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Smoothness Improvement of High Speed Recycled Paperboard through Base Coating Formula Optimization

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Smoothness Improvement of High Speed Recycled Paperboard Through Base Coating Formula Optimization

A thesis submitted in partial fulfillment of course requirements for the bachelor of science degree for the department of paper and printing science and engineering

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Senior Engineering Problem II - PAPER 473

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TABLE OF CONTENTS

ABSTRACT

As the trend in printing recycled paperboard shifts toward the rotogravure process, the surface smoothness of the paperboard is becoming increasingly important. Also, as recycled paperboard machine speeds increase, greater demands are being placed on the coating process and formulation to yield superior coating characteristics. The objective of this research project is to determine a base coat formulation that improves the base coating characteristics in high-speed recycled paperboard. This study examines the replacement of a traditional #1 clay with calcined clay and fine particle clay, which through their different properties alter the characteristics of the coating. The bulky calcined particles are more effective at filling the micro-valleys on the surface of the paperboard, while the smaller fine particle clay particles help prevent the coating from becoming dilatent. The less costly fine particle clay also offsets the high cost of the calcined clay.

The lab experiments on the Cylindrical Laboratory Coater have shown that at a constant coat weight, 20 parts calcined clay, 32 parts fine particle clay and 48 parts #1 clay provided improved smoothness and brightness while maintaining adequate flow characteristics. Above 20 parts of calcined clay the coating was very difficult to apply to the paperboard because of streaks. The coating consisting of 10 parts calcined clay, 32 parts fine particle clay and 58 parts #1 clay provided almost the same smoothness and brightness results, but costs less. This would be the most cost effective coating formulation for improving the surface smoothness and brightness characteristics of recycled paperboard.

Because only a relatively small amount of research has been done in this area, this project could be extended into any number of areas including the addition of delaminated clay, effect of coat weight, and pilot / machine trials.

Keywords: Recycled Paperboard, Coating, Smoothness, Calcined Clay, Blade Coater, High Speed

INTRODUCTION

The recycled paperboard industry is projected to produce 10.4 million tons of recycled paperboard in 1994 (1). In order to give the surface certain desirable properties, a significant portion of this will be coated with a variety of pigments combined with an even wider variety of synthetic and natural additives. The coating applied to recycled paperboard is important for several reasons:

1) it conceals the "dirty" paperboard surface
2) it provides visual appeal to the consumer
3) it provides smooth surface required for printing processes

Listed below are the major aspects of why this study is important, followed by a short discussion of why each aspect is included and how they will be dealt with.

BACKGROUND AND THEORETICAL

Importance of Surface Smoothness

The use of the rotogravure printing process in the recycled paperboard industry is steadily increasing because it provides the highest possible print quality, relatively low need for skilled operators, and cost effectiveness for long runs (up to 45,000 impressions per hour and up to 20 million impressions without the cylinder wearing out) (2, 3). Experience has shown that the surface smoothness of a coated board plays a significant role in the development of good printability. This applies principally to to rotogravure process, where good contact between the board surface and printing cylinder is of the utmost importance (4). It is easy to understand that as the use of rotogravure printing in the recycled paperboard industry becomes more widespread, the surface smoothness of recycled paperboard becomes increasingly important.

The purpose of this project is to determine the combination of #1 clay, calcined clay, and fine particle clay that provides the smoothest and brightest base coat. Important considerations to the project include the ability of the coating to be run at speeds greater than 1000 feet per minute and cost effectiveness.

Machine Speed

As the demand for recycled paperboard increases, recycled paperboard mills are trying to increase their production. The least costly method of doing this is to increase the speed of existing machines. This places additional demands on the coating systems of these machines, and may require a reformulation of the base coating.

Another method of increasing production is to build a new recycled paperboard machine from the ground up. Due to economies of scale, the best cost effectiveness will be provided by a large machine producing 500+ tons per day. Machines of this type will most likely deviate from the traditional format of a cylinder machine, but instead will be a multi-fourdrinier type. At present there is at least one triple fourdrinier recycled paperboard machine designed to operate at a speed of 1200 fpm in North America (5, 6). The increased operating speeds of either method place demands on the recycled paperboard coating operation that until now, have not been experienced. This study is an attempt to answer some of the questions posed by high speed coating in the recycled paperboard industry.

Base Coat Application

There is a wide variety of equipment used to coat recycled paperboard. In general, the most effective way of obtaining the required surface properties is through the use of two separate and distinct coating stations applying two separate and distinct coating formulations. This is because a relatively heavy coat weight is usually required to cover the dirty paperboard surface and obtain the desired final surface properties. The most common coater arrangement for coating recycled paperboard is a rod/blade coater followed by an air knife (2,6).

Figure 1: Air Knife Coater Operating Principle

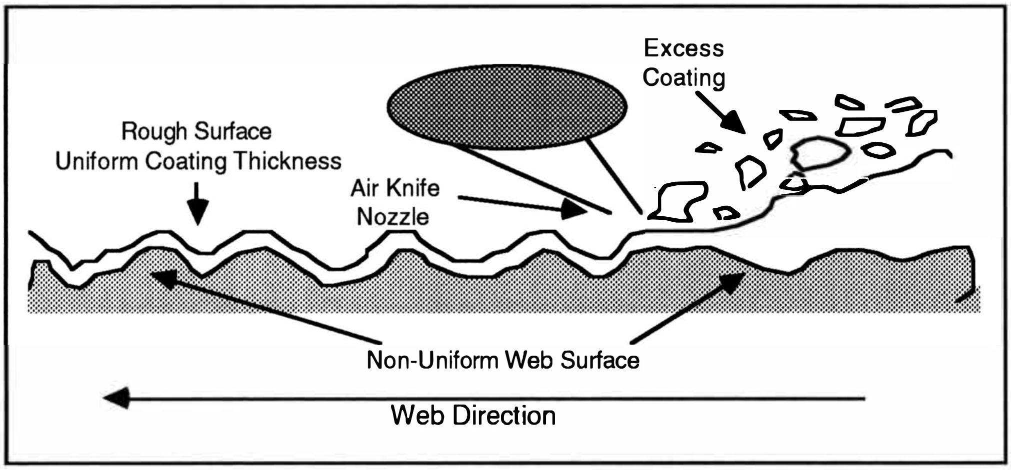


Figure 1 shows the operating principle of the air knife coater. It is commonly used to apply the top coat due to its ability to apply a uniform thickness coating. An air knife coating is the major contributor to improved paperboard surface coverage, but is not very effective at filling in the micro-valleys in the paperboard surface (leading to poor printability). Almost all coated recycled paperboard mills utilize an air knife to apply the top coat over a base coat.

Figure 2: Rod/Blade Coater Operating Principle

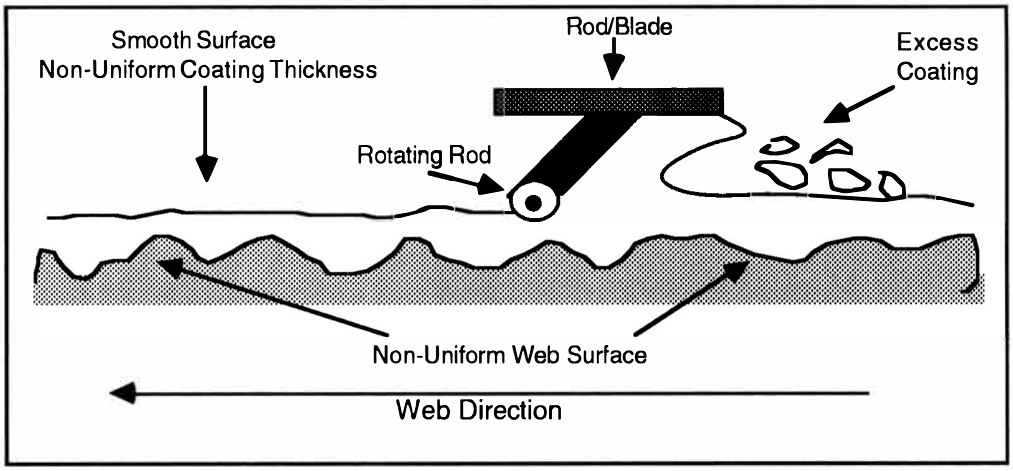


Figure 2 shows the operating principle of the rod/blade coater. It is similar to the blade coater but it includes a rotating rod usually wound with fine wire. The main advantages of the rod/blade coater are that the rod allows debris to pass under the "blade" without causing a streak and that they are suited very well for lower coating speeds of 300 - 600 fpm commonly found on recycled paperboard machines. However, when compared to a blade coater, it does not provide as good of smoothing characteristics.

Figure 3: Blade Coater Operating Principle

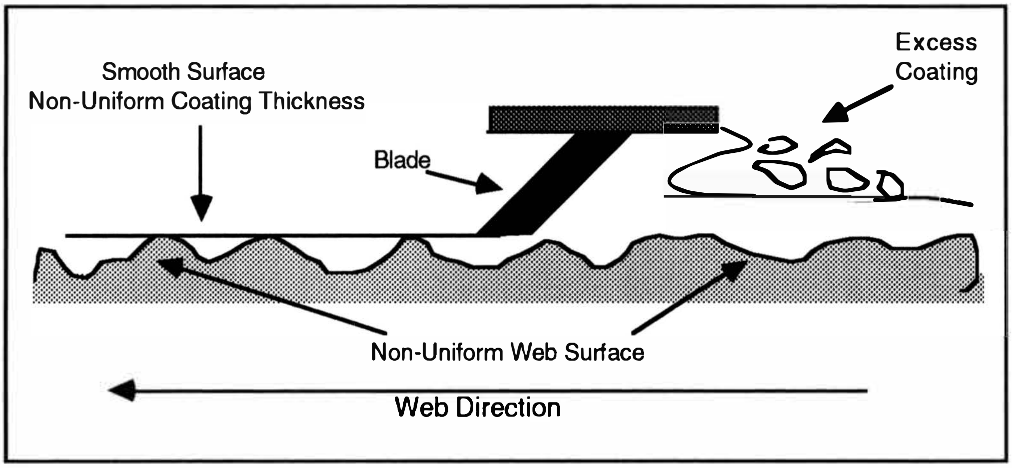


Figure 3 shows the operating principle of the blade coater. This method provides the most effective filling of the micro-valleys, and thus the smoothest surface. Although many claim that recycled paperboard is too rough to be coated with a blade coater, both blade and rod/blade have the proper speed compatibility to be installed on cylinder board machines (7).

EXPERIMENTAL PROCEDURE

Pigments

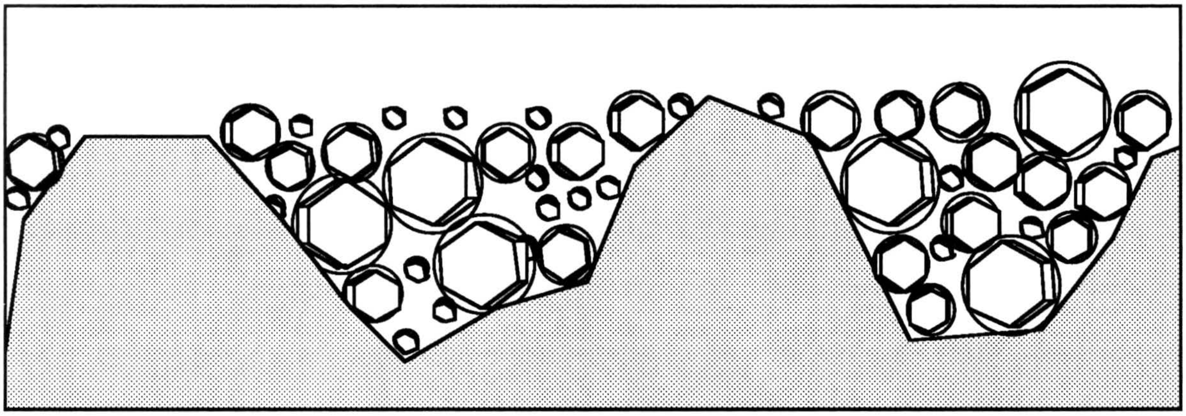
The pigments used in the experimental formulas were selected to optimize smoothness, optical properties and a premium on maintaining cost effectiveness. Clays (#1 and #2) are the most common pigment components of a base coat formula. This is primarily because of their overall performance and cost effectiveness. In the last several years many recycled paperboard mills have introduced various base coat formulas that include calcium carbonate, and more recently calcined clay (6). This project studies the ability of various pigment combinations using #1 clay, calcined clay, and fine particle clay to improve the surface smoothness and other coating properties. See Table 1 for a comparison of the pigment properties.

Table 1: Pigment Properties

Clay Type	G.E. Brightness	Particle Size (% Finer than 2 microns)	Screen Residue (% Retained, 325 Mesh)	pH
#1	87.3	92.0	0.0004	7.0
Calcined	92.7	89.4	0.0028	6.7
Fine Particle	86.5 - 88.0	95 - 99	0.0001	6.5 - 8.0

In order to understand the selection of these pigments it is important to comprehend the mechanism used to develop smoothness in paperboard. In figures 4 through 6, the different types of clay particles are represented by the hexagonal platelets. (The dotted lines surrounding the platelets indicate the effective volume of each particle.) The pores found on the surface of uncoated paperboard are on the order of 4 microns (4). The individual coating particles fill this void and cover the surface of the paperboard with a thin layer of coating. This void filling effect is illustrated for a typical #1 clay in figure 4.

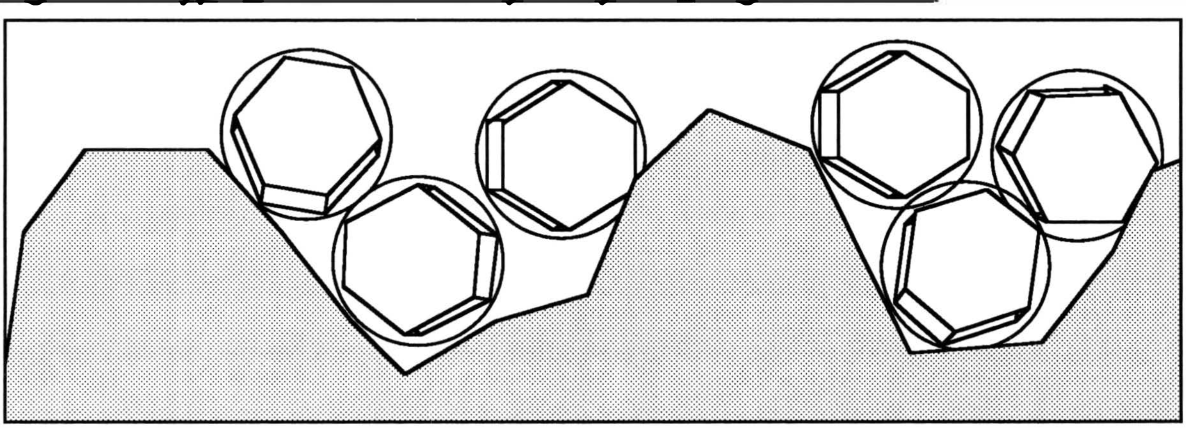
Figure 4: Typical #1 Clay Coating Structure*



* Not to Scale

By including relatively large calcined clay particles, the coating is able to fill the pores more effectively. Figure 5 illustrates the void filling effect of the large calcined clay particles by themselves. Notice that in this case, the void filling is not very effective because the particles are so large, and there are no small to medium sized.

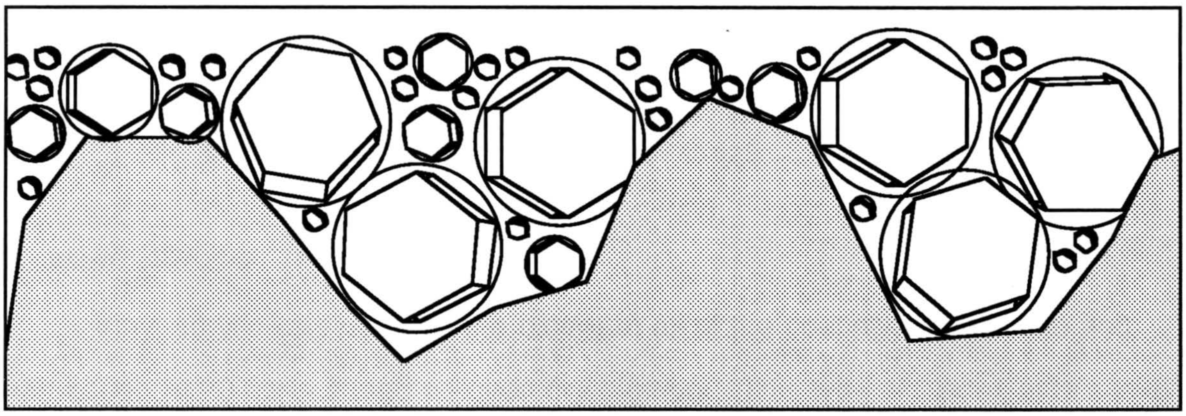
Figure 5: Typical Calcined Clay Only Coating Structure*



* Not to Scale

However in figure 6, the combined effect of the calcined clay particles with the smaller #1 and fine particle pigments can be seen. The large calcined clay particles fill in the bulk of the paperboard surface voids, while the #1 and fine particle pigments are allowed to fill in the much smaller voids between calcined clay particles and the paperboard surface. It is possible to achieve a higher smoothness in this manner, or instead to obtain a given smoothness target with a lower coat weight.

Figure 6: #1, Calcined and Fine Particle Clay Coating Structure*



* Not to Scale

In the experimental formulas, the calcined clay addition is varied from 0 to 30 parts, (the term "parts" refers to "parts per hundred") while the fine particle addition is varied from 0 to 48 parts. The remaining parts of each formula consists of #1 clay. The control formula is 100 parts #1 clay. The combinations of pigments used for the coating trials is found below in table 2. These combinations represent a four-by-four matrix varying the parts calcined clay, parts fine particle clay and parts #1 clay.

Both of the maximum pigment addition levels would most likely be impractical for use on the mill scale because of cost and rheology considerations. However, they were included in this study to observe the effects somewhat beyond what is practical with today's technology, but in the future may be worthwhile.

Table 2: Parts of Pigments in Coating Formulas

Given as: parts calcined clay / parts fine particle clay / parts #1 clay

1) 0/ 0/ 100	9) 0 / 32 / 68
2) 10 / 0 / 100	10) 10 / 32 / 58
3) 20 / 0 / 100	11) 20 / 32 / 48
4) 30 / 0 / 100	12) 30 / 32 / 38
5) 0 / 16 / 84	13) 0 / 48 / 52
6) 10 / 16 / 74	14) 10 / 48 / 42
7) 20 / 16 / 64	15) 20 / 48 / 32
8) 30 / 16 / 54	16) 30 / 48 / 22

Pigment Binder

Vinyl acrylic was used as the binder in all of the coating formulations and was added at 20 parts based on oven dry pigment. This type of binder, at this level of addition is common to the recycled paperboard industry, and was selected to reduce variability among the coating formulas (8, 6).

Coating Make Down

To make down the coating colors, the pigments were obtained predispersed from Thiele Kaolin. This ensured that the pigments were properly dispersed. The coatings were then made down with the pigment components according to Table 2: Parts of Pigments in Coating Formulas. The vinyl acrylic binder was then added. Water was added to achieve the target solids of 60.5%. For technical information sheets on the pigments and binder see Appendix 1.

In order to keep the focus of this project on studying how different pigments can be utilized to improve coating properties and to reduce coating color variability, the number of coating additives was kept to a minimum. This was done by not including coating additives such as a cobinder, viscosity modifier, insolubilizer, or lubricant, which in a mill operation are necessary, but do not significantly alter the pigments' performance on the laboratory coater.

Coating Application

Research has shown that coating with blade coaters improves the surface smoothness of recycled paperboard when compared to the classical method of rod/blade coating (9). Another reason blade coaters are becoming a popular alternative for base coat application in recycled paperboard production is its high flexibility with regard to obtainable coat weights and possible operating speeds (10).

The paperboard stock used was uncoated 0.021" paperboard produced on James River's K-1 triple fourdrinier recycled paperboard machine in Kalamazoo, Michigan. This James River grade is commonly produced at about 900 fpm. The coating was applied at 1200 fpm using the Cylindrical Lab Coater (CLC) equipped with a blade coater head. It was selected because it is a reliable, repeatable and flexible high speed laboratory blade coater that dramatically improves the ability to predict coating performance prior to pilot or production trials (11). The target coat weight was 2.0 lbs. per 1000 square feet (lb/MSF).

Coated Board Testing

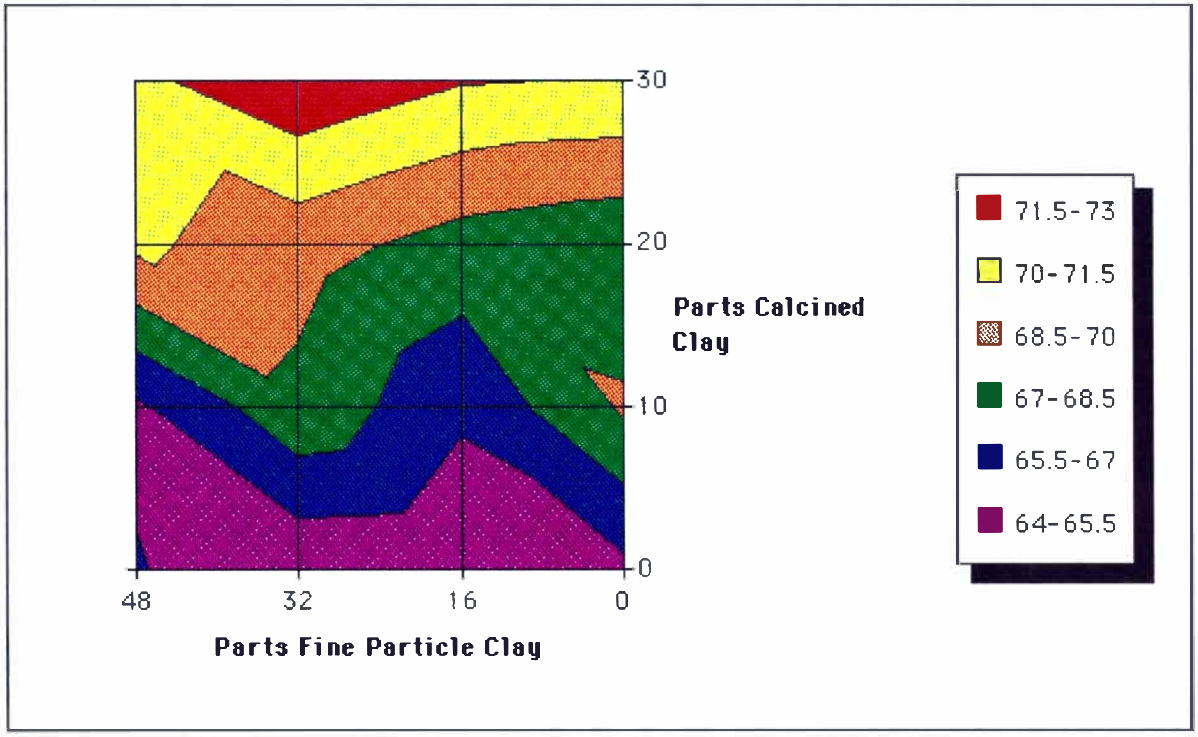
The coat weight of each test run was determined by cutting out a coated and uncoated 5 inch circle using a template and calculating the weight of the coating for a known unit area. Care was taken to ensure that the coated and uncoated samples were representative of the actual test area being examined. The three samples from each coating color closest to the 2.0 lb/MSF coat weight target were set aside for testing.

The physical testing of the coated samples consisted of TAPPI brightness and Parker Print Surf (PPS) because of their relatively wide acceptance throughout the industry as accepted measurement techniques. Also PPS was chosen to measure the surface smoothness because it has a high resolution at the smooth end of the scale (4). Both were measured 3 times for each of the sample circles for a total of nine values per coating color. The average and standard deviations for all testing can be found in Appendix 2.

RESULTS PRESENTATION

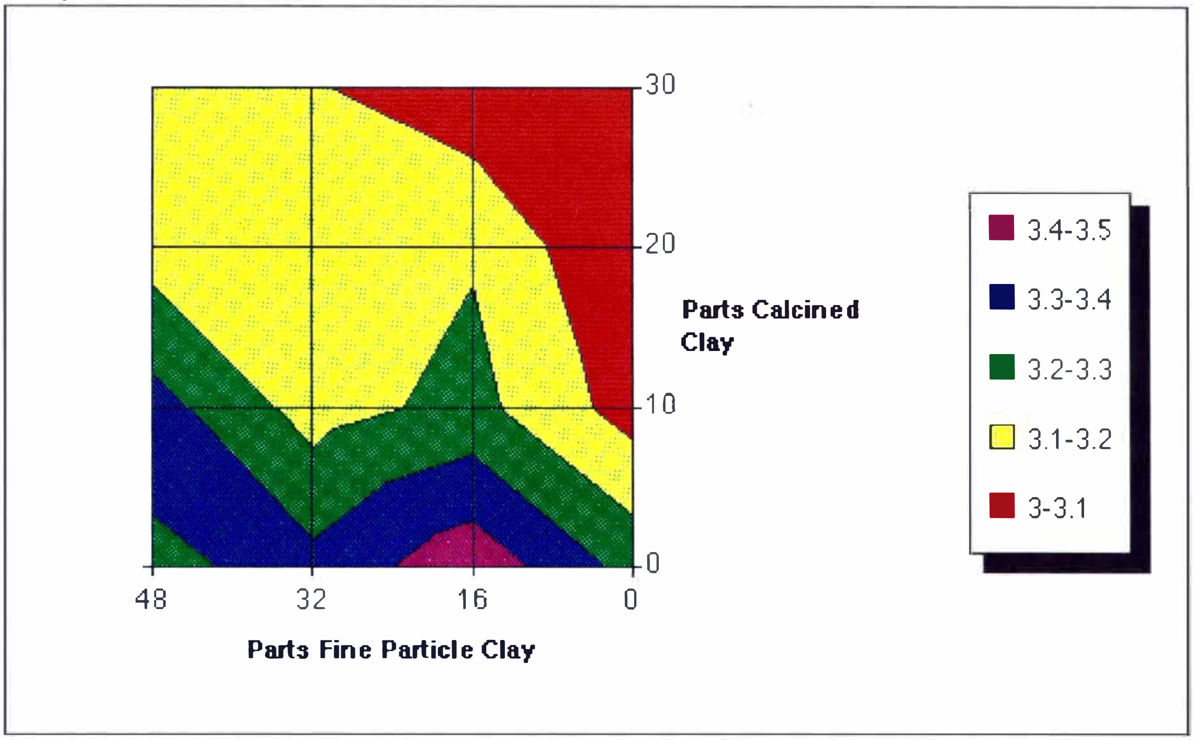
The data collected from the samples used to construct these graphs can be found in Appendix 2. In general when viewing the following graphs, the progression of undesirable values to desirable values follows the color progression of purple, blue, green, orange, yellow, red. This was done to simplify the reading of the graph and to compensate for the fact that the scales for the two test results are inverse (i.e. increasing brightness values are desirable and decreasing PPS values are desirable). Graph 1 below shows the TAPPI Brightness results for the 16 different coating formulations.

Graph 1: TAPPI Brightness Results



Graph 2 below shows the Parker Print Surf results for the 16 different coating formulations. Please note that the on PPS scale, increasing smoothness is indicated by a decreasing PPS value.

Graph 2: Parker Print Surf Results



DISCUSSION OF RESULTS

In graph 1 the TAPPI Brightness results are presented. The color gradients show that as the percent calcined clay increases, the brightness increases. The brightness does vary somewhat inconsistently with the parts fine particle clay. There appears to be a significant increase in brightness at the 32 parts fine particle clay for each of the calcined clay addition levels. Although from this graph it would appear that the best coating for base coat brightness would be one containing 30 parts calcined clay, it is important to keep in mind other variables that would affect its choice as the most desirable. As previously stated, this level of calcined clay would be impractical on the mill scale for cost and rheological reasons. *Therefore, the recommended coatings for brightness improvement of high-speed recycled* *paperboard base coat are the 20/32 and the 10/32 (calcined clay / fine particle clay) in that order.*

In graph 2 the PPS results are presented. The color gradients show that as the percent calcined clay increases, the smoothness increases. The smoothness does show a gradual decrease as the parts fine particle clay increase. However, there appears to be a significant increase in smoothness at the 32 parts fine particle clay for each of the calcined clay addition levels. Although from this graph it would appear that the best coating for base coat smoothness would be one containing 30 parts calcined clay, it is important to keep in mind other variables that would affect its choice as the most desirable. *Therefore, the recommended coatings for smoothness improvement of high-speed recycled paperboard base coat are the 20/32 and the 10/32 (calcined clay / fine particle clay) in that order.*

CONCLUSIONS AND RECOMMENDATIONS

From the data, it can be concluded the most desirable base coat formulations are the 20/32 and the 10/32 (calcined clay / fine particle clay) in that order. Although this study answers several questions about high-speed recycled paperboard base coating, it poses many more. Some of the opportunities to extend this project include:

1) Performing pilot coater trials with the 20/32 and the 10/32 (calcined clay / fine particle clay) formulations to determine their runnability and coater compatibility.

2) Performing further lab experiments replacing calcined clay with delaminated clay to determine its effect on the coating.

3) Further laboratory studies to determine the effects of each coating at variable coat weights.

ACKNOWLEDGEMENTS

I would like to thank Richard Reames, Matt Stoops and Dr. Ellsworth Shriver of Western Michigan University, Larry Mohler of Thiele Kaolin, James Watson of Rohm and Haas, and Merri Beebe of the James River Corporation for their contributions of time, effort, technical expertise, materials, and moral support. Their help with this project were significant ingredients for its success.

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Appendix 1
Pigment and Binder Technical Information Sheets

Thiele Kaolin Company
P.O. Box 1056
Sandersville, GA 31082-1056
~~912-552-3951~~
Fax 912-552-4105

SAMPLE TEST RESULTS

Thiele

January 31, 1993

TO: Western Michigan University
Department of Science & Engineering
McKrakin Hall
Kalamazoo, MI 49008

Attn: Mr. Lance Mikus

As requested by Larry Mohler we are forwarding the materials listed below at N/C Clay - Frt. Prepaid and look forward to your comments when your evaluation is completed. Please contact us if you need more information or samples. We appreciate your interest in our clays.

Date of Order: 1/14/94 Salesman: LM Via: UPS

GRADE	Kaogloss	Kaocal		
FORM	Slurry	Slurry		
DATE SHIPPED	1-28-94	1-28-94		
AMOUNT	90 dry lbs.	25 dry lbs.		
% BRIGHTNESS, GE	87.3	92.7		
MOISTURE	-	-		
% SOLIDS	70.4	51.1		
PARTICLE SIZE(Sedigraph) % <= 2 Microns	92.0	89.4		
pH*	7.0	6.7		
SCREEN RESIDUE % RETAINED 325 Mesh	.0004	.0028		
BROOKFIELD VISCOSITY @ - % Solids # 1 sp. @ 20 rpm	345 cp @70.4% Solids	295 cp @51.1% Solids		
HERCULES VISCOSITY** @ - % Solids	6.2 dynes 70.4% Solids	1.6 dynes 51.1% Solids		

*pH DRY CLAY AT 20% SOLIDS
SLURRY AT % SOLIDS SHIPPED
**Brookfield at 1100 rpm
cmj

Sincerely,

Billy Doolittle, Supervisor
Quality Control Lab

Enclosures: Cover Letter
MSDS
Spec Sheets

BSI REGISTERED FIRM
FM 22359

Thiele Kaolin Company
Reedy Creek Division
P.O. Box 337
Wrens. GA 30833-0337
706-547-2593
Fax 706-547-2786

Thiele

FEBRUARY 2, 1994

TO: LANCE MIKUS
WESTERN MICHIGAN UNIVERSITY
DEPT. OF SCIENCE & ENGINEERING
MCKRAKIN HALL
KALAMAZOO MI 49008
ATTN: LANCE MIKUS

As requested by LARRY MOHLER, we are forwarding the materials listed below at N/C and look forward to your comments when your evaluation is completed. Please contact us if you need more information or samples. We appreciate your interest in our clays.

Date of Order: 1-14-94 Salesman: LARRY MOHLER Via: UPS

GRADE	KAOFINE			
FORM	SLURRY			
DATE SHIPPED	2/3/94			
AMOUNT	5 GALLONS			
BRIGHTNESS, G.E., %	88.0			
% MOISTURE				
% SOLIDS	69.9			
PARTICLE SIZE % - 2 microns	97.2			
pH*	7.1			
SCREEN RESIDUE, % RETAINED 325 Mesh	.0004			
BROOKFIELD VISCOSITY, @ 69.9 % Solids	440 CPS			
HERCULES VISCOSITY, @ 69.9 % Solids	1.7 DYNES			
LOT NUMBER	2-1-25017			

*pH DRY CLAY AT 20% SOLIDS
SLURRY AT % SOLIDS SHIPPED

Very truly yours,

CC: RL, AL, LM, SALES

Quality Control Supervisor

BSI REGISTERED FIRM
FM 22359

RES 3103

vinyl acrylic
emulsion for recycled paperboard

Provides improved gluability, pick resistance, opacity and rheology properties.

Typical Properties

The following properties should not be considered specifications.

Ionic Nature	Anionic
Solids Content, %	50.0
pH (as packed)	6.0
Viscosity, cps Brookfield RVT, 20 rpm 25°C	120
Glass Transition Temperature, Tg°C (DSC method)	13
Density, 25°C	
lb/USgal	8.5
k/l	1.02

Appendix 2
Physical Test Results

Number	Parts #1 Clay	Parts Calcined Clay	Parts Fine Particle	Percent Solids	Brookfield Viscosity (cps)	Ct. Wt. (lb/MSF)	TAPPI Brightness	Parker Print Surf	Cost per Ton Pigment
1	100	0	0	60.5	92	2.01	65.1	3.27	$94
2	90	10	0	60.8	95	1.96	68.7	3.06	$126
3	80	20	0	60.5	109	1.94	67.4	3.29	$157
4	70	30	0	60.7	422	1.91	71.4	3.07	$159
5	84	0	16	60.5	95	2.05	64.1	3.47	$93
6	74	10	16	60.7	100	2.02	65.8	3.23	$124
7	64	20	16	60.6	128	1.99	67.9	3.19	$156
8	54	30	16	60.5	181	2.21	71.6	3.03	$188
9	68	0	32	60.5	102	2.06	64.3	3.33	$91
10	58	10	32	60.5	118	1.82	68.1	3.16	$123
11	48	20	32	60.8	138	2.04	69.1	3.12	$155
12	38	30	32	60.8	169	2.41	72.7	3.11	$186
13	52	0	48	60.5	132	2.12	65.6	3.28	$90
14	42	10	48	60.3	127	2.02	65.2	3.34	$122
15	32	20	48	60.5	150	2.06	70.3	3.16	$153
16	22	30	48	60.5	170	2.04	71.1	3.18	$185