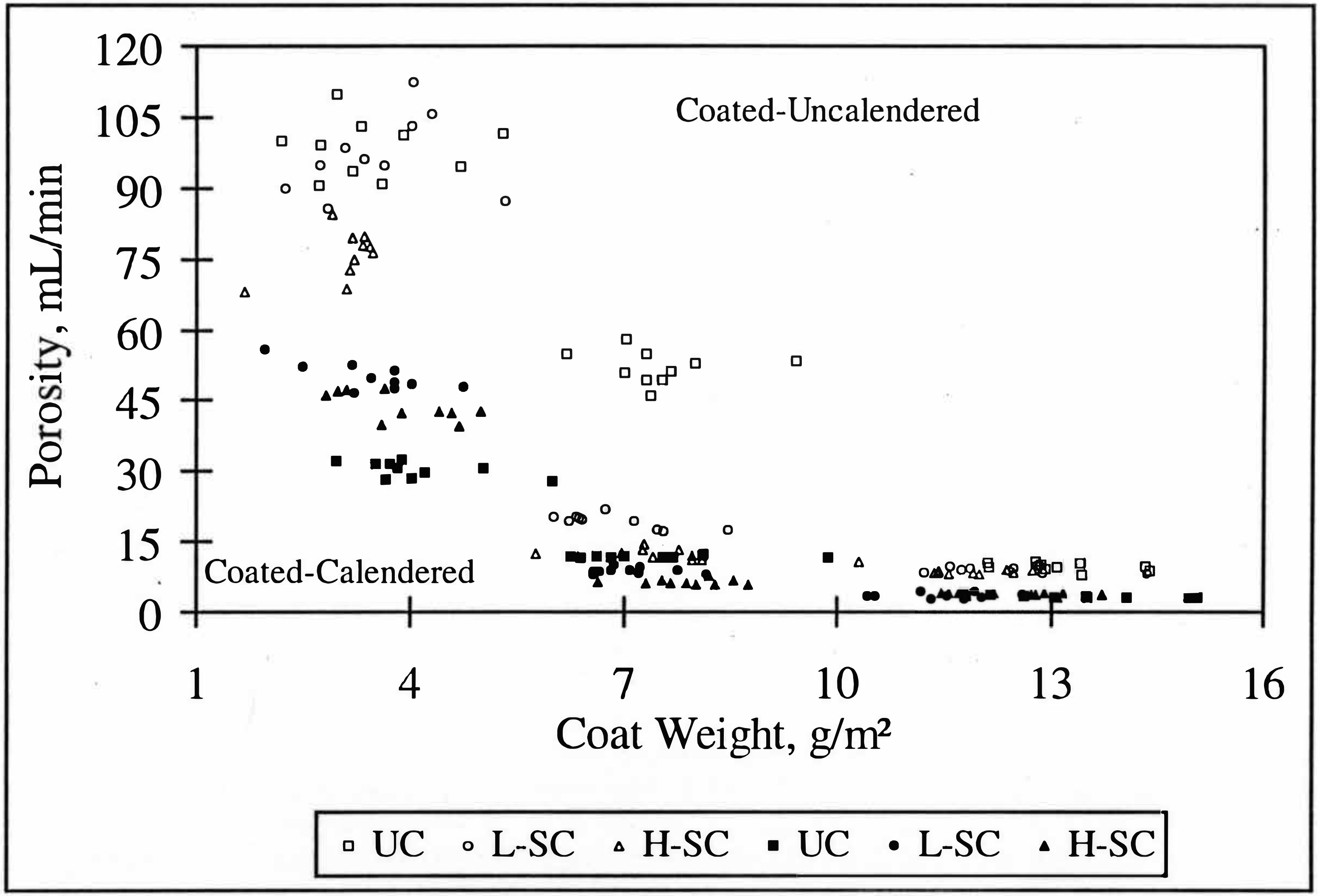

Figure 12. Effect of SC-Precalendering on the Porosity of Coated Sheets.

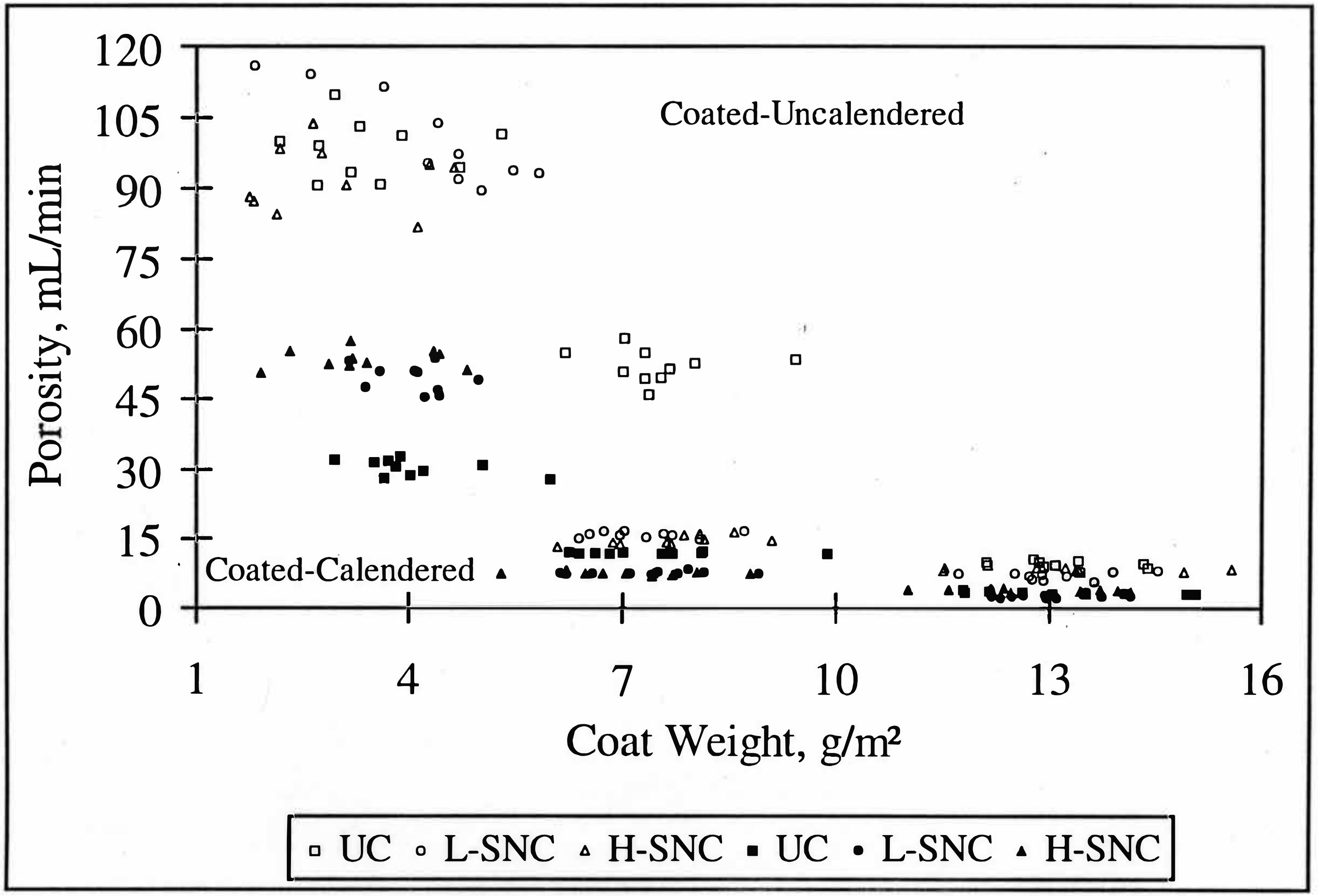

Figure 13. Effect of SNC-Precalendering on the Porosity of Coated Sheets.

Table 4

Change in Porosity (mL/min) With Coat Weight (g/m^2) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered Low	Machine Calendered High	Supercalendered Low	Supercalendered High	Soft Nip Calendered Low	Soft Nip Calendered High
Porosity Before Coating, mL/min	662	595	474	475	361	491	466
Coated-Uncalendered							
Coat Weight (4 g/m^2)	98.4	105	36.4	87.8	75.9	100	92.1
Coat Weight (8 g/m^2)	52.4	77.4	12.3	19.3	12.3	15.9	14.6
Coat Weight (12 g/m^2)	9.66	11.0	9.51	9.03	8.66	7.22	8.59
Coated-Calendered							
Coat Weight (4 g/m^2)	30.3	54.3	15.7	50.0	43.7	49.3	53.5
Coat Weight (8 g/m^2)	11.8	31.0	5.99	8.80	6.32	7.5	7.37
Coat Weight (12 g/m^2)	3.30	6.05	3.40	3.44	3.74	2.48	3.86

coat weight itself was more important in this context, and the intensity of precalendering of the base sheet before coating had no impact on the final porosity of the sheet at high coat weights. At medium coat weights the precalendered (MC, SC and SNC) sheets were less porous than the uncalendered sheets except for the low intensity MC sheets. At low coat weights the precalendered (MC, SC and SNC) sheets had the same porosity values as the uncalendered sheets, except for the high intensity MC sheets. At low coat weights, type of precalendering seems to exert some influence on the final porosity values. This may be due to increased fiber swelling at low coat weights.

As expected, post-calendering reduced the porosity of the sheet in all cases. When the uncalendered and precalendered (MC, SC and SNC) sheets were coated and subsequently calendered, the final porosity values was not significantly different at high coat weights. At medium coat weights precalendered (MC, SC and SNC) sheets were less porous than uncalendered sheets except for low intensity MC sheets. A reverse trend was seen in the low coat weight samples that were post-calendered. The uncalendered sheets had lower porosity values than precalendered samples after post-calendering in SC and SNC sheets.

Delta Gloss of Coated Sheets

Part of the coated-uncalendered sheets were printed on the Moser Gravure-Proof Press to evaluate the effect of precalendering on delta gloss. Figures 14-16 show the change in delta gloss of coated sheets as a function of coat weight due to

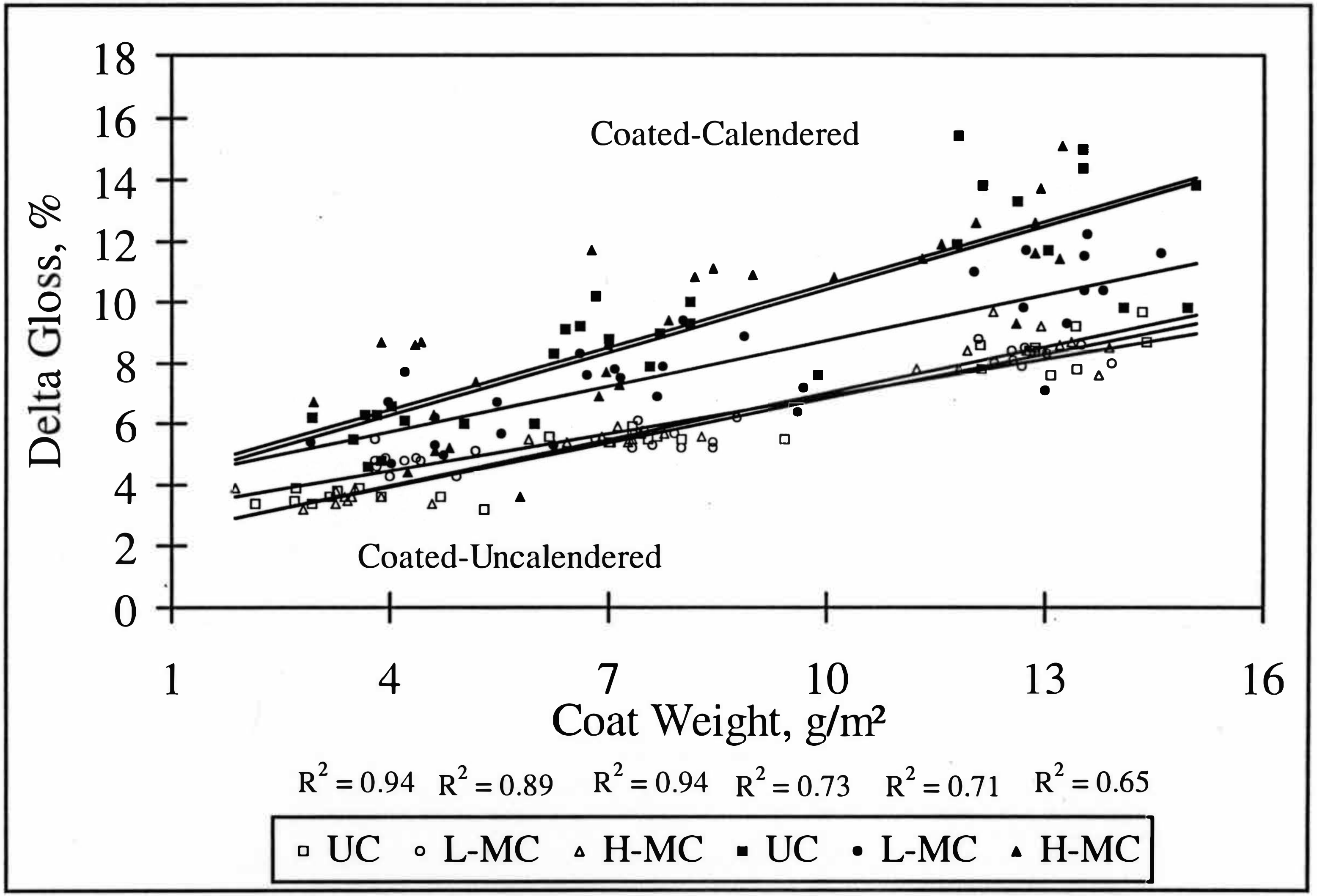

Figure 14. Effect of MC-Precalendering on the Delta Gloss of Coated-Printed Sheets.

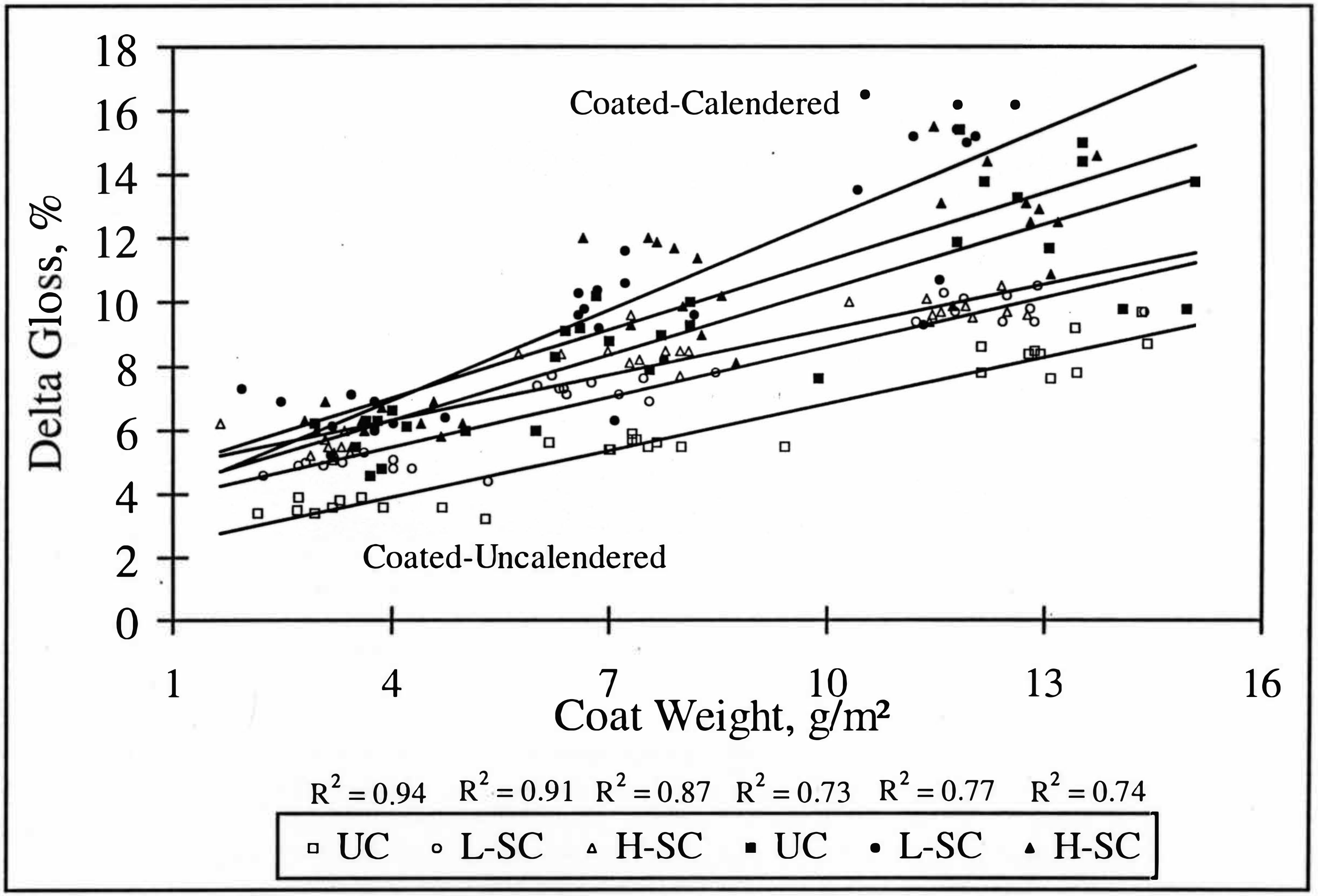

Figure 15. Effect of SC-Precalendering on the Delta Gloss of Coated-Printed Sheets.

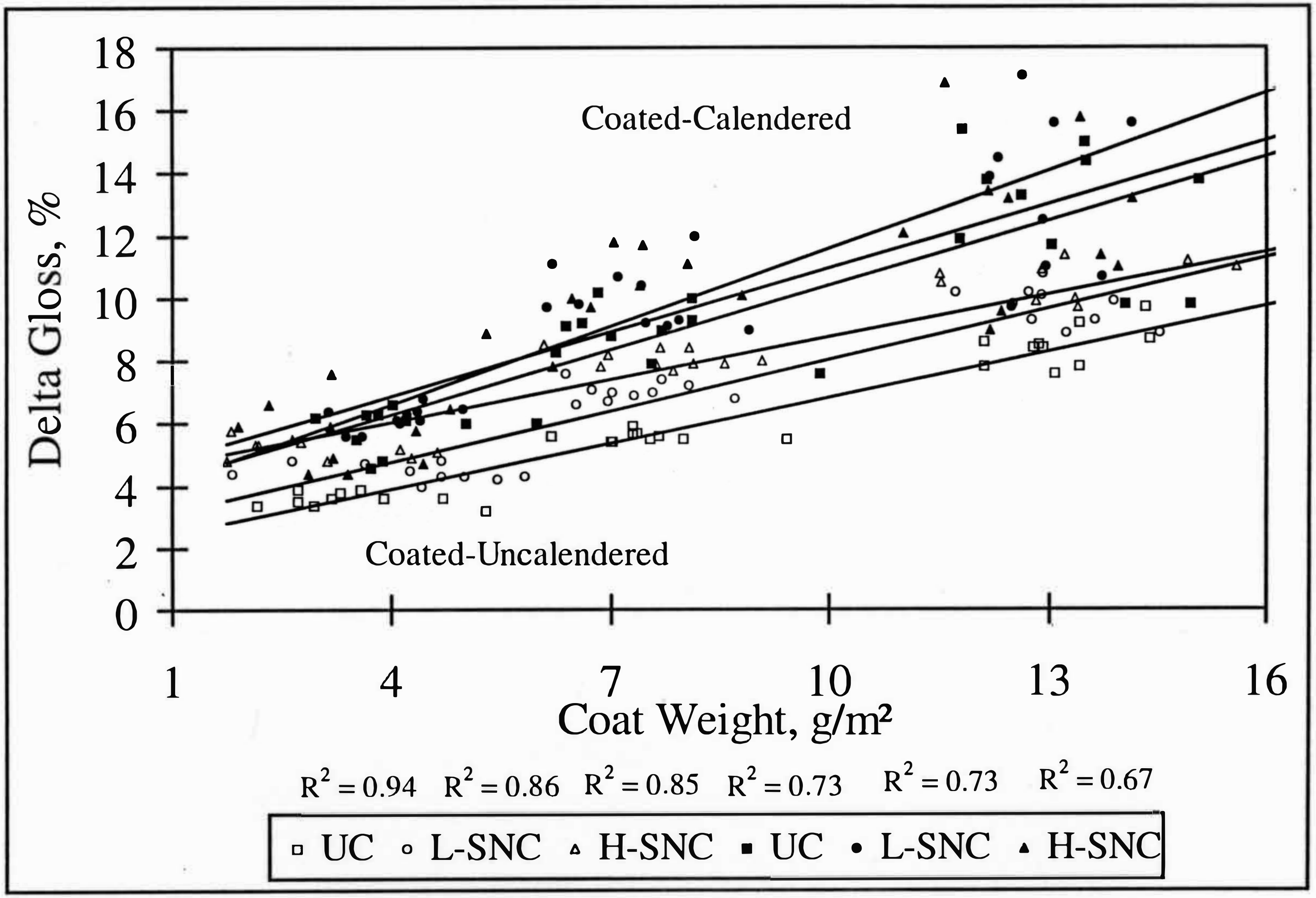

Figure 16. Effect of SNC-Precalendering on the Delta Gloss of Coated-Printed Sheets.

precalendering. The delta gloss values are presented both before and after post calendering. In the case of coated-uncalendered sheets, the precalendering (SC and SNC) had a positive effect on the delta gloss of the final product, since they had a higher delta gloss than the uncalendered sheets. The samples that were precalendered to high intensity had a higher delta gloss values than the low intensity calendering in all cases except MC. It is also evident that increasing the coat weight increased the delta gloss of the final product (Table 5). It is also shown that the SC and SNC sheets had more delta gloss development than MC sheets at all coat weights.

As expected, the post calendering of the coated sheets improved the delta gloss of the sheets. At low coat weights the uncalendered and precalendered (MC, SC and SNC) sheets had the same delta gloss development. At medium and high coat weights the precalendered (SC and SNC) had higher delta gloss values than the uncalendered sheets. It can be clearly seen that precalendering operation enhanced the delta gloss values in the case of SC and SNC at medium and high coat weights. Precalendering (MC) did not improve the final delta gloss values in all cases. The impact of precalendering was more pronounced at medium and higher coat weights.

Print Density of Coated Sheets

The print density values as a function of coat weight are presented at varying coat weights for different precalendering conditions in Figures 17-19. The slope and print density values are given in Table 6. Precalendering had a positive influence on the final print density values. It is clearly seen that the precalendered base sheets had

Table 5

Change in Delta Gloss (%)With Coat Weight (g/m²) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered Low	Machine Calendered High	Supercalendered Low	Supercalendered High	Soft Nip Calendered Low	Soft Nip Calendered High
<u>Coated-Uncalendered</u>							
Coat W eight (4 g/m²)	3.59	4.80	3.59	4.88	5.53	4.43	5.21
Coat Weight (8 g/m²)	5.58	5.56	5.58	7.37	8.44	7.03	8.07
Coat Weight (12 g/m²)	8.47	8.30	8.47	9.85	9.80	9.74	10.5
Slope, %/g	0.49	0.41	0.51	0.52	0.47	0.54	0.45
<u>Coated-Calendered</u>							
Coat Weight (4 g/m²)	5.84	5.87	6.47	6.42	6.33	6.18	5.67
Coat Weight (8 g/m²)	9.94	7.79	9.31	9.56	10.6	10.0	10.1
Coat Weight (12 g/m²)	12.9	10.5	12.0	14.3	12.9	14.0	12.6
Slope, %/g	0.69	0.50	0.68	0.95	0.71	0.83	0.68

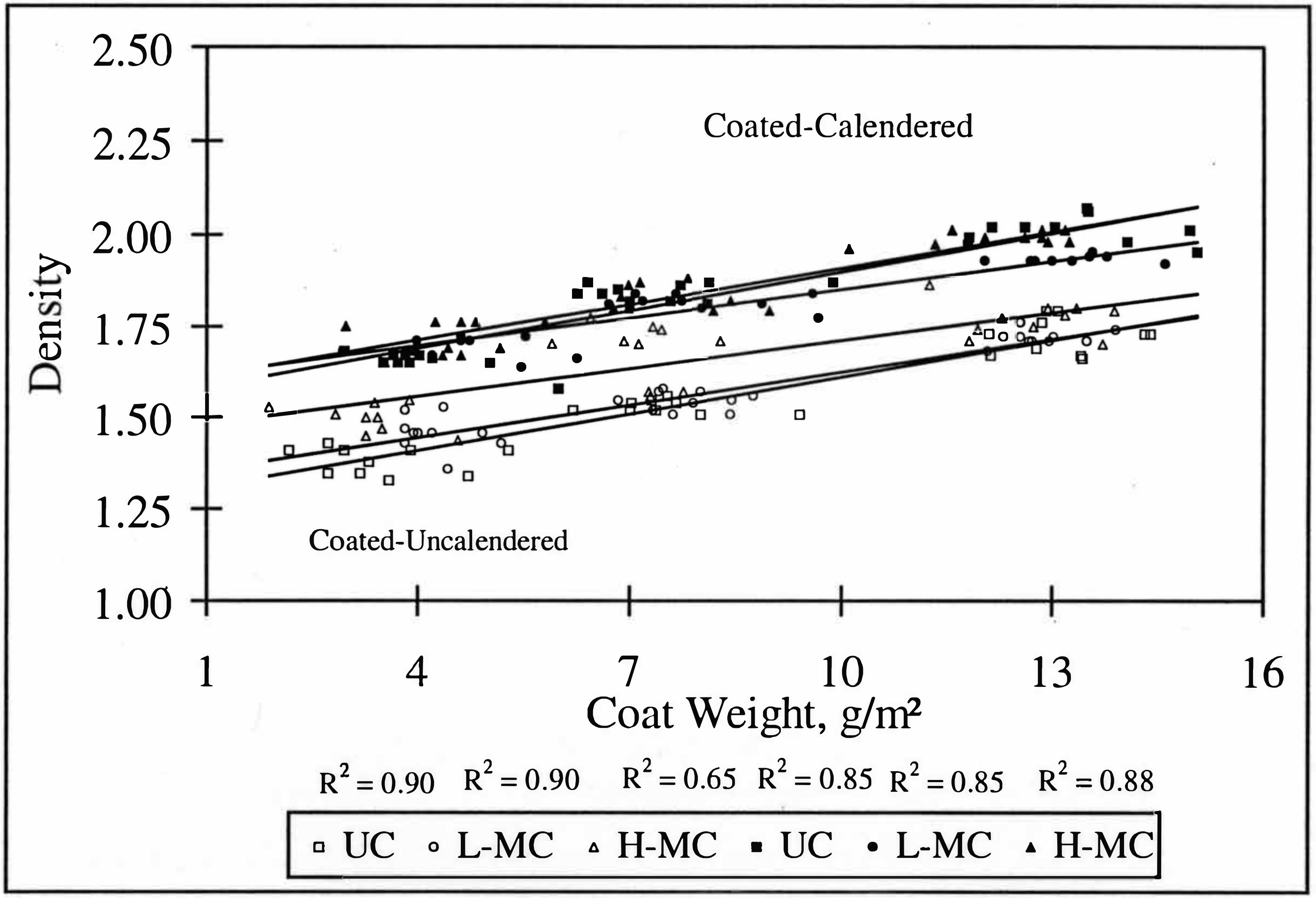

Figure 17. Effect of MC-Precalendering on the Print Density of Coated-Printed Sheets.

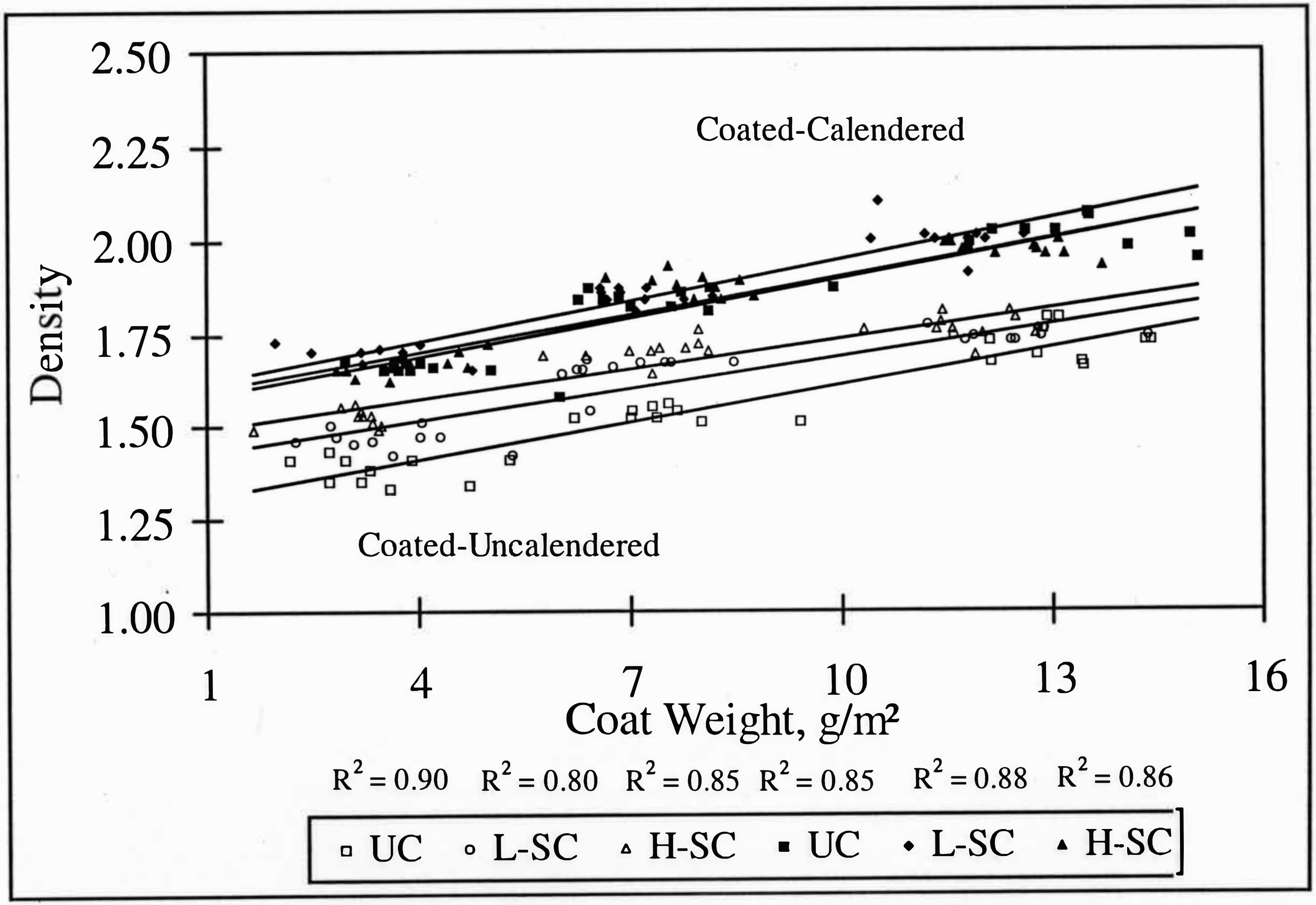

Figure 18. Effect of SC-Precalendering on the Print Density of Coated-Printed Sheets.

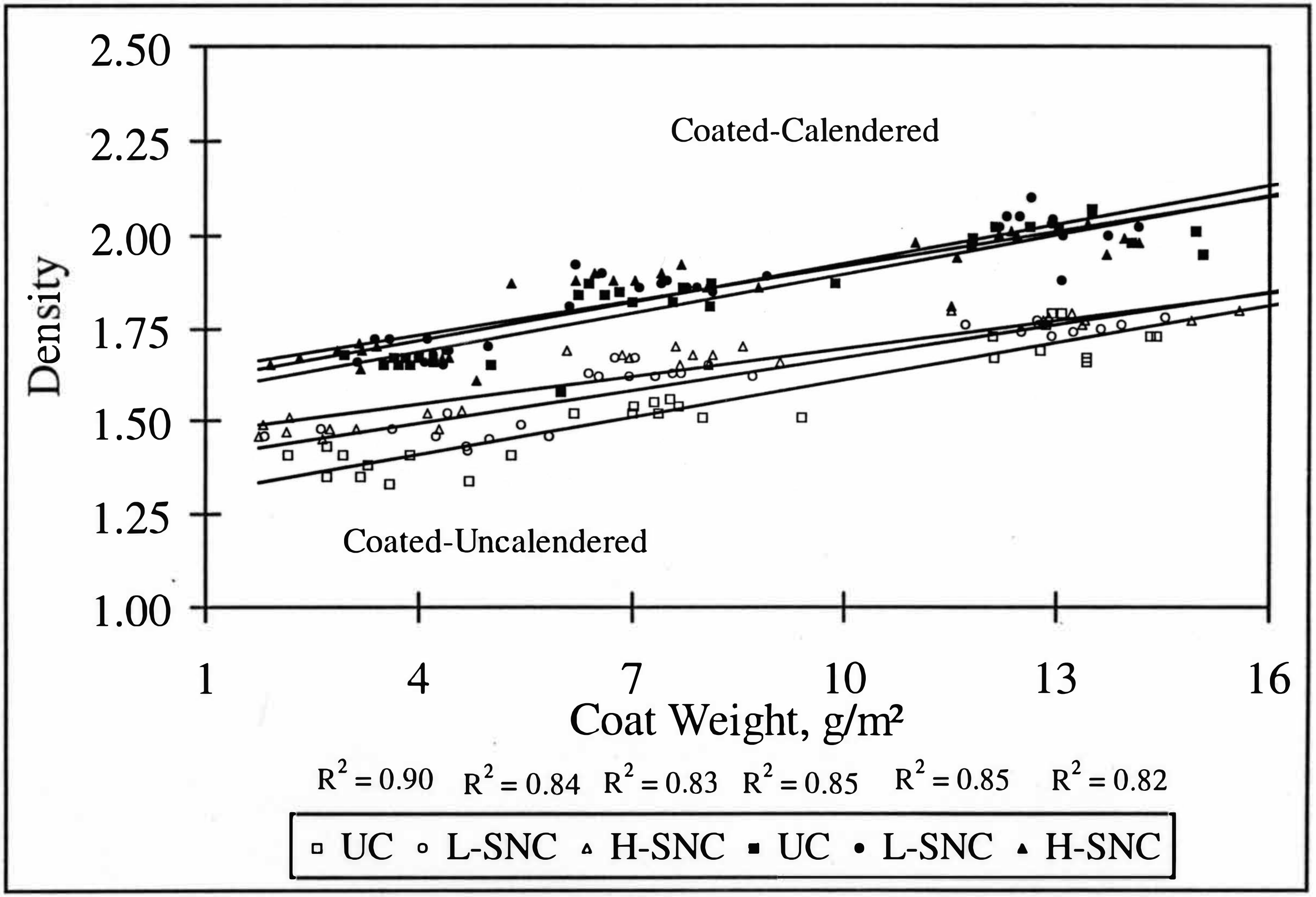

Figure 19. Effect of SNC-Precalendering on the Print Density of Coated-Printed Sheets.

Table 6

Change in Print Density With Coat Weight (g/m²) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered Low	Machine Calendered High	Supercalendered Low	Supercalendered High	Soft Nip Calendered Low	Soft Nip Calendered High
<u>Coated-Uncalendered</u>							
Coat W eight (4 g/m²)	1.38	1.45	1.51	1.46	1.52	1.46	1.48
Coat Weight (8 g/m²)	1.53	1.54	1.67	1.65	1.70	1.64	1.68
Coat Weight (12 g/m²)	1.72	1.72	1.77	1.74	1.77	1.76	1.78
Slope	0.03	0.03	0.03	0.03	0.03	0.03	0.02
<u>Coated-Calendered</u>							
Coat Weight (4 g/m²)	1.65	1.69	1.72	1.70	1.66	1.69	1.67
Coat Weight (8 g/m²)	1.85	1.82	1.83	1.85	1.88	1.87	1.88
Coat Weight (12 g/m²)	2.01	1.93	1.99	2.00	1.97	2.02	1.99
Slope	0.04	0.03	0.03	0.03	0.03	0.03	0.03

a higher print density than uncalendered sheets. The high intensity precalendered sheets resulted in higher print density values. There seemed to be no significant difference in the final print density values obtained by different methods of precalendering. With increasing coat weight the print density of the coated sheet increased.

Post calendering of the coated sheets increased the print density of the sheets significantly at all coat weights. The data obtained in this experiment indicate that when the when the uncalendered and precalendered (MC, SC and SNC) sheets were coated and subsequently calendered, the final print density values were not significantly different. The differential effects of precalendering were lost when the coated sheets were precalendered. Linear regression lines were drawn through the data points for a coat weight ranging from 2-16 g/m². The R^2 values of the regression lines are shown in the figures for easy reference throughout this discussion.

Surface Latex Content and Distribution of Coated Sheets

Figures 20-22 show the effect of the surface latex content of post-calendered sheets as a function of coat weight due to different precalendering conditions. The surface latex content on the coating surface is expressed in parts per hundred as shown in the figures. Table 7 summarizes the final latex content on the surface and slope of the sheets subjected to different precalendering conditions. The latex content on the surface of the sheet was determined using an UV-technique (22). It is evident from the figures that the latex content in the coating surface is higher at high coat

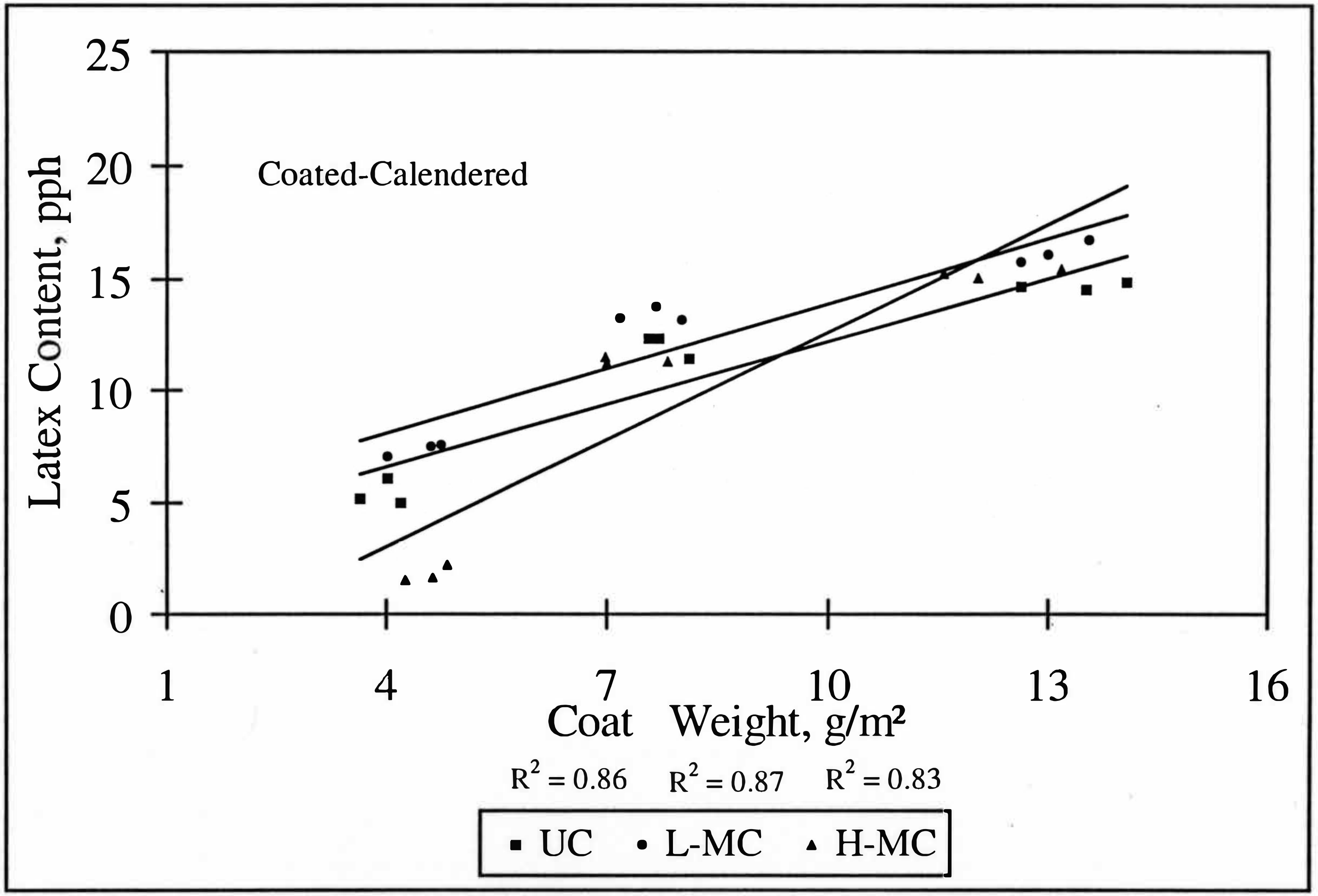

Figure 20. Effect of MC-Precalendering on Surface Latex Content of Coated Sheets.

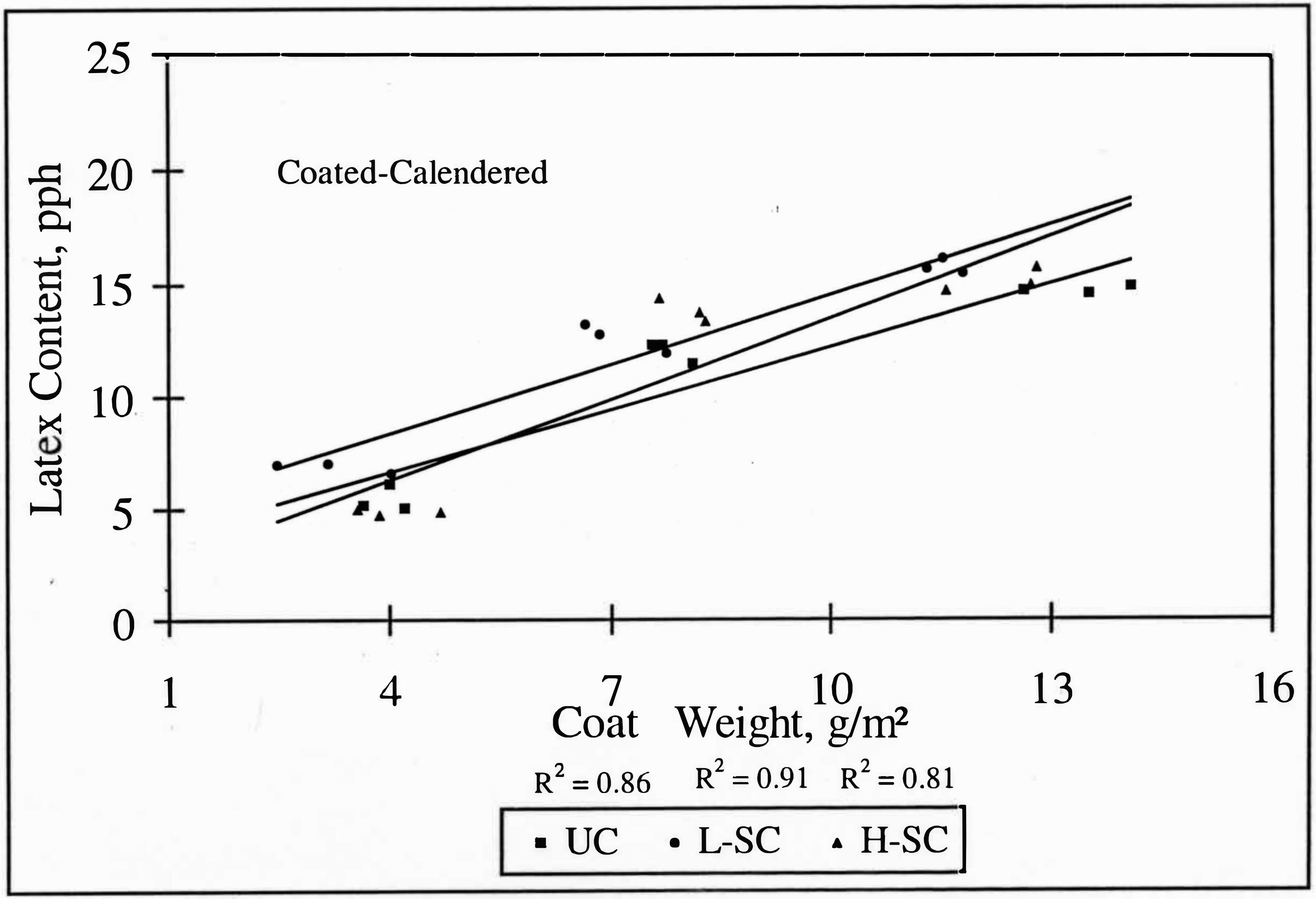

Figure 21. Effect of SC-Precalendering on Surface Latex Content of Coated Sheets.

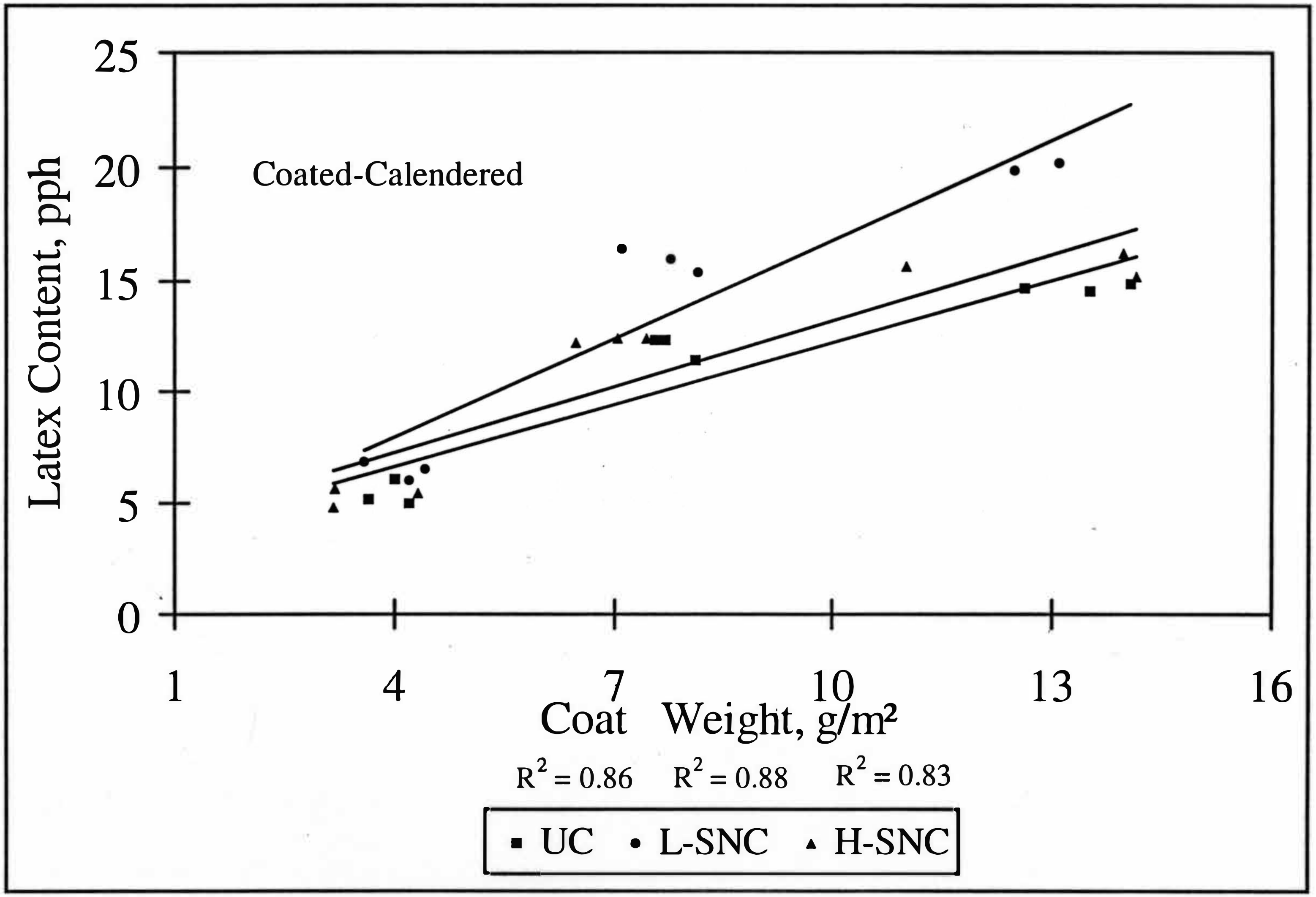

Figure 22. Effect of MC-Precalendering on Surface Latex Content of Coated Sheets.

Table 7

Change in Latex Content (pph) on the Surface With Coat Weight (g/m²) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered Low	Machine Calendered High	Supercalendered Low	Supercalendered High	Soft Nip Calendered Low	Soft Nip Calendered High
<u>Coated-Calendered</u>							
Coat W eight (4 g/m²)	5.45	7.39	1.84	6.87	4.84	6.48	5.31
Coat Weight (8 g/m²)	12.03	13.4	11.34	12.62	13.82	15.89	12.33
Coat Weight (12 g/m²)	14.69	16.19	15.23	15.71	14.39	20.07	15.67

weights than at low coat weights. It can be seen that precalendering had an effect on the latex content on the surface of the coated sheets. Sheets that were precalendered to high intensity had a lower latex content on the surface than the sheets that were precalendered to low intensity at all coat weights. The sheets that was calendered using a MC to a high intensity had the lowest latex content on the surface at low coat weights. The highest latex content was found in SNC sheet at the higher coat weights. When calendered and uncalendered sheets were compared no specific trend was found. Work done by Engström and Rigdahl (16) shows that surface latex content or the redistribution of the latex does not cause problems to the printer. It is only when it is unevenly distributed, it may cause mottled print problems.

Figure 23 shows the coefficient of variation in styrene butadiene surface latex content in the coating surface as a function of the styrene butadiene surface latex content for the post calendered sheets. The figure indicates that when the surface latex content is higher, was more evenly distributed on the surface of the sheets. This agrees with the results presented by Engström et al (16). This also indicates that the surface latex distribution was not dependent on the type of precalendering (MC, SC and SNC) as shown in Figure 23.

Mass Distribution of Coated Sheets

Figures 24-26 show the coefficient of variation in blackening (absorbance) in the coating surface as a function of coat weight due to different precalendering conditions. The coefficient of variation of the absorbance increased with increasing

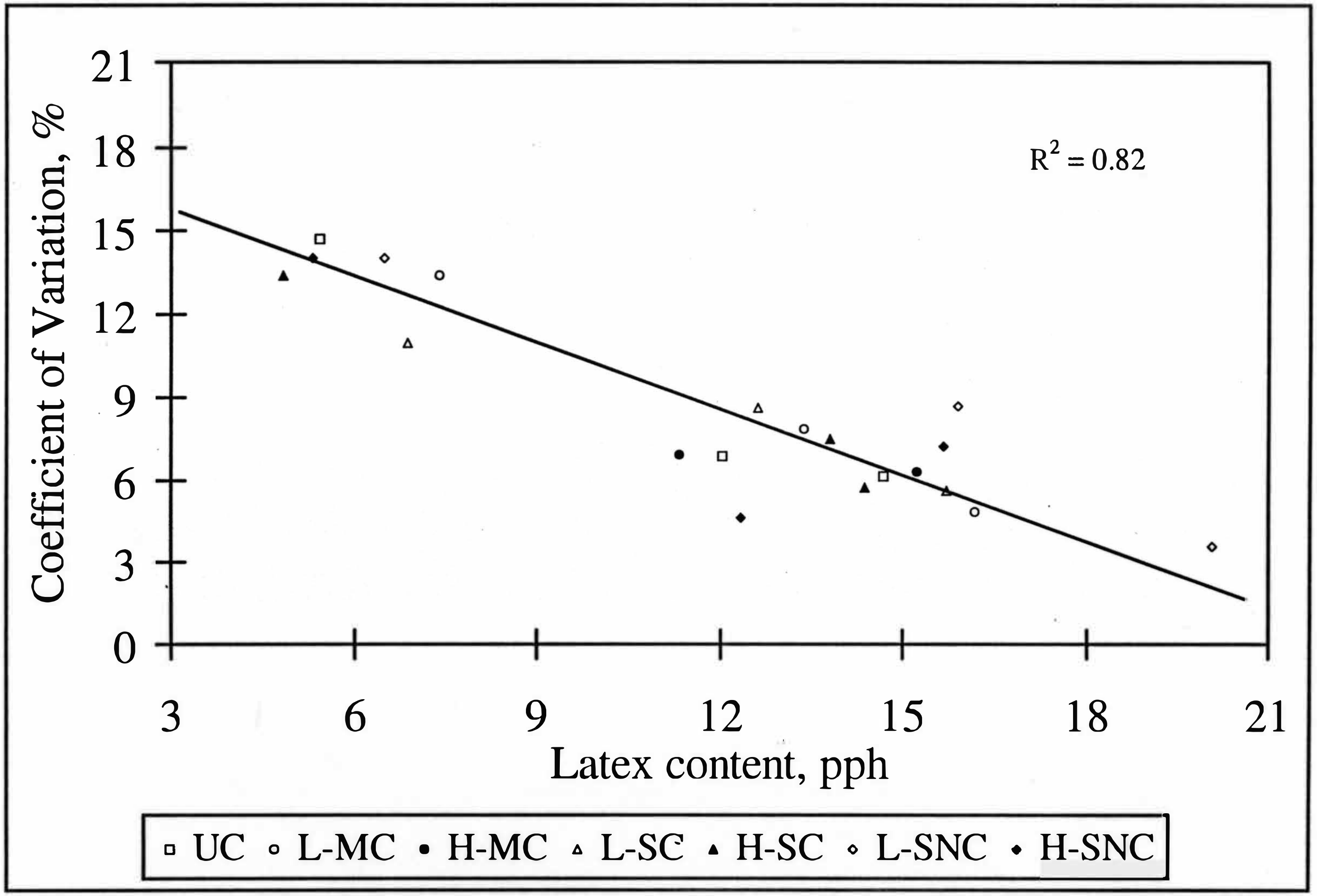

Figure 23. Coefficient of Variation of Surface Latex Content as a Function of Surface Latex Content of Coated Sheets.

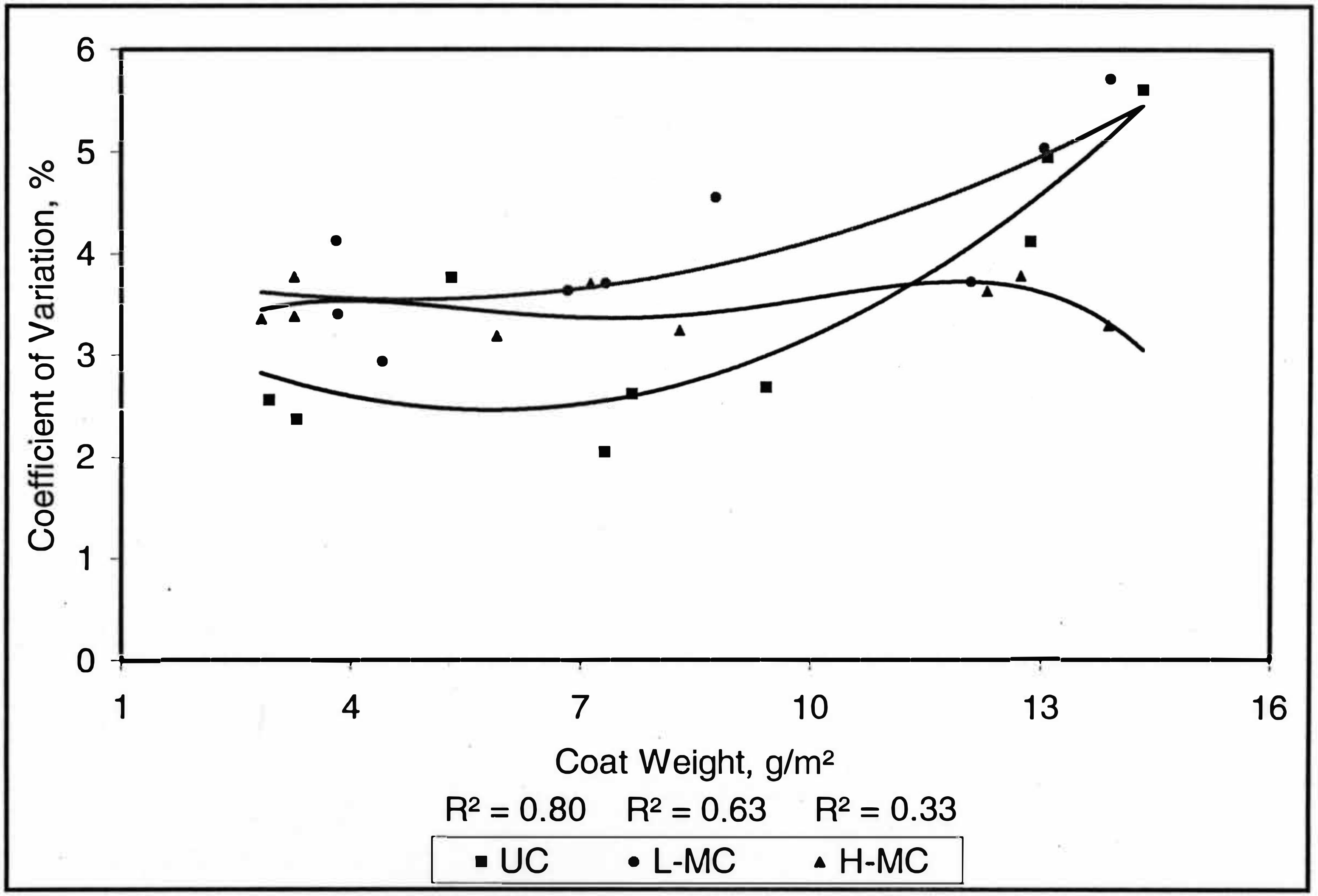

Figure 24. Effect of MC-Precalendering on Mass Distribution of Coated-Printed Sheets.

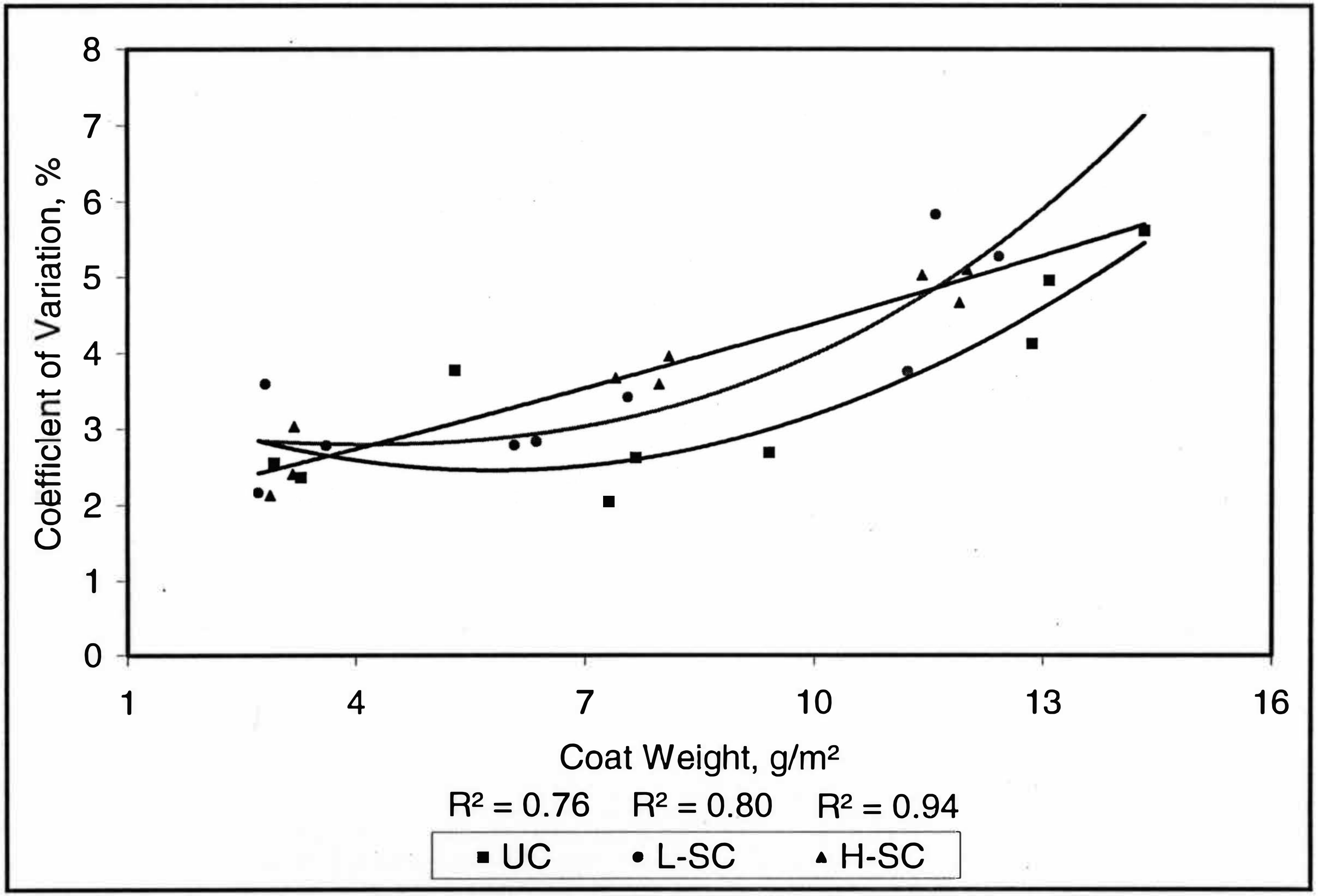

Figure 25. Effect of SC-Precalendering on Mass Distribution of Coated-Printed Sheets.

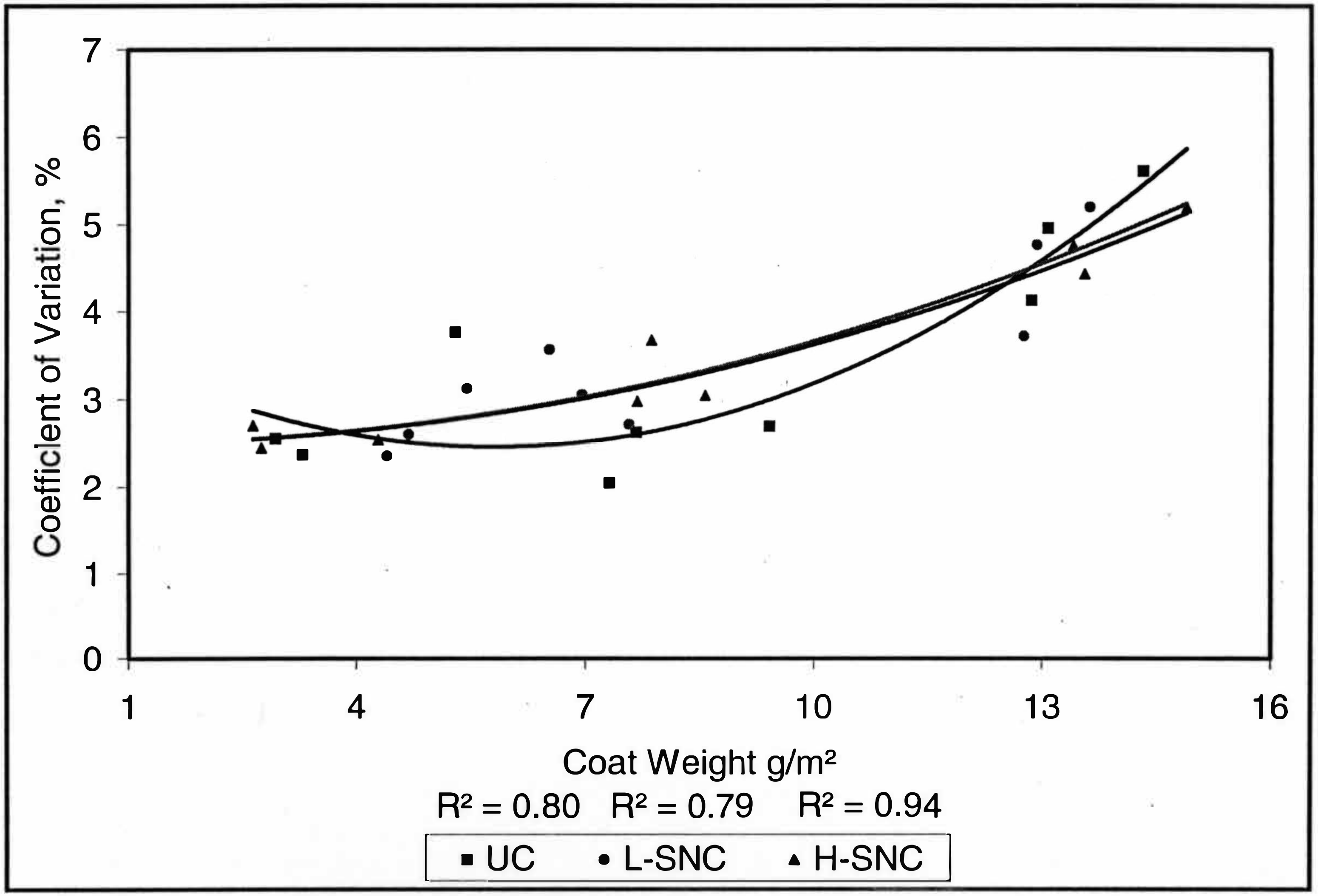

Figure 26. Effect of SNC-Precalendering on Mass Distribution of Coated-Printed Sheets.

coat weight. This may be due to the deformation of the base paper when it comes in contact with a large amount of liquid phase in the coating color, at higher coat weights. When precalendered and uncalendered sheets were compared the MC precalendered sheets had a higher coefficient of variation at low and medium coat weights. SC precalendered sheets had a higher coefficient of variation of absorbance at medium and high coat weights. In the case of SNC precalendered sheets there seem to be some differences, but less pronounced. The data (Table 8) indicate that uncalendered sheets had a more uniform coating layer. When the sheets were precalendered the coating layer appears to be less uniform, i.e. the thickness became more uneven.

Figure 27 shows the coefficient of variation in mass distribution in the coating surface as a function of styrene butadiene latex content for the coated sheets. The figure indicates that when the surface latex content is lower, the coating mass distribution was more even. The data also indicates that the coating mass distribution was not dependent on the type of precalendering (MC, SC and SNC) as shown in Figure 27.

Table 8

Change in Coefficient of Variation (%) in Mass Distribution With Coat Weight (g/m²) for Different Types of Precalendering Conditions

Calendering Conditions	Uncalendered	Machine Calendered		Supercalendered		Soft Nip Calendered	
		Low	High	Low	High	Low	High
<u>Coated-Calendered</u>							
Coat W eight (4 g/m²)	2.98	3.80	4.04	3.31	2.67	2.74	2.76
Coat Weight (8 g/m²)	2.60	4.01	4.40	3.25	4.08	3.27	3.83
Coat Weight (12 g/m²)	4.95	5.14	3.91	5.57	5.11	5.41	5.10

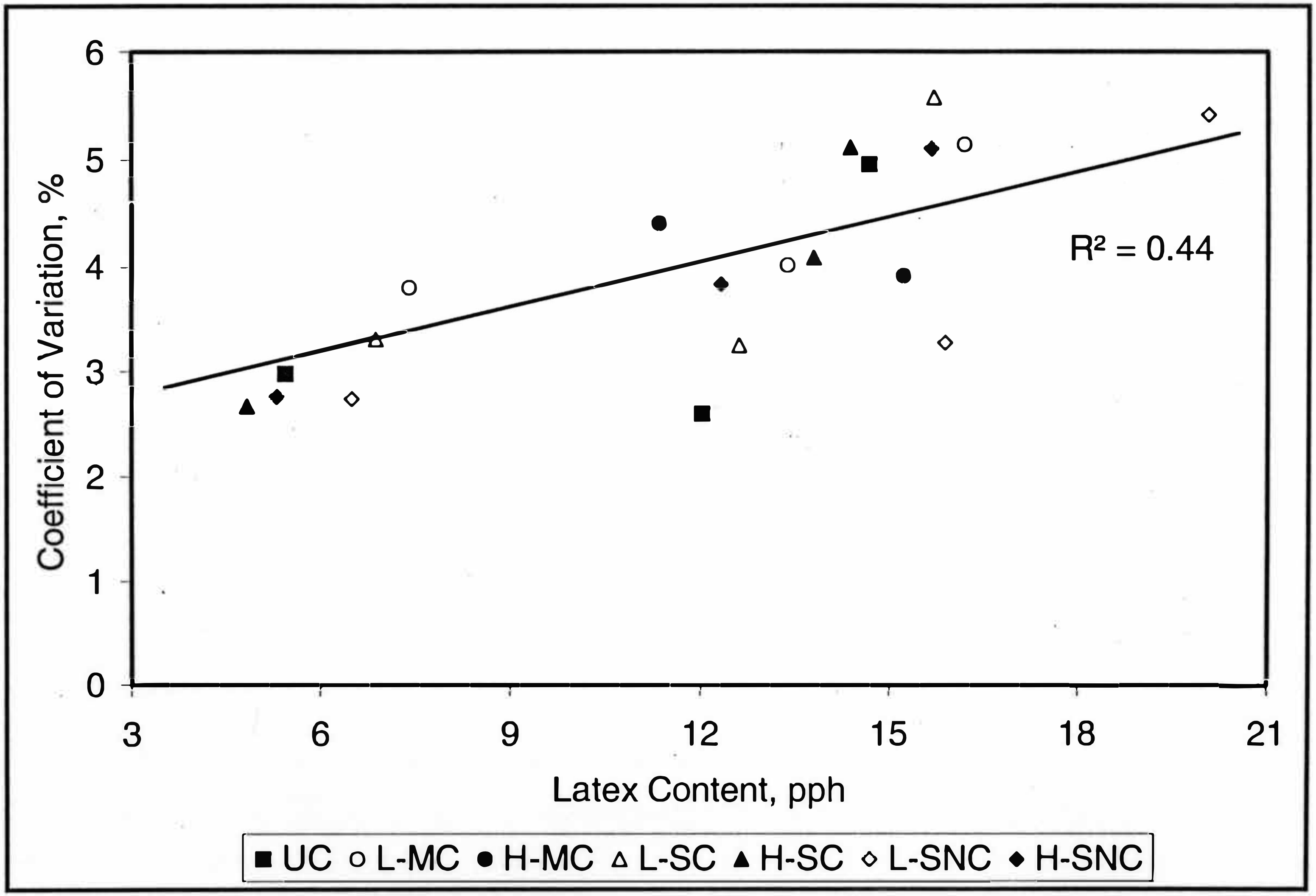

Figure 27. Coefficient of Variation in Mass Distribution as a Function of Surface Latex Content of Coated Sheets.

CHAPTER VI

CONCLUSIONS

The results obtained from this study indicate that precalendering of the base sheet (woodfree) before coating had a positive effect on the properties of coated sheet. The surface roughness of the sheet was improved due to precalendering. It also appears that the intensity of calendering seems to be the deciding factor in achieving the final surface properties of the coated sheet. Post calendering of the coated sheets virtually eliminated the differences in properties achieved by different precalendering. Hence, precalendering of the base sheets, as a pretreatment is effective only if the coated sheet is not post calendered. Any differential effect achieved through various precalendering operations, was made up in the post calendering of coated sheets. Different precalendering (MC, SC and SNC) methods did not seem to have any significant impact on the final roughness values obtained. The final gloss values of uncalendered and precalendered (MC, SC and SNC) sheets were the same in the case of coated sheets. Results also indicated that neither the type of calender used nor the intensity of calendering id not influence the final gloss vales. Similar effect was found in the case of coated post-calendered sheets. In the case of porosity, the coat weight seemed to be the controlling factor at high coat weights. But at low and medium coat weights precalendering can be used as a tool to achieve different porosity values of the final coated sheets.

In a different study by Steffner et al. (20) blade coated woodfree base paper . Part of the base paper was base paper was coated in an uncalendered state, while the other part was precalendered in a pilot calender with a steel/steel nip and soft polymer/steel nip. With the steel/steel nip the temperature of the of heated roll was 40, 100 and 200°C and with the soft polymer/steel nip it was 40 or 100°C. After precalendering the base sheet was coated in a laboratory coater and the coat weight was held constant at 10 g/m². Part of the sheet was post calendered with a soft nip calender. They showed that precalendering of the base sheets reduced the surface roughness and increased the gloss of coated sheet, which agrees with this present study. He also reported that the calendering conditions and the type of calender used affected the final properties in the same manner. However differences can be expected if the material used in the base paper contains other types of fibers. Engström and Lafaye (4) has reported that precalendering of a wood-containing base paper has resulted in a increase in roughness and covering ability of the coating and increase in print mottle.

The delta gloss and print density of the coated sheets were also influenced by precalendering in a positive way. Precalendered sheets had a higher delta gloss and print density than the uncalendered sheets. The level of calendering seems to be the deciding factor in achieving the final delta gloss and print density development. Post calendering improved the delta gloss and print density of coated sheets at medium and high coat weights for SC and SNC sheets. In the case of print density the values were the same in all cases. Delta gloss seemed to affected by the type of calender used in the precalendering operation. SC and SNC gave higher delta gloss values than the MC. In the case of print density there seems to be no difference due to the type of calender used in the precalendering operation.

The styrene butadiene latex content on the surface of the coated sheets was affected by the precalendering conditions. The type of calender used had a greater effect. SNC precalendered sheets had the highest latex content on the surface. The latex content on the surface was the lowest on the MC precalendered sheets. The intensity of precalendering also seems to have an effect on the surface latex content. Different precalendering (MC, SC and SNC) methods seem to affect the distribution of surface latex content in the same way.

Coating mass distribution seemed to be negatively affected by precalendering the base sheets and the type of calender used. Precalendered (MC and SC) sheets had a higher coefficient of variation of the absorbance after burn out treatment than the uncalendered sheets. In the case of SNC precalendered sheets the difference was marginal.

This present work has helped in quantifying some of the effects of precalendering on the properties of the coated end products. It can be concluded that precalendering is a tool that can be used in understanding and control properties like roughness, gloss, porosity, delta gloss, surface latex content and surface mass distribution to achieve improved sheet quality.

CHAPTER VII

SUGGESTION FOR FURTHER STUDY

1. Fiber swelling or plasticity determines how well the fibers conform to one another when in contact with water. Recycled fibers are known to be less conformable than virgin fibers. The process that causes roughening is due to swelling and debonding. Hence further study could be done to quantify the response of precalendering on surface properties of recycled fiber.

2. In this study it seen that the precalendering (MC, SC and SNC) had an effect on the final roughness, gloss and porosity values at low coat weights (2-5 g/m^2). This might be due to poor coating hold out, which can result in large pores and the coating color may sink into the sheet leaving the surface pores incompletely covered. Hence further study can be done by pretreating the base sheet with a sizing agent and quantify the response of precalendering on the surface properties of woodfree fibers.

3. Further study can also be done to find the response of precalendering on the strength properties of coated sheets and brightness and opacity.

Appendix A

Supporting Data

Table 9

Roughness Values for Sheets Subjected to Different Precalendering Conditions

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	4.24	7.81	12.83	4.64	7.91	13.28
Precalendering Conditions				Low-Machine Calendered			
1	5.63	5.44	5.48	4.11	3.02	2.55	1.82
2	5.34	5.51	5.64	4.17	3.40	2.55	1.93
3	5.24	5.85	5.20	4.14	3.23	2.61	1.77
4	5.56	5.27	5.64	4.15	3.28	2.63	1.78
5	5.57	5.85	5.52	4.18	3.23	2.76	1.79
6	5.44	5.63	5.50	3.95	3.47	2.66	1.82
7	5.68	6.23	5.21	3.89	3.36	2.72	1.89
8	5.29	6.00	5.61	4.17	3.16	2.72	1.72
9	5.25	5.84	5.55	4.18	3.38	2.69	1.71
10	5.36	5.81	5.55	4.08	3.20	2.70	1.78
Average, %	5.44	5.74	5.49	4.10	3.27	2.66	1.80
S.D.	0.16	0.28	0.16	0.10	0.13	0.07	0.07
C.V. %	3.00	4.93	2.91	2.49	4.07	2.73	3.80

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.35	7.17	12.71	4.49	7.51	12.27
Precalendering Conditions				High-Machine Calendered			
1	4.61	5.46	4.49	3.49	2.89	2.10	1.79
2	4.98	5.08	3.93	3.71	2.58	2.21	1.74
3	4.57	5.31	4.26	3.65	2.61	2.15	1.72
4	4.35	5.22	4.02	3.90	2.79	1.93	1.76
5	4.59	4.95	4.31	3.58	2.73	2.15	1.88
6	4.41	5.07	3.76	3.60	2.68	2.16	1.79
7	4.51	5.21	4.14	3.55	2.76	2.17	1.70
8	4.84	4.87	4.08	3.43	2.76	2.29	1.75
9	4.89	4.62	3.87	3.78	2.68	2.41	1.70
10	4.83	4.80	4.13	3.50	2.69	2.36	1.78
Average, %	4.66	5.06	4.10	3.62	2.72	2.19	1.76
S.D.	0.21	0.25	0.22	0.14	0.09	0.14	0.05
C.V. %	4.60	5.02	5.32	3.99	3.31	6.23	3.05

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.55	6.88	12.42	3.43	7.09	11.51
Precalendering Conditions	Low-Supercalendered						
1	5.06	5.54	4.92	4.23	2.89	2.22	2.29
2	5.22	5.87	4.93	4.17	2.99	2.23	1.96
3	5.07	5.69	4.68	3.94	2.88	2.24	2.17
4	5.05	5.77	4.77	4.19	2.93	2.34	1.95
5	5.15	5.96	4.77	4.06	2.89	2.34	2.1
6	5.14	5.69	4.87	4.18	2.87	2.22	2.02
7	5.15	5.93	4.67	3.95	2.81	2.30	2
8	5.20	5.94	4.86	3.89	2.80	2.33	1.99
9	5.09	5.93	4.79	3.95	3.00	2.22	1.96
10	5.02	5.95	4.69	3.89	3.00	2.27	1.92
Average, %	5.12	5.83	4.80	4.05	2.91	2.27	2.04
S.D.	0.07	0.15	0.10	0.14	0.07	0.05	0.12
C.V. %	1.31	2.51	2.02	3.36	2.52	2.29	5.73

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.07	7.29	11.76	3.86	7.88	12.53
Precalendering Conditions	High-Supercalendered						
1	4.32	4.95	3.71	3.49	3.07	2.05	1.70
2	4.44	5.03	3.64	3.49	3.03	2.13	1.67
3	4.49	5.30	3.62	3.54	3.10	2.08	1.66
4	4.36	5.16	3.69	3.35	2.92	2.13	1.76
5	4.30	5.12	3.48	3.50	3.04	2.08	1.72
6	4.36	4.95	3.56	3.51	2.91	2.06	1.77
7	4.26	4.96	3.79	3.40	3.02	2.06	1.81
8	4.38	5.00	3.78	3.61	3.05	2.08	1.69
9	4.30	4.88	3.75	3.53	2.95	2.12	1.71
10	4.27	4.82	3.77	3.54	3.03	2.16	1.80
Average, %	4.35	5.02	3.68	3.50	3.01	2.10	1.73
S.D.	0.07	0.14	0.10	0.07	0.06	0.04	0.05
C.V. %	1.70	2.83	2.80	2.11	2.12	1.78	3.07

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	4.24	7.31	13.09	4.07	7.37	12.96
Precalendering Conditions				Low-Soft Nip Calendered			
1	5.16	5.25	4.34	3.97	2.96	2.24	1.71
2	5.19	5.64	4.62	3.81	2.95	2.27	1.69
3	5.13	5.81	4.62	4.00	2.84	2.21	1.73
4	4.89	5.30	4.48	3.89	2.86	2.15	1.72
5	4.95	5.24	4.41	3.84	2.76	2.32	1.77
6	5.08	5.48	4.52	3.95	2.86	2.19	1.72
7	4.87	5.55	4.65	3.84	3.13	2.19	1.64
8	4.77	5.50	4.52	3.87	2.82	2.31	1.70
9	5.01	5.67	4.44	4.13	2.95	2.16	1.73
10	4.99	5.49	4.50	4.03	2.91	2.26	1.61
Average, %	5.00	5.49	4.51	3.93	2.90	2.23	1.70
S.D.	0.14	0.19	0.10	0.10	0.10	0.06	0.05
C.V. %	2.74	3.42	2.20	2.58	3.52	2.67	2.73

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	2.95	7.69	13.56	3.36	7.11	12.71
Precalendering Conditions				High-Soft Nip Calendered			
1	4.51	4.96	4.32	3.59	3.30	2.16	1.62
2	4.46	5.19	4.04	3.62	3.09	2.26	1.74
3	4.48	5.03	3.93	3.56	3.13	2.15	1.68
4	4.44	5.07	4.14	3.81	3.13	2.16	1.80
5	4.55	5.07	4.16	3.80	3.12	2.03	1.93
6	4.41	4.83	4.19	3.49	2.94	2.23	1.71
7	4.60	5.14	4.25	3.70	2.96	2.28	1.76
8	4.48	5.12	4.01	3.60	3.13	2.19	1.78
9	4.62	5.14	3.93	3.52	3.15	2.20	1.76
10	4.68	5.13	4.00	3.53	3.01	2.20	1.77
Average, %	4.52	5.07	4.10	3.62	3.10	2.19	1.76
S.D.	0.09	0.11	0.13	0.11	0.10	0.07	0.08
C.V. %	1.92	2.10	3.29	3.12	3.38	3.19	4.64

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m^2	0	3.45	7.47	13.14	4.07	7.44	13.25
Precalendering Conditions				Uncalendered			
1	6.67	6.51	6.55	5.01	2.95	2.30	1.56
2	6.90	6.73	6.57	4.98	2.79	2.21	1.56
3	6.77	6.55	6.59	4.91	2.99	2.24	1.48
4	6.82	6.76	6.47	4.95	2.99	2.28	1.51
5	6.73	6.45	6.55	4.97	2.94	2.30	1.58
6	6.82	6.87	6.56	5.03	2.92	2.40	1.67
7	6.88	6.59	6.65	5.06	2.80	2.30	1.70
8	6.78	6.82	6.44	5.09	2.86	2.23	1.59
9	6.61	6.43	6.59	4.80	2.90	2.14	1.52
10	6.49	6.60	6.39	4.80	2.66	2.24	1.48
Average, %	6.75	6.63	6.54	4.96	2.88	2.26	1.57
S.D.	0.13	0.16	0.08	0.10	0.10	0.07	0.07
C.V. %	1.88	2.34	1.21	2.00	3.62	3.06	4.75

Table 10

Gloss Values for Sheets Subjected to Different Precalendering Conditions

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0		4.24		7.81		12.83		4.64		7.91		13.28	
Precalendering Conditions	Low-Machine Calendered													
1	7.60	7.80	11.90	11.70	12.30	12.80	14.40	14.60	26.30	25.50	38.10	37.80	52.90	52.80
2	7.90	8.00	11.80	12.00	12.40	13.10	14.70	14.80	25.80	26.30	37.20	38.00	51.50	52.40
3	8.70	8.40	11.30	12.10	12.70	12.80	15.00	15.20	25.80	26.00	36.80	37.10	53.20	53.30
4	8.00	7.90	11.40	12.20	12.20	12.90	14.50	14.50	26.00	25.70	37.10	37.90	53.60	53.70
5	7.50	7.80	11.60	12.00	12.80	13.40	14.60	15.00	25.90	25.70	38.00	37.70	53.60	53.80
6	7.60	7.50	11.90	12.40	12.70	13.00	14.60	15.20	25.70	26.00	36.60	36.90	51.60	52.40
7	7.90	7.50	11.50	12.00	12.80	13.10	14.80	15.10	26.60	26.50	34.20	35.30	52.20	52.80
8	7.60	7.80	11.70	11.90	12.50	13.10	14.70	15.20	25.60	26.10	38.60	39.50	52.80	54.30
9	8.30	8.00	11.70	12.00	12.70	13.00	14.80	14.90	26.60	26.30	36.80	36.70	53.10	53.00
10	7.30	7.10	11.50	11.70	12.40	12.80	14.70	15.30	26.60	26.60	37.10	37.60	51.80	51.20
Average, %	7.84		11.63		12.55		14.68		26.09		37.05		52.63	
Standard Deviation	0.42		0.21		0.22		0.17		0.40		1.20		0.80	
Coefficient of Variation, %	5.32		1.77		1.73		1.15		1.53		3.23		1.52	

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		3.35		7.17		12.71		4.49		7.51		12.27	
Precalendering Conditions	High-Machine Calendered													
1	10.70	10.20	12.70	13.50	12.90	13.10	15.10	16.00	29.60	30.10	40.90	39.80	49.60	49.90
2	11.00	9.00	12.10	13.90	12.80	13.70	14.70	15.30	31.10	29.40	41.30	41.50	50.50	48.70
3	10.20	10.80	12.10	13.00	12.80	12.80	15.10	16.10	29.60	29.90	40.00	41.60	51.90	52.70
4	12.10	10.10	12.10	13.60	12.60	13.60	15.20	16.00	28.40	30.00	43.90	42.40	50.90	50.30
5	10.60	11.20	12.70	13.50	13.00	13.50	14.80	15.40	29.00	29.30	43.40	41.70	50.10	51.10
6	9.80	10.80	11.90	12.90	13.00	13.70	14.80	15.50	30.70	29.30	43.40	40.70	49.60	50.30
7	10.70	11.10	12.50	13.50	12.80	13.60	14.80	15.50	29.00	29.90	40.30	40.40	50.10	50.80
8	11.30	10.90	12.40	13.50	13.20	14.20	15.10	15.70	29.80	30.40	37.60	38.60	51.00	52.40
9	9.30	9.40	12.40	14.00	14.10	14.90	15.10	15.90	28.70	29.80	38.30	40.00	52.50	54.30
10	9.60	11.00	12.70	13.30	13.70	14.50	14.80	15.50	30.60	30.40	38.10	39.10	54.30	55.00
Average, %	10.53		12.36		13.09		14.95		29.65		40.72		51.05	
Standard Deviation	0.84		0.30		0.47		0.18		0.91		2.31		1.48	
Coefficient of Variation, %	7.98		2.39		3.56		1.23		3.07		5.67		2.90	

Table 10--Continued

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		3.55		6.88		12.42		3.43		7.09		11.51	
Precalendering Conditions							Low-Supercalendered							
1	8.70	8.40	11.90	12.30	12.10	12.40	14.20	14.50	27.80	28.10	37.20	37.40	58.60	57.50
2	9.40	8.80	11.80	12.30	12.00	12.50	14.30	14.50	29.10	27.90	37.60	37.60	61.30	59.40
3	8.90	8.30	11.50	12.20	12.30	12.60	14.40	14.80	29.00	28.40	37.40	37.50	58.40	59.40
4	9.50	8.60	11.70	12.20	12.10	12.80	13.70	14.60	29.80	28.60	38.10	37.90	56.80	57.10
5	8.50	8.80	11.40	12.00	12.60	12.70	14.50	14.70	29.00	28.30	37.40	38.50	56.60	55.40
6	9.70	8.90	11.60	12.70	12.20	12.50	14.30	14.40	28.30	27.70	38.20	37.90	56.30	56.40
7	9.40	8.90	10.90	11.50	12.30	12.80	14.40	15.40	28.00	28.20	38.70	38.10	55.10	55.40
8	8.70	8.80	10.80	11.00	12.20	12.50	14.70	15.00	27.20	27.30	38.40	38.50	58.40	59.50
9	9.70	8.70	10.80	11.50	12.40	12.70	14.60	14.80	29.30	27.80	38.80	38.20	53.90	57.10
10	8.90	8.70	10.90	11.40	12.40	12.70	14.40	14.50	28.00	28.30	37.10	36.90	54.10	56.10
Average, %	9.14		11.33		12.26		14.35		28.55		37.89		56.95	
Standard Deviation	0.45		0.44		0.18		0.27		0.81		0.63		2.29	
Coefficient of Variation, %	4.90		3.86		1.45		1.89		2.83		1.66		4.02	

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		3.07		7.29		11.76		3.86		7.88		12.53	
Precalendering Conditions							High-Supercalendered							
1	9.90	9.80	11.80	12.40	13.60	14.40	14.50	14.90	28.00	27.30	41.50	42.10	54.00	53.80
2	10.60	10.10	11.90	12.80	14.00	14.20	14.80	15.00	28.00	27.80	42.50	42.20	53.20	55.00
3	10.40	9.90	12.00	12.60	13.70	14.10	14.40	14.90	28.90	27.70	41.80	42.20	54.80	53.90
4	10.40	10.20	11.80	12.20	13.80	14.00	14.50	15.40	27.80	28.90	42.90	41.60	50.90	51.30
5	10.80	10.30	12.30	12.80	13.80	14.20	14.40	14.90	28.40	27.30	43.50	41.70	50.00	50.50
6	10.70	10.20	12.30	12.60	14.00	13.80	14.40	14.30	28.90	27.30	42.70	41.40	50.70	51.00
7	10.40	10.00	12.60	12.90	13.50	13.70	14.60	14.70	27.90	27.20	40.80	41.20	49.80	49.00
8	10.10	10.20	12.30	12.80	13.70	14.00	14.40	14.50	28.10	27.00	40.60	41.30	51.80	51.10
9	10.10	9.90	12.20	12.30	13.60	13.80	14.40	14.90	28.70	27.80	40.60	40.70	52.70	53.00
10	10.80	10.20	13.10	13.40	13.60	13.80	14.60	14.80	28.70	27.70	41.00	41.50	51.30	52.30
Average, µm	10.42		12.23		13.73		14.50		28.34		41.79		51.92	
Standard Deviation	0.31		0.40		0.17		0.13		0.43		1.05		1.70	
Coefficient of Variation, %	2.99		3.27		1.24		0.92		1.52		2.52		3.27	

Table 10--Continued

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		4.24		7.31		13.09		4.07		7.37		12.96	
Precalendering Conditions	Low-Soft Nip Calendered													
1	8.00	7.50	10.60	11.00	11.80	12.00	13.40	13.90	30.50	29.70	35.30	35.00	54.90	54.00
2	8.10	7.50	10.60	11.60	11.60	12.20	13.80	14.40	30.00	29.80	39.10	38.80	55.30	56.10
3	7.90	7.70	10.60	11.20	11.60	12.10	13.60	13.60	30.70	29.80	38.80	39.40	56.70	56.20
4	7.80	7.70	10.70	11.30	11.60	12.10	13.50	14.00	29.40	28.70	38.00	39.20	55.40	57.10
5	8.00	7.40	10.70	11.40	11.70	12.00	13.30	13.80	29.00	28.80	38.40	38.80	55.30	54.20
6	7.70	7.20	10.60	11.20	11.40	11.80	13.50	14.20	29.50	28.70	37.70	38.20	55.30	54.30
7	8.30	7.70	10.40	11.00	11.30	11.50	13.20	13.60	29.00	28.40	38.40	38.60	55.70	55.40
8	8.00	7.80	10.60	11.10	11.20	11.40	13.10	13.30	29.00	29.80	39.50	39.90	56.20	52.90
9	8.00	7.90	10.50	11.10	11.50	11.60	13.00	13.40	28.80	29.00	39.30	39.20	54.60	54.50
10	8.10	7.70	10.50	11.20	11.60	11.90	13.00	13.60	29.30	29.10	38.70	39.10	55.50	54.80
Average, µm	7.99		10.58		11.53		13.34		29.52		38.32		55.49	
Standard Deviation	0.17		0.09		0.18		0.27		0.66		1.20		0.60	
Coefficient of Variation, %	2.08		0.87		1.59		2.01		2.25		3.13		1.09	

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		2.95		7.69		13.56		3.36		7.11		12.71	
Precalendering Conditions	High-Soft Nip Calendered													
1	9.50	9.30	11.40	12.70	12.40	13.20	15.30	16.20	28.00	27.50	37.70	37.30	59.40	59.80
2	9.00	9.20	11.00	11.90	12.00	12.70	15.00	15.80	28.60	28.50	37.30	37.80	58.00	57.60
3	9.10	9.30	11.40	12.20	12.40	13.20	15.20	15.80	27.50	28.40	37.80	37.90	56.70	57.30
4	9.00	10.00	11.20	12.30	12.10	13.00	15.10	15.90	28.00	28.80	37.90	38.70	53.80	55.90
5	9.30	8.90	11.10	11.80	12.40	13.00	15.20	15.80	29.10	29.50	38.20	38.50	56.00	54.40
6	9.20	9.10	11.30	12.40	12.40	13.20	14.70	15.40	28.80	29.70	38.30	39.20	56.60	56.50
7	9.60	9.30	11.50	11.70	12.30	13.90	14.70	15.40	28.60	28.40	38.00	38.00	57.70	56.60
8	9.80	8.50	11.40	12.50	12.60	12.90	14.50	15.00	28.70	29.00	38.80	38.90	54.10	55.10
9	9.70	9.30	11.10	12.10	12.50	13.00	14.60	15.40	29.30	28.80	38.90	38.70	55.20	53.50
10	9.60	9.30	11.30	12.50	12.60	13.20	14.80	15.30	28.60	29.00	38.60	38.40	55.30	54.20
Average, µm	9.38		11.27		12.37		14.91		28.52		38.15		56.28	
Standard Deviation	0.30		0.16		0.19		0.28		0.54		0.51		1.77	
Coefficient of Variation, %	3.17		1.45		1.57		1.91		1.90		1.34		3.14	

Table 10--Continued

Observations	Uncoated		Coated-Uncalendered						Coated-Calendered					
	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
Coat Weight, g/m²	0.00		3.45		7.47		13.14		4.07		7.44		13.25	
Precalendering Conditions							Uncalendered							
1	6.30	6.10	10.50	10.90	11.00	11.30	13.80	13.90	27.80	28.60	39.30	40.90	53.80	54.40
2	6.50	6.20	10.60	11.00	11.20	11.40	13.90	14.20	27.90	27.80	40.70	41.80	56.00	54.90
3	6.60	6.10	10.50	10.90	10.90	11.30	14.00	14.00	28.00	27.60	40.50	41.30	55.40	55.80
4	6.40	6.10	10.60	10.60	11.20	11.50	13.80	13.80	27.60	27.00	40.30	41.00	54.80	54.20
5	6.40	6.40	10.80	10.90	11.10	11.30	13.70	14.20	27.40	26.90	40.70	41.40	53.00	53.10
6	6.50	6.10	10.50	10.70	10.10	11.10	14.20	14.70	26.60	26.80	40.60	41.20	51.90	52.20
7	6.40	5.90	10.80	10.80	11.10	11.50	13.80	13.90	27.70	27.90	40.60	41.20	51.00	52.70
8	6.60	6.00	10.80	11.10	10.90	11.20	13.90	14.50	27.70	27.20	42.30	41.60	55.00	56.10
9	6.50	6.00	10.70	10.90	11.10	11.60	13.80	14.30	27.90	28.10	41.90	41.70	56.60	57.20
10	6.30	6.20	10.70	11.10	11.20	11.30	13.70	14.20	28.20	28.30	42.10	41.50	57.40	57.20
Average, µm	6.45		10.65		10.98		13.86		27.68		40.90		54.49	
Standard Deviation	0.11		0.13		0.33		0.15		0.44		0.93		2.05	
Coefficient of Variation, %	1.67		1.19		3.00		1.09		1.59		2.27		3.77	

Table 11

Porosity Values for Sheets Subjected to Different Precalendering Conditions

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	4.24	7.81	12.83	4.64	7.91	13.28
Precalendering Conditions				Low-Machine Calendered			
1	619.4	99.66	86.77	11.8	51.49	28.29	6.33
2	620.5	99.23	92.31	11.24	55.46	30.7	5.99
3	635.7	104.6	71.11	11.17	50.83	31.86	8.3
4	692.3	114.8	87.93	11.56	57.35	29.98	5.66
5	618.1	106.8	84.64	11	55.56	29.92	5.39
6	604.7	102.9	71.83	11.3	54.1	33.86	5.74
7	591	109.3	67.35	10.83	55.27	33.68	5.86
8	499	106.4	68.12	10.7	55.06	34.37	5.52
9	555.2	106.2	70.28	10.65	55.12	29.76	5.89
10	521.6	106.4	74.32	10.45	52.86	27.79	5.78
Average, %	595.75	105.63	77.47	11.07	54.31	31.02	6.05
S.D.	56.96	4.54	9.38	0.42	2.01	2.33	0.83
C.V. %	9.56	4.30	12.10	3.84	3.71	7.52	13.78

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.35	7.17	12.71	4.49	7.51	12.27
Precalendering Conditions				High-Machine Calendered			
1	492.2	34.19	15.72	8.85	15.85	5.5	3.35
2	486.8	33.96	12.97	9.88	14.81	5.4	3.4
3	466.3	45.58	13.63	8.69	15.2	5.42	3.23
4	522.7	40.71	12.31	9.06	15.1	5	3.37
5	463.6	33.77	12.37	10.9	15.12	5.48	3.48
6	427.2	37.37	10.63	8.03	15.75	5.67	3.47
7	461.9	38.02	11.55	11.17	16.04	5.64	3.51
8	485.5	37.89	11.77	11.01	18.43	7.54	3.54
9	467.8	30.14	10.92	8.79	16.46	6.82	3.45
10	474.2	33.15	11.84	8.71	14.8	7.42	3.23
Average, %	474.82	36.48	12.37	9.51	15.76	5.99	3.40
S.D.	24.80	4.42	1.48	1.14	1.09	0.91	0.11
C.V. %	5.22	12.13	11.93	12.01	6.92	15.26	3.20

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.55	6.88	12.42	3.43	7.09	11.51
Precalendering Conditions				Low-Supercalendered			
1	486.4	94.9	20.4	9.58	55.89	10.18	3.11
2	437.3	85.77	19.99	8.23	52.26	8.64	2.73
3	479.7	94.86	19.61	8.65	52.34	9	2.88
4	481.6	95.98	21.78	9.86	48.5	8.82	3.31
5	463.8	98.41	19.35	9.3	49.72	8.7	3.4
6	432.9	89.91	20.15	8.99	46.61	8.08	3.46
7	507.3	87.04	17.52	8.17	48.01	7.94	4.2
8	507.4	112.4	19.41	8.35	48.65	8.29	3.21
9	440.1	103.2	17.58	9.33	51.28	8.89	4.37
10	520.5	15.79	17.27	9.85	47.55	9.43	3.75
Average, %	475.70	87.83	19.31	9.03	50.08	8.80	3.44
S.D.	31.43	26.49	1.45	0.65	2.84	0.66	0.53
C.V. %	6.61	30.16	7.51	7.21	5.67	7.49	15.42

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	3.07	7.29	11.76	3.86	7.88	12.53
Precalendering Conditions				High-Supercalendered			
1	345.2	84.38	10.97	8.41	42.45	7.54	3.65
2	345	79.6	11.07	7.91	39.52	5.81	3.58
3	320.8	74.74	11.58	8.37	39.96	5.88	3.2
4	338.5	77.66	12.01	8.16	42.6	5.85	3.6
5	343.8	76.35	13.09	8.34	42.64	6.08	3.85
6	348.4	79.82	13.33	8.7	42.43	6.09	3.9
7	440.4	77.89	14.28	7.97	47.55	5.99	4
8	389	68.17	12.49	10.81	47.03	6.49	3.89
9	396	72.59	12.08	9.01	47.19	6.74	3.86
10	343	68.61	12.57	8.93	45.97	6.77	3.84
Average, %	361.01	75.98	12.35	8.66	43.73	6.32	3.74
S.D.	36.09	5.09	1.03	0.84	2.99	0.56	0.23
C.V. %	10.00	6.70	8.38	9.70	6.83	8.80	6.29

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	4.24	7.31	13.09	4.07	7.37	12.96
Precalendering Conditions				Low-Soft Nip Calendered			
1	498.4	97.3	16.04	6.3	45.24	7.75	2.62
2	469.2	103.5	15.9	6.44	45.65	7.27	2.29
3	460.3	93.82	15.85	6	46.93	7.25	2.45
4	532.3	93.3	16.57	8.29	48.97	7.3	2.48
5	439.2	95.27	15.18	7.85	50.84	7.55	2.63
6	496	91.97	16.77	7.74	47.6	7.84	2.93
7	491	89.49	14.86	7.03	50.71	8.3	2.26
8	488.4	111.3	15.7	8.17	53.54	7.09	2.45
9	526.6	114.2	16.67	7.11	50.92	7.17	2.29
10	518.1	115.6	15.52	7.28	53.09	7.52	2.41
Average, %	491.95	100.58	15.91	7.22	49.35	7.50	2.48
S.D.	29.60	9.83	0.63	0.80	2.94	0.37	0.20
C.V. %	6.02	9.77	3.98	11.03	5.95	4.97	8.19

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	0	2.95	7.69	13.56	3.36	7.11	12.71
Precalendering Conditions				High-Soft Nip Calendered			
1	493.8	97.46	13.98	8.16	57.44	7.32	3.49
2	455.8	95.08	16.43	8.49	55.26	7.35	3.81
3	465.2	103.8	15.84	8.76	53.74	7.3	4
4	457	98.3	14.05	8.45	52.28	7.11	4.24
5	514.7	94.43	14.47	8.1	51.31	7.47	3.87
6	428.8	84.58	13.32	8.89	50.55	7.35	3.9
7	459.6	87.31	13.98	8.27	55.13	7.89	4.08
8	478.4	81.66	15.91	8.91	54.7	7.62	3.69
9	447.5	88.17	14.16	8.98	52.31	7.54	4.18
10	468.2	90.81	14.8	8.93	52.8	6.82	3.31
Average, %	466.90	92.16	14.69	8.59	53.55	7.38	3.86
S.D.	24.15	6.86	1.03	0.34	2.10	0.29	0.30
C.V. %	5.17	7.45	6.98	3.97	3.92	3.91	7.67

Observations	Uncoated	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m^2	0	3.45	7.47	13.14	4.07	7.44	13.25
Precalendering Conditions				Uncalendered			
1	675.4	103.1	54.8	10.12	28.64	11.6	3.32
2	630.4	109.9	51.39	9.18	28.2	11.61	3.07
3	696.3	101.5	53.26	9.75	27.87	11.78	3.09
4	654.4	101.3	52.85	9.47	29.67	12.12	3.3
5	654.9	99.96	54.85	10.32	32.23	11.76	3.48
6	630.4	99.14	57.86	7.88	31.63	12.27	3.58
7	666.9	90.92	49.5	10.86	31.61	12.08	4.07
8	679.4	93.62	50.89	10.46	30.66	11.73	3.09
9	663.7	94.39	49.52	8.9	30.76	11.93	2.99
10	672.9	90.63	45.92	9.62	32.67	11.94	2.96
Average, %	662.47	98.45	52.08	9.66	30.39	11.88	3.30
S.D.	20.84	6.06	3.39	0.87	1.72	0.22	0.34
C.V. %	3.15	6.16	6.51	8.97	5.65	1.89	10.40

Table 12

Coat Weight of Sheets Subjected to Different Precalendering Conditions

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	Low-Machine Calendered					
1	3.80	6.83	12.56	4.61	8.02	12.69
2	3.82	7.32	12.95	2.92	7.17	13.01
3	4.42	7.60	12.08	4.74	7.66	13.29
4	4.20	7.40	12.73	4.02	6.60	12.03
5	3.93	7.47	12.68	3.98	6.70	12.75
6	3.80	7.89	13.02	4.62	7.73	13.55
7	5.18	8.76	13.49	5.48	8.87	13.79
8	4.00	7.99	12.54	4.21	7.07	13.55
9	4.36	8.44	13.91	5.53	9.69	13.59
10	4.91	8.43	12.30	6.24	9.61	14.60
Average, %	4.24	7.81	12.8	4.64	7.91	13.3
S.D.	0.48	0.60	0.55	0.95	1.13	0.71
C.V. %	11.3	7.71	4.26	20.4	14.3	5.32

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	High-Machine Calendered					
1	3.26	7.12	13.88	4.82	7.82	13.19
2	3.26	6.91	12.73	4.62	6.97	11.56
3	2.83	5.90	12.29	4.25	7.00	12.04
4	3.39	7.32	13.73	5.79	8.43	12.94
5	4.57	8.28	13.19	5.17	8.99	12.87
6	1.89	6.43	11.24	2.97	6.76	10.10
7	3.53	7.44	11.93	4.60	8.18	11.32
8	3.88	7.25	12.95	4.34	6.96	12.61
9	3.49	7.28	13.35	4.42	6.87	12.87
10	3.42	7.76	11.82	3.88	7.14	13.25
Average, %	3.35	7.17	12.7	4.49	7.51	12.3
S.D.	0.69	0.66	0.87	0.75	0.79	1.01
C.V. %	20.5	9.19	6.86	16.7	10.5	8.25

Table 12--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	Low-Supercalendered					
1	3.62	6.02	11.59	1.97	6.85	11.79
2	2.83	6.37	11.22	2.49	6.65	11.31
3	2.74	6.42	12.42	3.17	7.08	11.79
4	3.34	6.75	12.80	4.02	7.76	11.53
5	3.07	7.14	12.48	3.44	6.57	10.53
6	2.25	6.32	11.75	3.20	6.58	10.42
7	5.34	8.48	14.36	4.75	8.17	11.92
8	4.03	6.23	12.89	3.77	7.21	12.04
9	4.02	7.48	11.87	3.77	6.83	11.17
10	4.29	7.56	12.84	3.77	7.22	12.59
Average, %	3.55	6.88	12.4	3.43	7.09	11.5
S.D.	0.90	0.77	0.89	0.79	0.53	0.67
C.V. %	25.4	11.3	7.19	23.0	7.42	5.85

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	High-Supercalendered					
1	2.89	8.10	11.90	3.87	8.20	12.73
2	3.18	7.97	12.00	4.69	8.28	12.79
3	3.20	7.40	11.41	3.58	8.02	13.08
4	3.43	7.97	12.48	4.99	8.75	13.71
5	3.46	7.77	11.35	4.40	7.65	11.56
6	3.35	7.28	11.43	4.58	7.89	11.46
7	3.32	7.29	11.56	3.63	7.30	11.71
8	1.67	5.77	10.31	2.97	6.65	12.19
9	3.13	6.35	12.39	3.09	7.53	13.17
10	3.09	6.97	12.75	2.82	8.54	12.91
Average, %	3.07	7.29	11.8	3.86	7.88	12.5
S.D.	0.52	0.75	0.71	0.77	0.63	0.76
C.V. %	17.0	10.3	6.02	20.0	7.93	6.08

Table 12--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	Low-Soft Nip Calendered					
1	4.68	7.57	12.93	4.21	8.15	13.09
2	4.40	6.54	12.76	4.42	7.10	13.10
3	5.45	6.96	13.63	4.40	7.77	13.74
4	5.83	8.71	14.54	4.97	8.91	14.15
5	4.25	6.39	11.72	3.59	6.58	12.65
6	4.69	7.03	12.51	3.38	7.48	12.94
7	5.00	8.08	13.25	4.11	7.93	12.96
8	3.64	7.70	13.91	4.35	7.41	12.49
9	2.64	6.75	12.73	4.07	6.20	12.31
10	1.84	7.32	12.90	3.15	6.13	12.20
Average, %	4.24	7.31	13.1	4.07	7.37	13.0
S.D.	1.23	0.72	0.79	0.55	0.89	0.61
C.V. %	29.1	9.91	6.03	13.5	12.0	4.74

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions	High-Soft Nip Calendered					
1	2.76	7.67	14.90	3.18	7.04	14.15
2	4.28	8.57	15.57	4.33	7.44	13.96
3	2.65	7.86	13.41	3.20	6.47	12.20
4	2.19	7.61	13.37	3.16	7.70	12.36
5	4.62	9.09	16.40	4.81	8.80	13.72
6	2.15	6.09	12.82	1.92	5.30	11.00
7	1.82	6.96	11.51	2.33	6.20	11.59
8	4.11	8.08	13.22	4.42	8.05	13.44
9	1.75	6.86	11.52	2.87	6.73	12.18
10	3.13	8.14	12.91	3.40	7.40	12.46
Average, %	2.95	7.69	13.6	3.36	7.11	12.7
S.D.	1.05	0.88	1.61	0.92	1.00	1.06
C.V. %	35.8	11.4	11.9	27.4	14.0	8.34

Table 12--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Precalendering Conditions			Uncalendered			
1	3.29	7.31	12.86	4.01	7.70	12.62
2	2.94	7.66	12.93	3.65	7.56	14.07
3	5.30	9.42	14.33	5.99	9.88	15.06
4	3.88	8.00	13.08	4.20	8.11	13.51
5	2.17	6.19	12.11	2.95	6.82	11.81
6	2.72	7.02	13.43	3.71	8.12	12.15
7	3.58	7.31	12.78	3.51	6.25	11.79
8	3.18	6.99	13.42	3.81	6.39	13.51
9	4.70	7.53	14.40	5.02	7.00	14.95
10	2.72	7.37	12.13	3.88	6.61	13.05
Average, %	3.45	7.48	13.15	4.07	7.44	13.25
S.D.	0.96	0.83	0.78	0.86	1.09	1.19
C.V. %	27.8	11.1	5.9	21.0	14.7	9.0

Table 13

Delta Gloss of Printed Sheets Subjected to Different Precalendering Conditions

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	4.24	7.81	12.83	4.64	7.91	13.28
Precalendering Conditions	Low-Machine Calendered					
1	4.80	5.50	8.10	5.30	9.40	9.80
2	4.60	5.20	8.40	5.40	7.50	7.10
3	4.80	5.30	8.80	5.00	6.90	9.30
4	4.80	6.10	8.50	4.70	8.30	11.0
5	4.90	5.80	7.90	6.70	7.60	11.7
6	5.50	5.70	8.30	6.20	7.90	11.5
7	5.10	6.20	8.60	6.70	8.90	10.4
8	4.30	5.20	8.40	7.70	7.80	10.4
9	4.90	5.20	8.00	5.70	7.20	12.2
10	4.30	5.40	8.00	5.30	6.40	11.6
Average, %	4.80	5.56	8.30	5.87	7.79	10.5
S.D.	0.36	0.37	0.29	0.93	0.90	1.50
C.V. %	7.41	6.74	3.55	15.9	11.6	14.3

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.35	7.17	12.71	4.49	7.51	12.27
Precalendering Conditions	High-Machine Calendered					
1	3.80	5.90	8.50	5.20	9.40	11.4
2	3.40	5.60	8.40	5.10	8.60	11.9
3	3.20	5.50	9.70	4.40	8.70	12.6
4	3.60	5.50	7.60	3.60	11.1	13.7
5	3.40	5.60	8.60	7.40	10.9	11.6
6	3.90	5.40	7.80	6.70	11.7	10.8
7	3.90	5.70	8.40	6.30	10.8	11.4
8	3.60	5.40	9.20	8.60	7.70	9.30
9	3.60	5.50	8.70	8.70	6.90	12.6
10	3.50	5.70	7.80	8.70	7.30	15.1
Average, %	3.59	5.58	8.47	6.47	9.31	12.0
S.D.	0.23	0.15	0.65	1.87	1.73	1.59
C.V. %	6.36	2.78	7.65	28.9	18.6	13.2

Table 13--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.55	6.88	12.42	3.43	7.09	11.51
Precalendering Conditions	Low-Supercalendered					
1	5.30	7.40	10.30	7.30	9.20	16.2
2	5.00	7.30	9.40	6.90	9.80	9.30
3	4.90	7.10	9.40	5.20	6.30	15.4
4	5.00	7.50	9.80	6.20	8.20	10.7
5	4.90	7.10	10.20	7.10	10.3	16.5
6	4.60	7.30	9.70	6.10	9.60	13.5
7	4.40	7.80	9.70	6.40	9.60	15.0
8	5.10	7.70	10.50	6.90	11.6	15.2
9	4.80	7.60	10.10	6.10	10.4	15.2
10	4.80	6.90	9.40	6.00	10.6	16.2
Average, %	4.88	7.37	9.9	6.42	9.56	14.3
S.D.	0.25	0.29	0.40	0.63	1.46	2.45
C.V. %	5.18	3.89	4.10	9.87	15.3	17.1

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.07	7.29	11.76	3.86	7.88	12.53
Precalendering Conditions	High-Supercalendered					
1	5.20	8.50	9.90	6.70	11.4	13.1
2	5.10	8.50	9.50	5.80	9.00	12.5
3	5.30	8.20	9.40	6.30	9.90	10.9
4	5.30	7.70	9.70	6.20	8.10	14.6
5	5.50	8.50	10.10	6.20	11.9	13.1
6	6.00	8.10	9.60	6.90	11.7	15.5
7	5.50	9.60	9.70	6.00	9.30	9.90
8	6.20	8.40	10.00	6.00	12.0	14.4
9	5.50	8.40	10.50	6.90	12.0	12.5
10	5.70	8.50	9.60	6.30	10.2	12.9
Average, %	5.53	8.44	9.8	6.33	10.6	12.9
S.D.	0.35	0.48	0.33	0.38	1.44	1.68
C.V. %	6.32	5.70	3.37	6.05	13.6	13.0

Table 13--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	4.24	7.31	13.09	4.07	7.37	12.96
Precalendering Conditions	Low-Soft Nip Calendered					
1	4.30	7.00	10.80	6.30	12.0	15.6
2	4.00	6.60	9.30	6.80	10.7	18.9
3	4.20	6.70	9.30	6.10	9.10	10.7
4	4.30	6.80	8.90	6.50	9.00	15.6
5	4.50	7.60	10.20	5.60	9.80	17.1
6	4.80	7.00	9.80	5.60	9.20	12.5
7	4.30	7.20	8.90	6.00	9.30	11.0
8	4.70	7.40	9.90	6.40	10.4	9.70
9	4.80	7.10	10.20	6.10	11.1	14.5
10	4.40	6.90	10.10	6.40	9.70	13.9
Average, %	4.43	7.03	9.7	6.18	10.0	14.0
S.D.	0.27	0.31	0.62	0.38	1.00	2.97
C.V. %	6.02	4.40	6.41	6.19	9.93	21.3

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	2.95	7.69	13.56	3.36	7.11	12.71
Precalendering Conditions	High-Soft Nip Calendered					
1	5.40	8.40	11.20	7.60	11.8	13.2
2	4.90	7.90	11.00	5.80	11.7	11.0
3	5.50	7.70	9.70	4.90	10.0	9.00
4	5.30	7.90	10.00	5.90	9.00	9.60
5	5.10	8.00	9.20	6.50	10.1	11.4
6	5.30	8.50	9.90	5.90	8.90	12.1
7	5.80	8.20	10.80	6.60	7.80	16.9
8	5.20	8.40	11.40	4.70	11.1	15.8
9	4.80	7.80	10.50	4.40	9.70	13.4
10	4.80	7.90	10.90	4.40	10.4	13.2
Average, %	5.21	8.07	10.5	5.67	10.1	12.6
S.D.	0.32	0.28	0.72	1.06	1.27	2.50
C.V. %	6.17	3.51	6.93	18.7	12.7	19.9

Table 13--Continued

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.45	7.47	13.14	4.07	7.44	13.25
Precalendering Conditions			Uncalendered			
1	3.80	5.90	8.50	6.60	9.00	13.3
2	3.40	5.60	8.40	6.30	7.90	9.80
3	3.20	5.50	9.70	6.00	7.60	13.8
4	3.60	5.50	7.60	6.10	10.0	15.0
5	3.40	5.60	8.60	6.20	10.2	15.4
6	3.90	5.40	7.80	4.60	9.30	13.8
7	3.90	5.70	8.40	5.50	8.30	11.9
8	3.60	5.40	9.20	6.30	9.10	14.4
9	3.60	5.50	8.70	6.00	8.80	9.80
10	3.50	5.70	7.80	4.80	9.20	11.7
Average, %	3.59	5.58	8.47	5.84	8.94	12.9
S.D.	0.23	0.15	0.65	0.67	0.83	2.01
C.V. %	6.36	2.78	7.65	11.4	9.32	15.6

Table 14

Density of Printed Sheets Subjected to Different Precalendering Conditions

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	4.24	7.81	12.83	4.64	7.91	13.28
Precalendering Conditions	Low-Machine Calendered					
1	1.43	1.55	1.72	1.72	1.80	1.93
2	1.47	1.52	1.71	1.68	1.82	1.93
3	1.36	1.51	1.68	1.71	1.84	1.93
4	1.46	1.57	1.71	1.67	1.84	1.93
5	1.46	1.58	1.71	1.71	1.81	1.93
6	1.52	1.54	1.72	1.71	1.82	1.94
7	1.43	1.56	1.71	1.64	1.81	1.94
8	1.46	1.57	1.76	1.67	1.84	1.94
9	1.53	1.55	1.74	1.72	1.77	1.95
10	1.46	1.51	1.72	1.66	1.84	1.92
Average, %	1.46	1.55	1.72	1.69	1.82	1.93
S.D.	0.05	0.03	0.02	0.03	0.02	0.01
C.V. %	3.26	1.65	1.22	1.69	1.25	0.44

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.35	7.17	12.71	4.49	7.51	12.27
Precalendering Conditions	High-Machine Calendered					
1	1.45	1.70	1.79	1.76	1.88	2.01
2	1.50	1.71	1.75	1.76	1.80	2.01
3	1.51	1.70	1.77	1.76	1.81	1.99
4	1.54	1.75	1.70	1.76	1.82	1.98
5	1.44	1.71	1.78	1.69	1.79	1.99
6	1.53	1.77	1.86	1.75	1.80	1.96
7	1.65	1.74	1.74	1.67	1.79	1.97
8	1.55	1.57	1.80	1.67	1.86	1.99
9	1.47	1.56	1.80	1.69	1.83	2.01
10	1.50	1.57	1.71	1.68	1.87	1.98
Average, %	1.51	1.68	1.77	1.72	1.83	1.99
S.D.	0.06	0.08	0.05	0.04	0.03	0.02
C.V. %	3.98	4.77	2.68	2.43	1.85	0.87

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.55	6.88	12.42	3.43	7.09	11.51
Precalendering Conditions	Low-Supercalendered					
1	1.42	1.64	1.74	1.73	1.86	2.00
2	1.47	1.68	1.77	1.70	1.84	2.00
3	1.50	1.54	1.73	1.70	1.81	1.91
4	1.46	1.66	1.76	1.72	1.84	2.00
5	1.45	1.67	1.73	1.71	1.87	2.10
6	1.46	1.65	1.73	1.67	1.86	2.00
7	1.42	1.67	1.74	1.65	1.85	2.01
8	1.51	1.65	1.76	1.68	1.84	2.00
9	1.47	1.67	1.74	1.69	1.87	2.01
10	1.47	1.67	1.74	1.70	1.87	2.01
Average, %	1.46	1.65	1.74	1.70	1.85	2.00
S.D.	0.03	0.04	0.01	0.02	0.02	0.05
C.V. %	1.99	2.46	0.82	1.40	1.03	2.25

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.07	7.29	11.76	3.86	7.88	12.53
Precalendering Conditions	High-Supercalendered					
1	1.55	1.70	1.69	1.67	1.87	1.98
2	1.54	1.72	1.75	1.66	1.84	1.97
3	1.53	1.71	1.78	1.62	1.90	2.00
4	1.49	1.76	1.79	1.72	1.85	1.93
5	1.50	1.71	1.76	1.67	1.88	1.99
6	1.51	1.70	1.81	1.70	1.84	1.99
7	1.53	1.64	1.76	1.66	1.89	1.97
8	1.49	1.69	1.76	1.65	1.90	1.96
9	1.53	1.69	1.81	1.63	1.93	1.96
10	1.56	1.70	1.75	1.65	1.89	1.96
Average, %	1.52	1.70	1.77	1.66	1.88	1.97
S.D.	0.02	0.03	0.04	0.03	0.03	0.02
C.V. %	1.61	1.75	1.98	1.79	1.56	1.03

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	4.24	7.31	13.09	4.07	7.37	12.96
Precalendering Conditions	Low-Soft Nip Calendered					
1	1.43	1.63	1.73	1.68	1.85	1.88
2	1.52	1.62	1.76	1.69	1.86	2.00
3	1.49	1.62	1.75	1.69	1.86	2.00
4	1.46	1.62	1.78	1.70	1.89	2.02
5	1.46	1.63	1.76	1.72	1.90	2.10
6	1.42	1.67	1.74	1.72	1.88	2.03
7	1.45	1.65	1.74	1.72	1.86	2.04
8	1.48	1.63	1.76	1.65	1.87	2.05
9	1.48	1.67	1.77	1.66	1.92	2.05
10	1.46	1.62	1.77	1.66	1.81	2.02
Average, %	1.47	1.64	1.76	1.69	1.87	2.02
S.D.	0.03	0.02	0.02	0.03	0.03	0.06
C.V. %	1.99	1.23	0.90	1.57	1.61	2.82

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	2.95	7.69	13.56	3.36	7.11	12.71
Precalendering Con	High-Soft Nip Calendered					
1	1.48	1.65	1.77	1.64	1.88	1.98
2	1.48	1.70	1.80	1.67	1.89	1.99
3	1.45	1.68	1.77	1.69	1.90	2.00
4	1.51	1.70	1.76	1.71	1.92	2.01
5	1.53	1.66	1.72	1.61	1.86	1.95
6	1.47	1.69	1.77	1.65	1.87	1.98
7	1.49	1.67	1.80	1.67	1.88	1.94
8	1.52	1.65	1.79	1.67	1.86	2.03
9	1.46	1.68	1.81	1.69	1.88	2.00
10	1.48	1.68	1.78	1.70	1.90	2.00
Average	1.49	1.68	1.78	1.67	1.88	1.99
Standard Deviation	0.03	0.02	0.03	0.03	0.02	0.03
:fficient of Variatior	1.74	1.10	1.45	1.81	1.01	1.36

Observations	Coated-Uncalendered			Coated-Calendered		
Coat Weight, g/m²	3.45	7.47	13.14	4.07	7.44	13.25
Precalendering Conditions			Uncalendered			
1	1.38	1.55	1.76	1.67	1.86	2.02
2	1.41	1.54	1.79	1.67	1.82	1.98
3	1.41	1.51	1.73	1.58	1.87	1.95
4	1.41	1.51	1.79	1.66	1.81	2.07
5	1.41	1.52	1.73	1.68	1.85	1.99
6	1.43	1.54	1.66	1.65	1.87	2.02
7	1.33	1.55	1.69	1.65	1.84	1.97
8	1.35	1.52	1.67	1.67	1.87	2.06
9	1.34	1.56	1.73	1.65	1.82	2.01
10	1.35	1.52	1.67	1.65	1.84	2.02
Average, %	1.38	1.53	1.72	1.65	1.85	2.01
S.D.	0.04	0.02	0.05	0.03	0.02	0.04
C.V. %	2.64	1.18	2.82	1.69	1.23	1.88

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