Metered Size Press Pigmentation for Fiber Reduction

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ABSTRACT

Recent formulation design experiments have begun to show how pigmented sizes may be designed for fiber replacement without sacrificing paper properties. Pigment shapes and sizes influence paper mechanical properties and pigment color affects sheet brightness, opacity, whiteness and shade. This report shares results obtained using combinations of these variables investigated at laboratory and pilot scales. Average pigment shape is varied through the ratio between ground calcium carbonate and kaolin. Variations in both calcium carbonate and kaolin size and kaolin brightness are also included. Variations in optical brightener content are used to offset differences in pigment brightness. Results demonstrate that stiffness and other mechanical and optical qualities can be maintained while reducing the amount of fiber used, with significant potential economic advantages.

INTRODUCTION

Over the last several decades, many authors have studied the effects of filling and coating pigments, and coating and sizing formulation design, on paper mechanical and optical properties [1-15]. During the last few years, considerable attention has been paid to the effects of pigment shape on mechanical properties. Lyons discussed work done by Husband using nanodimensional engineering of clay coatings to increase sheet stiffness [16]. Husband, et.al. have examined the effects of pigment shape on the in-plane and out-of-plane tensile properties of freestanding pigment coating films and on the stiffness of coated papers. [17-19, 21-22]. Gagnon, et.al. studied the effect of pigmenting and binder type and level on the fiber reduction potential of pigmented size [20].

Recent trends in papermaking show that papers, both coated and uncoated, have become brighter, bluer and lighter in basis weight. This is expected to continue in the foreseeable future, as fiber costs have increased significantly and papermakers are struggling to maintain quality while reducing costs. An interesting area of development work is fiber reduction while keeping optical and surface properties the same. Typically, replacement of fiber in uncoated paper is achieved with pigments either as filler or in pigmented sizing formulations. However, when pigments are added to the paper at the expense of fiber there is almost always a penalty in terms of paper stiffness.

In uncoated freesheet applications the most common mineral used is ground calcium carbonate. This is a low aspect ratio, nearly isotropic pigment. Addition of kaolin has not usually been considered acceptable due to brightness and shade considerations. However, research done at Imerys has shown that high aspect ratio, or platy, kaolins provide significant in-plane directional modulus improvements. The current extension of this work is to evaluate minimal levels of platy kaolins in combination with ground calcium carbonate for practical applications as a freesheet surface treatment, thereby minimizing deleterious effects on final sheet brightness and color while maximizing stiffness development.

This work used a metered size press (MSP) applicator, probably the most common type used for size application in the uncoated freesheet market. It was felt that the MSP would provide greater coating holdout than either a puddle size press or any blade applicator. Greater holdout should enhance the mechanical I-beam effect of the coating on the basestock. It is understood that other types of applicators could potentially be used. MSPs are widely available throughout the industry, giving this work broad applicability.

EXPERIMENTAL PROCEDURES, RESULTS AND DISCUSSION

Laboratory Scale Optical Brightening Agent Addition Rate Experiment

A laboratory experiment was done at the Imerys Paper Technology Center in Sandersville, GA to determine optical brightening agent (OBA) addition rates for a pilot coater trial. A particular concern when kaolin is used to coat a high brightness freesheet basestock is that kaolins are typically somewhat yellow in comparison to both the basestock and the calcium carbonates used in and on these grades. Two ground calcium carbonates (GCCs) differed primarily in particle size. Two kaolins used had different brightnesses, Hunter b values and particle sizes. Both kaolins had high aspect ratios to help provide bending resistance. Physical properties of the pigments used in this laboratory experiment are provided in Table I. The pigment physical property variations were expected to influence size holdout and stiffness. In addition to the grades of kaolin and GCC, the ratio between the kaolins and GCCs was also varied. In this experiment, the binder system was held constant. The coating formulation matrix is given in Table II. Three different OBA levels were used for each sizing system.

Coatings were applied by hand drawdown using wirewound rods onto sheets of one of the basestocks intended to be used in the pilot coater trial. The coatweight applied was 5 g/m^2. Coated strips were calendered at 51.7 ºC (125 ºF) using a single steel nip between 15.2 cm (6”) rolls at 7.6 m/min. (25 ft./min.) with a lineal pressure of 30.8 kN/m (176 pli).

The only response of interest from this experiment was the brightness as a function of OBA level for each sizing formulation. It was intended that an OBA level be found for each sizing system to yield equivalent brightness for all systems during the pilot scale coating trial. This was complicated by the fact that the laboratory experiment was done with single sided coating, whereas the pilot trial would be two sided. To estimate the brightness and fluorescence of two-side coated sheets from one-side coated sheets, measurements were taken of the coated side of a sheet backed by a stack of sheets with the coated side up and with the coated side down. The difference between these was then added to the value with the coated side up to approximate the effect of two coated layers at the boundary between the first and second sheets in the stack. An asymptotic regression model of brightness as a function of OBA level was used to estimate the OBA levels given in Table III for use in the pilot coating study. These values were arrived at by inverting each regression equation for the same brightness.

Table I. Physical Properties of Pigments used in Laboratory OBA Addition Rate Experiment.

Pigment ID	GCC1	GCC2	KaolinA	KaolinB
Brightness	95	96	88	90
Hunter b	0.6	0.3	3.2	2.5
Mass % finer than 2 um ESD	91	65	86	97
Mass % finer than 0.25 um ESD	22	14	32	53
Shape	isotropic	isotropic	highly platy	highly platy

Table II. Coating Formulations and Rheologies used in Laboratory OBA Addition Rate Experiment.

Coating ID	1	2	3	4	5	6
Starch	100	100	100	100	100	100
GCC1		100		70	50	70
GCC2			100			
KaolinA				30	50	
KaolinB						30
Temperature (ºC)	37.8	37.8	37.8	37.8	37.8	37.8
% Solids	14	20.4	20.2	20	20	20.4
Brookfield Viscosity, #3 spindle, 100 rpm (cPs)	226	229	126	289	359	312
Hercules Apparent Viscosity, 4400 rpm (cPs)	29.6	21.6	23.9	36.6	36.2	32.8

Table III. OBA Levels Chosen for Pilot Coating.

Coating ID	1	2	3	4	5	6
OBA parts	10	3.7	5.5	4.5	6.5	4.5

Pilot Coating Trial

Pilot coating work was performed at Western Michigan University's Pilot Plant. Two uncoated stocks were used, 50# and 60# freesheet offset produced on the same paper machine using only water at the size press. Multiple basis weight stocks were used in an attempt to provide data to allow computation of response surfaces with one dimension being the basis weight.

Coating formulations used in the pilot trial were the same as those used in the laboratory scale OBA level determination, with the addition of 1.5 parts insolubilizer in the pigmented sizes. Coating properties, including coating solids, temperature and viscosity, are shown in Table IV. Coatings were applied using a rod metered size press. A variety of 2"grooved rods were used at different rod pressures to achieve size pickup ramps with each sizing formulation on each basestock. Coatweights, or pickup levels, were targeted at 100, 130 and 160 #/ton, or 4.1, 5.3 and 6.5 g/m^2 for the 50# stock and 4.9, 6.3 and 7.8 g/m^2 for the 60# stock. Almost all coatings were applied at 308 m/min. (1000 ft./min.). Only the clear size at the highest pickup on the heavier base had to be run at a lower speed, 275 m/min (900 ft./min), due to drying constraints. Calendering was done online through a steel-to-steel nip with a lineal pressure of 52.5 kN/m (300 pli). Coater conditions, including metering rod types, tube pressures, calendering temperatures and results including moisture, size pickup and finished basis weight, are shown in Table V. Gas fired infra-red and air flotation dryers were used to achieve the reported moisture levels. The IR dryers had four burners, two on each side of the sheet, arranged in two banks.

Table IV. Pilot Coating Color Properties.

Coating	Solids (%)	Temperature (ºC)	pH	Brookfield Viscometer			Hercules Viscometer Apparent Viscosity @ 4400 rpm (cPs)
				Spindle	rpm	Viscosity (cPs)	
Clear Size	19.1	65.6	7.2	1	20	85	*
GCC1	20.4	41.7	7.5	2	20	204	29.5
					100	176	
GCC2	20.3	42.2	7.6	2	20	150	27.1
					100	156	
30 GCC1 70 KaolinA	20.1	37.2	7.7	2	20	522	27.1
					100	257	
50 GCC1 50 KaolinA	20.4	35.6	7.7	2	20	654	29.1
					100	309	
30 GCC1 70 KaolinB	20	35.6	7.7	2	20	658	31
					100	324	

A large number of response variables were measured on the coated paper samples. Unfortunately, it is physically impossible to fit the measurement results even into an Appendix for interested readers. Response surface regression analyses were conducted for all of the response variables using StatSoft Statistica. A "Best Subsets" regression mode was used in which regression terms are chosen so as to maximize the adjusted R^2 value. The adjusted R^2 is adjusted to take into account the number of degrees of freedom used by the regression model. Using this statistic to optimize the regression helps to minimize the number of terms included in the model. Six independent variables used in the regressions included the finished basis weight, size pickup and formulation levels of the four different pigments used. Each independent variable was considered in linear and square powers and in cross terms with every other variable. All possible combinations of all of these linear, square and cross terms were tried for each response variable, for a total 145,497 possible models for each dependent variable. All of the regressions were statistically significant at a 1% significance level.

Table V. Pilot Coater Conditions.

Coating	IPI 1/2" Grooved Rod Type	Tube Pressure top / bottom (k pascals)	Calender Temperature (ºC)	Moisture (%)	Size Pickup (#/ton)	Size Pickup (g/m^2)	Finished Basis Weight (#/3000 sq.ft.)	Finished Basis Weight (g/m^2)
Clear Size	Lox003	138 / 138	33.3	3.6	84.5	3.2	47.2	76.9
	004	179 / 172	33.3	4	111.5	4.3	47.9	78.0
	005	138 / 145	33.3	3.4	134.5	5.3	48.4	78.9
	004	152 / 152	31.7	4.8	85.9	4.1	58.8	95.7
	005	345 / 345	33.3	4.9	132.0	6.4	59.6	97.0
	005	172 / 152	*	5.6	144.9	7.1	60.1	97.8
GCC1	33	200 / 207	33.3	3	101.8	3.6	43.2	70.4
	Lox003	352 / 345	33.3	4.5	139.9	5.0	44.2	72.0
	Lox003	138 / 145	33.3	4.4	152.5	5.5	44.6	72.5
	Lox003	138 / 159	33.3	3.1	82.9	4.0	58.7	95.6
	004	186 / 193	33.3	5.7	130.9	6.3	59.5	96.9
	005	159 / 152	33.3	4.9	151.3	7.4	60.3	98.2
GCC2	33	214 / 221	33.3	3.2	95.9	3.5	44.4	72.3
	Lox003	338 / 345	33.3	4	136.4	5.0	44.7	72.8
	Lox003	138 / 138	33.3	5.4	164.8	6.0	45.0	73.2
	Lox003	138 / 138	33.3	3.7	87.1	4.1	58.3	94.9
	004	159 / 159	33.3	4.4	119.7	5.8	59.2	96.4
	005	145 / 145	33.3	5.4	146.3	7.1	59.9	97.6
30 GCC1 70 KaolinA	33	179 / 179	35	4.5	95.9	3.7	47.1	76.7
	Lox003	345 / 345	34.4	3.9	110.7	4.3	47.8	77.9
	Lox003	131 / 145	34.4	5.7	145.8	5.7	48.2	78.5
	Lox003	131 / 138	35.6	4	88.4	4.2	58.1	94.6
	004	165 / 186	35	4.5	123.2	6.0	59.4	96.7
	005	138 / 138	35	5.6	156.3	7.6	60.1	97.8
50 GCC1 50 KaolinA	33	172 / 179	36.1	2.4	82.2	3.2	47.8	77.8
	Lox003	352 / 338	36.1	3.2	118.0	4.5	47.1	76.7
	Lox003	131 / 138	36.1	4.8	144.9	5.7	48.6	79.0
	Lox003	131 / 138	35.6	4.2	97.7	4.7	58.8	95.7
	004	165 / 152	35.6	3.8	119.5	5.8	59.5	96.8
	005	124 / 138	35.6	4.2	143.0	7.0	60.4	98.4
30 GCC1 70 KaolinB	33	179 / 186	36.7	3.6	88.0	3.4	47.3	77.0
	Lox003	345 / 352	36.7	3.1	110.9	4.3	48.0	78.2
	Lox003	138 / 138	36.7	4.8	139.0	5.5	48.8	79.4
	Lox003	207 / 207	37.2	4.6	99.7	4.8	59.4	96.6
	004	207 / 234	37.2	4.1	128.8	6.3	60.1	97.9
	005	131 / 145	37.2	4.6	155.3	7.7	60.7	98.8

Figure 1 shows an example of a desirability response surface, bending resistance as a function of size pickup and GCC1 level. This particular response is not monotonic in either independent variable, with an optimum value for both variables. It is interesting to note that the optimum GCC1 level corresponds to sizing formulations that included kaolin.

Figure 2 gives an entire set of desirability response surfaces for whiteness as a function of finished basis weight, size pickup, and sizing pigmentation type and level. It is particularly interesting to note the undesirable response to GCC1 and the desirable responses to KaolinA and KaolinB. It must be acknowledged that these responses are also dependent upon the varying OBA levels used for the different sizing pigmentation systems. What these responses indicate is that the OBA levels of Table III were not high enough for GCC1 (Coating ID 3) and higher than they needed to be for KaolinA (Coating IDs 4 and 5) and Kaolin B (Coating ID 6).

Figure 1. Response of Bending Resistance to Size Pickup and GCC1 Level.

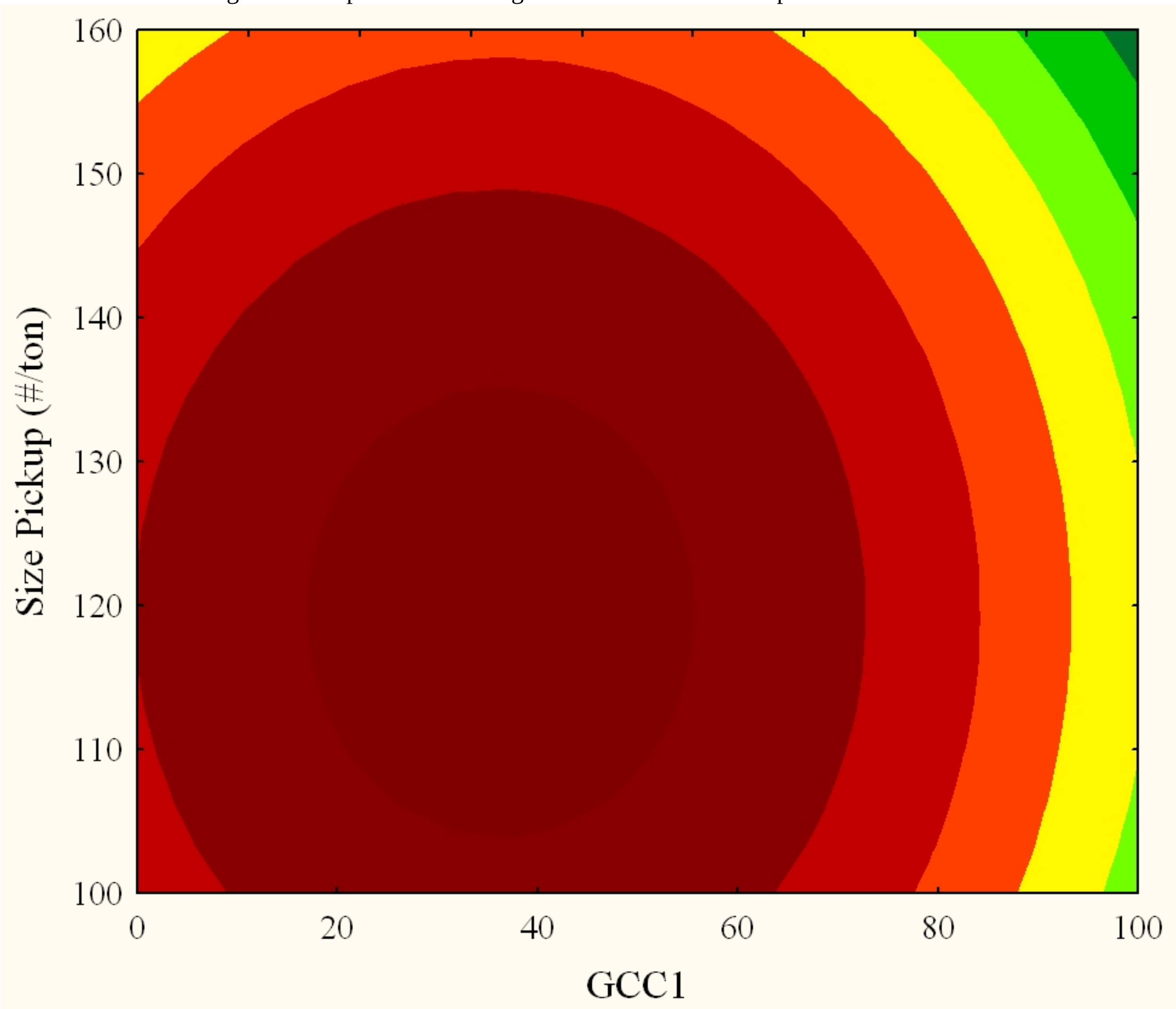
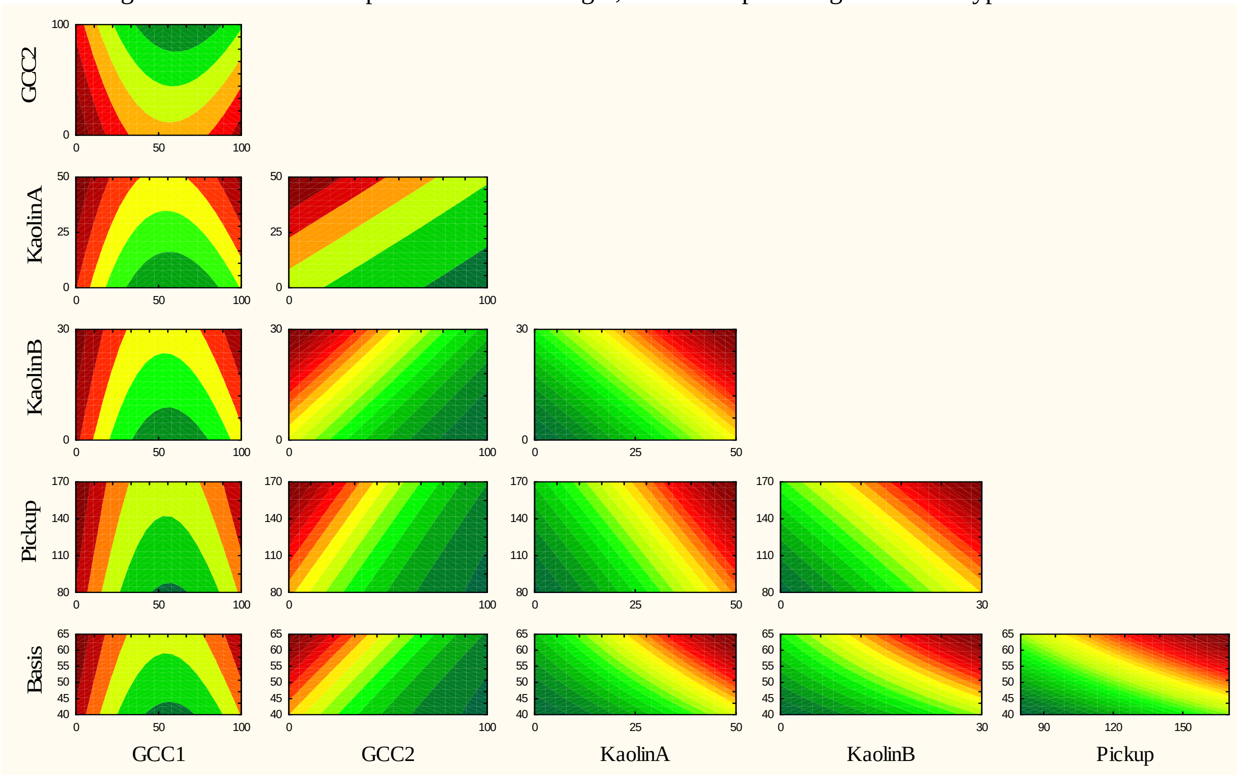


Table VI presents an attempt to summarize results of the regressions. The first column in this table lists some of the properties that were measured. The second column lists the adjusted R^2 for the regression model, which describes the amount of variation in the response that is accounted for by the model, adjusted for the degrees of freedom used by the model. Note that the vast majority of the variation in each property is accounted for by the models, except for Sheffield smoothness. Less than half of the variation in smoothness is accounted for. The third column in the table, with the title "D o G," gives the "Direction of Goodness" assumed for the response variables. For example, for Hunter b, reductions in value have been treated as desirable. In this table, a "+" signifies that the independent variable had a desirable influence on the response variable, whereas a "-" indicates an undesirable influence. An "=" indicates little or no influence. A "+/-" indicates that the independent variable gave mixed responses, perhaps similar to the response shown in Figure 1.

If the qualitative response descriptors of Table VI are given numerical values, the general influence of each variable on sheet quality may be assessed. For this purpose, a +1 could be assigned to desirable influences and a -1 to undesirable influences, with zeros assigned to otherwise. The last three rows of Table VI present results of summing these desirable and undesirable influences. Basis weight and pickup are both strongly positive, GCC1 is exactly neutral, GCC2 negative and both kaolins are, on average, positive influences on overall sheet quality.

Figure 2. Whiteness Responses to Basis Weight, Size Pickup and Pigmentation Types and Levels.



There will always be some covariation between different sheet properties. For example, it is common for brightness and opacity to be inversely related through optical absorption and directly related through optical scatter. Other examples particularly relevant to this current work are the relationships between caliper, bulk, stiffness, basis weight and size pickup. For a homogeneous sheet, the stiffness should vary as the cube of the caliper, and caliper should vary directly with basis weight. However, in this work the finished sheets are not homogeneous, but have significant surface layers on both sides of the sheets that are composed of the sizing system.

It is hypothesized that the depth of penetration of the sizing layer into the underlying fiber and filler from the wet end of the paper machine may depend on the material used in the sizing formulation. It is generally accepted that the maximum dimension of objects dispersed in a fluid medium defines how those objects will penetrate into a porous filtering medium. Clear starch size has very small solubilized particles, and even individual dissolved molecules, and will thus penetrate into a paper sheet more easily than a pigmented size. Among the four pigments employed, KaolinA has the largest maximum dimension, followed by GCC2, KaolinB and GCC1 with the smallest maximum dimension. It should be expected that these dimensions will relate directly to how well the size solution is localized at the paper surface.

The z-directional distributions of the sizing solutions will vary with the composition of the sizing and the amount of sizing picked up. This variation should be expected to affect the stiffness of the paper sheets. Stiffer sizing compositions that are held out better at the surface of the paper should provide greater contributions to sheet stiffness through the mechanical I-beam effect. Thus, it should be expected that kaolin-containing sizing solutions, which are stiffer, and particularly KaolinA which will be held out best, should provide superior sheet stiffness.

Sizing solutions, particularly pigmented solutions, have greater density than porous paper fiber mats. Increasing size pickup while maintaining basis weight, i.e., reducing wet-end basis weight, will increase the density of the sheet, reducing bulk and caliper. For more flexible sizing solutions, the reduction in caliper may offset the increased strength of the top and bottom of the mechanical I-beam, resulting in a reduction in stiffness as size pickup is increased. On the other hand, for stiffer sizing solutions, the increase in I-beam flange strength may overcome the loss in bending strength due to loss of caliper, resulting in increasing stiffness with increasing size pickup.

Table VI. Summary of Response Surface Regression Results.

Measurement	Adjusted R^2	D o G	Basis	Pickup	GCC1	GCC2	KaolinA	KaolinB
Brightness	0.82	+	-	+	+/-	=	+	+
Opacity	0.99	+	+	-	+	+	+	+
Caliper	0.97	+	+	-	+	=	=	-
Formation	0.89	+	+/-	-	+	+	=	=
Bending Resistance	0.98	+	+	+/-	+/-	-	=	=
Sheffield	0.44	-	+/-	+	+	+	+	=
Pick	0.97	+	+/-	+	-	-	-	=
Whiteness	0.98	+	+	+	+/-	-	+	+
Low Pressure Gurley	0.87	+	+	+	=	+	+	+
Hercules Sizing	0.89	+	+	+	=	+	+	=
Hunter b	0.98	-	+	+	-	-	=	=
Tensile Peak Load	0.98	+	+	+	-	-	-	-
Tensile Energy Absorption	0.95	+	+	+	+/-	-	=	=
Tensile Elongation	0.91	+	+	+	+/-	-	=	=
Scott Bond	0.90	+	=	+	+/-	-	-	=
Burst	0.96	+	+	+	-	-	-	-
Tear	0.98	+	+	-	+/-	+	=	=
+'s			+12	+12	+4	+6	+6	+4
-'s			-1	-4	-4	-9	-4	-3
overall			+11	+8	0	-3	+2	+1

Economic Implications

The uncoated freesheet market is generally considered to be a commodity market. It is not likely that some remarkably improved quality attribute is going to help a producer garner greater market share or higher product pricing. Consumers in this market are primarily interested in consistency of performance rather than some outstanding quality. Thus, the economic goal of producers is typically to minimize costs while maintaining essential product qualities.

The experiments described here illustrate a route to cost savings by substituting pigmented size for wood fiber. The calcium carbonate and kaolin pigments combined with the starch binder might be expected to cost about half as much as wood fiber on a mass basis. Every pound per ton of pigmented size that can be substituted for fiber represents a cost savings roughly equivalent to half a pound of fiber per ton of paper.

Figures 3 and 4 illustrate bending resistance for each formulation at 100, 130 and 160 #/ton size pickup levels at 50 and 60 #/ream basis weights. Data in these graphs are calculated from regression equations at equal pickup and basis weight points for each formulation. These figures show several interesting trends. Perhaps the most economically important trend shown is that when kaolin is included in the sizing formulation, bending resistance increases with increasing size pickup. For starch only, or starch with GCC only, bending resistance decreases with increasing size pickup. The implication of this is that increasing size pickup with kaolin included can actually enhance this sheet quality at the same time that it is enhancing production economics. Another interesting trend relates to the affect of pigment type and usage at any particular pickup level or basis weight. If GCC alone is added to a sizing solution, bending resistant drops in almost all cases. If kaolin is included along with the GCC, bending resistance is maintained or improved in almost all cases. There also appear to be some differences in how the pigments influence bending resistance at the different basis weights. At the lighter basis weight, the finer kaolin is superior and there is little difference between the GCCs. At the heavier basis weight, the high level of the coarser kaolin is best and the finer GCC is less bad than the coarser GCC.

A more concrete connection to the economic bottom line might be achieved through a numerical demonstration. The example that will be used here is a hard constraint on bending resistance, which may be related to runnability in office copiers and printers, for example. Four different “control” cases will be considered, 50 and 60 #/ream basis weight sheets made with 100 #/ton of size consisting of either 100% starch or 50 starch : 50 ultrafine GCC, the

GCC1 used here. Table VII provides details of the basis weights and size pickups with kaolin needed to match the bending resistance of the control cases. The potential basestock basis weight reduction percentage is also shown for each case. The basestock basis weight reduction potentials shown are substantial, particularly in comparison to GCC-only pigmentation.

Of course, the results displayed in Table VII have been arrived at through a constraint on bending resistance only. A frequently cited psychological constraint on kaolin use in a high brightness, high whiteness grade such as this is the color of the pigment itself, which is generally assumed to undesirably impact the color of the sheet. However, this prejudice is undeserved, as evidenced by the information presented in Tables III and VI. From Table III, the kaolin-containing sizes require far less OBA than a starch-only size to achieve a particular brightness, and have a similar requirement to one of the GCC-only sizes. In Table VII, the kaolins are significantly more favorable for brightness and whiteness than the GCCs. The potential reasons for this is include increased optical scatter as well as improved sizing holdout.

Figure 2. Bending Resistance at 50# Basis Weight.

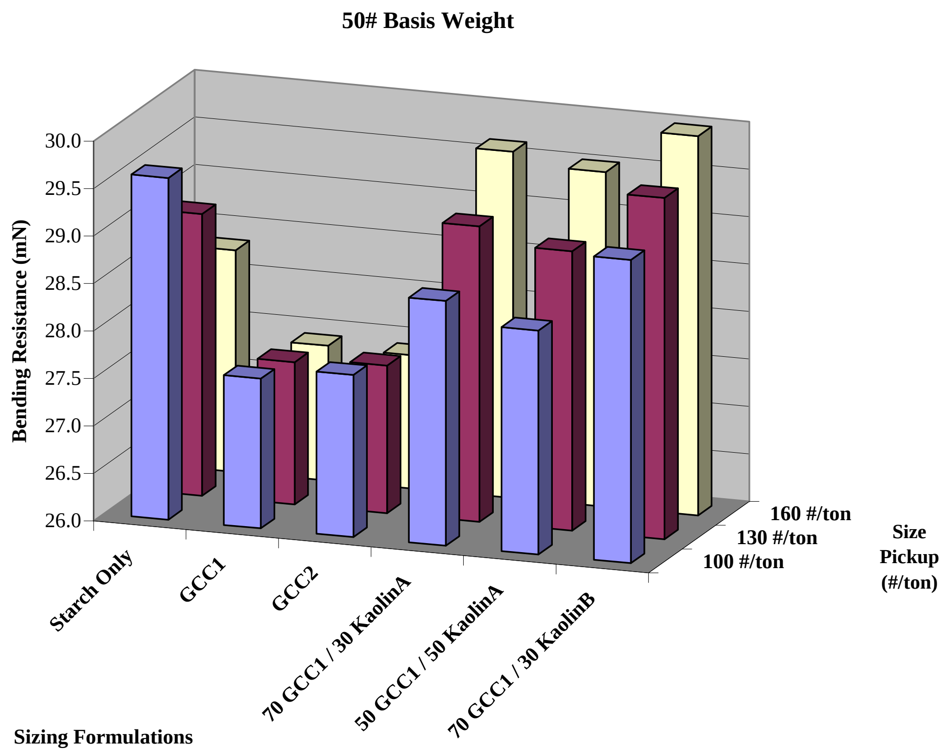


Figure 3. Bending Resistance at 60# Basis Weight.

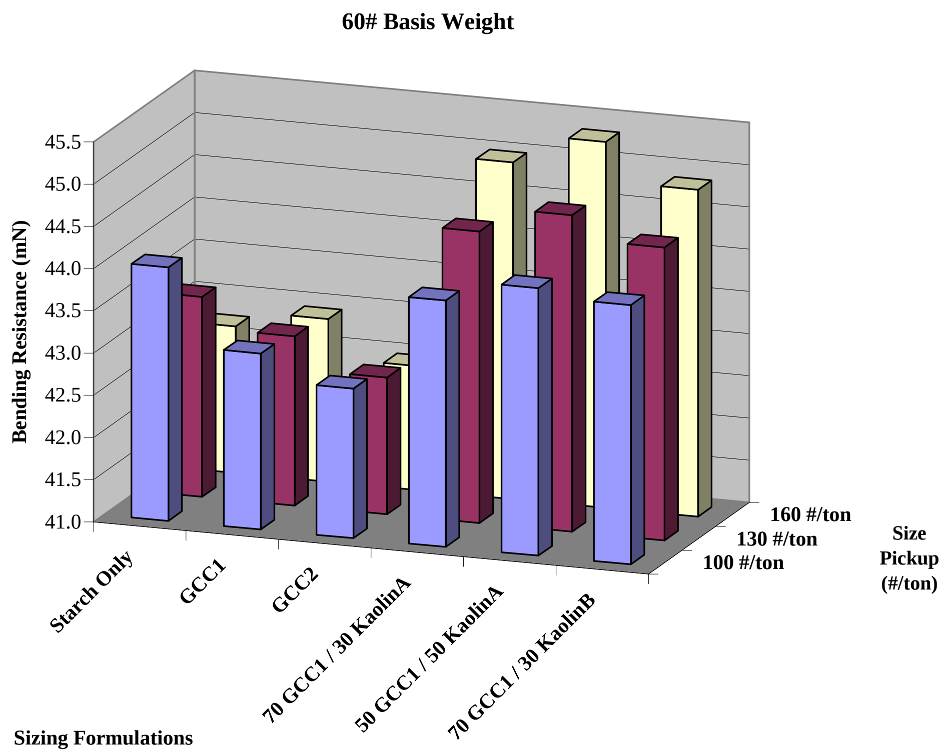


Table VII. Bending Resistance-Based Fiber Reduction Potentials Using Kaolin in Pigmented Sizing.

Control Cases 100 # size / ton paper	70 GCC1: 30 KaolinA			50 GCC1: 50 KaolinA			70 GCC1: 30 KaolinB		
	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction
Clear Size 50# basis	157	50	**3.0**	164	50	**3.4**	160	49.7	**3.7**
Clear Size 60# basis	160	59.4	**4.1**	160	59.2	**4.4**	160	59.4	**4.1**
1 Starch: 1 GCC1 50# basis	160	48.7	**5.7**	160	48.8	**5.5**	160	48.4	**6.3**
1 Starch: 1 GCC1 60# basis	160	58.8	**5.1**	160	58.6	**5.4**	160	58.6	**5.4**

CONCLUSION

The laboratory and pilot scale work reported here has demonstrated the potential for significant cost reductions in the production of uncoated freesheet grades through optimization of the pigmentation of the sizing system. On the basis of bending resistance, or stiffness, it may be possible to achieve over 5% reduction in the wet end basis weight through a change in the pigmentation system used in sizing. In particular, the highest potential levels of savings are achievable when switching from a GCC-only pigmented size to a system that includes substantial amounts of platy kaolin. Not only do the platy kaolins enhance the stiffness of the sheet, even with reduction in finished basis weight, but they also provide better brightness and whiteness than one of the GCCs used, and require much less OBA than a pure starch size.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the skillful contributions of the Western Michigan University Coating Pilot Plant crew and the Imerys Sandersville Technology Center Paper Testing Team. The Imerys Sandersville Paper Technology Team scientific staff also provided many valuable inputs from experimental design through data interpretation.

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APPENDIX

Materials Identification

GCC1 – Imerys Carbital FG
GCC2 – Imerys Carbital 60
KaolinA – Imerys Astra-Plate
KaolinB – Imerys Contour Xtreme
Starch – Penford Gum 270
Optical Brightening Agent - Tinopal ABP-A
Insolubilizer – Berset 2125

Access to Knowledge, Access to Networks.

Metered Size Press Pigmentation for Fiber Reduction

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Motivation for Research

- De-Materialization!
  - Recent research has shown that anisotropic kaolin particles provide anisotropic strength properties in paper coatings
    - Greater in-plane strength, but lower out-of-plane strength
  - Uncoated freesheet paper typically used in xerographic copying requires stiffness for runnability, but exerts little Z-direction debonding force on the paper surface
  - Producers frequently use size press applicators to apply sizing, frequently with ground calcium carbonate (GCC) pigmentation
  - Replacing as little as 30% of the GCC with kaolin, or 50% of the starch with GCC and kaolin, may allow large increases in sizing application, saving wet end basis weight and possibly even finished basis weight

But Kaolin is Too Yellow!

- **Not True!**
  - Current research included variations in ratio between 100% GCC and 50 GCC:50 Kaolin
  - Optical Brightening Agent (OBA) levels were varied in lab-scale work to find addition rates to give equivalent brightness
  - Much less OBA was required for any pigmented size in comparison to starch-only
  - Less OBA was required for some kaolin-containing formulas than one 100% GCC formula
  - With adjusted levels used at pilot scale, kaolin had stronger desirability for brightness, whiteness and b-value than either GCC!
  - Results most likely due to enhanced optical scatter and coating holdout

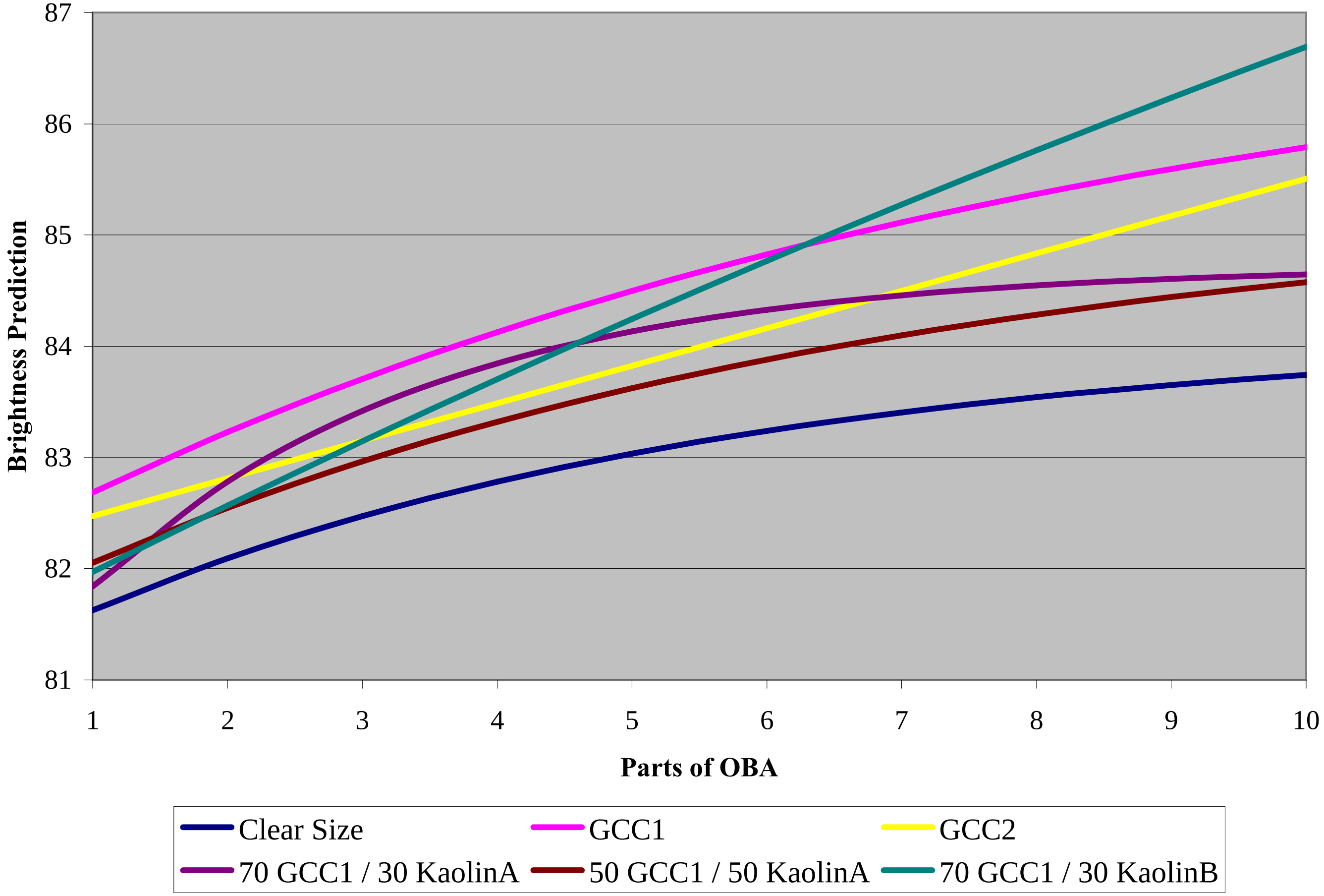
Pigment Properties

Pigment ID	GCC1	GCC2	KaolinA	KaolinB
Brightness	95	96	88	90
Hunter b	0.6	0.3	3.2	2.5
Mass % finer than 2 um ESD	91	65	86	97
Mass % finer than 0.25 um ESD	22	14	32	53
Shape	isotropic	isotropic	highly platy	highly platy

Sizing Formulations

Coating ID	1	2	3	4	5	6
Starch	100	100	100	100	100	100
GCC1		100		70	50	70
GCC2			100			
KaolinA				30	50	
KaolinB						30
Temperature (ºC)	37.8	37.8	37.8	37.8	37.8	37.8
% Solids	14	20.4	20.2	20	20	20.4
Brookfield Viscosity #3 spindle, 100 rpm (cPs)	226	229	126	289	359	312
Hercules Apparent Viscosity 4400 rpm (cPs)	29.6	21.6	23.9	36.6	36.2	32.8

Laboratory Drawdown Brightness vs. OBA Levels



C2S brightness estimated from C1S lab drawdowns

This lab data was used to set OBA levels for pilot coater trial

Pilot Coating Color Properties

Coating	Solids (%)	Temperature (ºC)	pH	Brookfield Viscometer			Hercules Viscometer Apparent Viscosity @ 4400 rpm (cPs)
				Spindle	rpm	Viscosity (cPs)	
Clear Size	19.1	65.6	7.2	1	20	85	*
GCC1	20.4	41.7	7.5	2	20	204	29.5
					100	176	
GCC2	20.3	42.2	7.6	2	20	150	27.1
					100	156	
30 GCC1 70 KaolinA	20.1	37.2	7.7	2	20	522	27.1
					100	257	
50 GCC1 50 KaolinA	20.4	35.6	7.7	2	20	654	29.1
					100	309	
30 GCC1 70 KaolinB	20	35.6	7.7	2	20	658	31
					100	324	

Pilot Coater Conditions

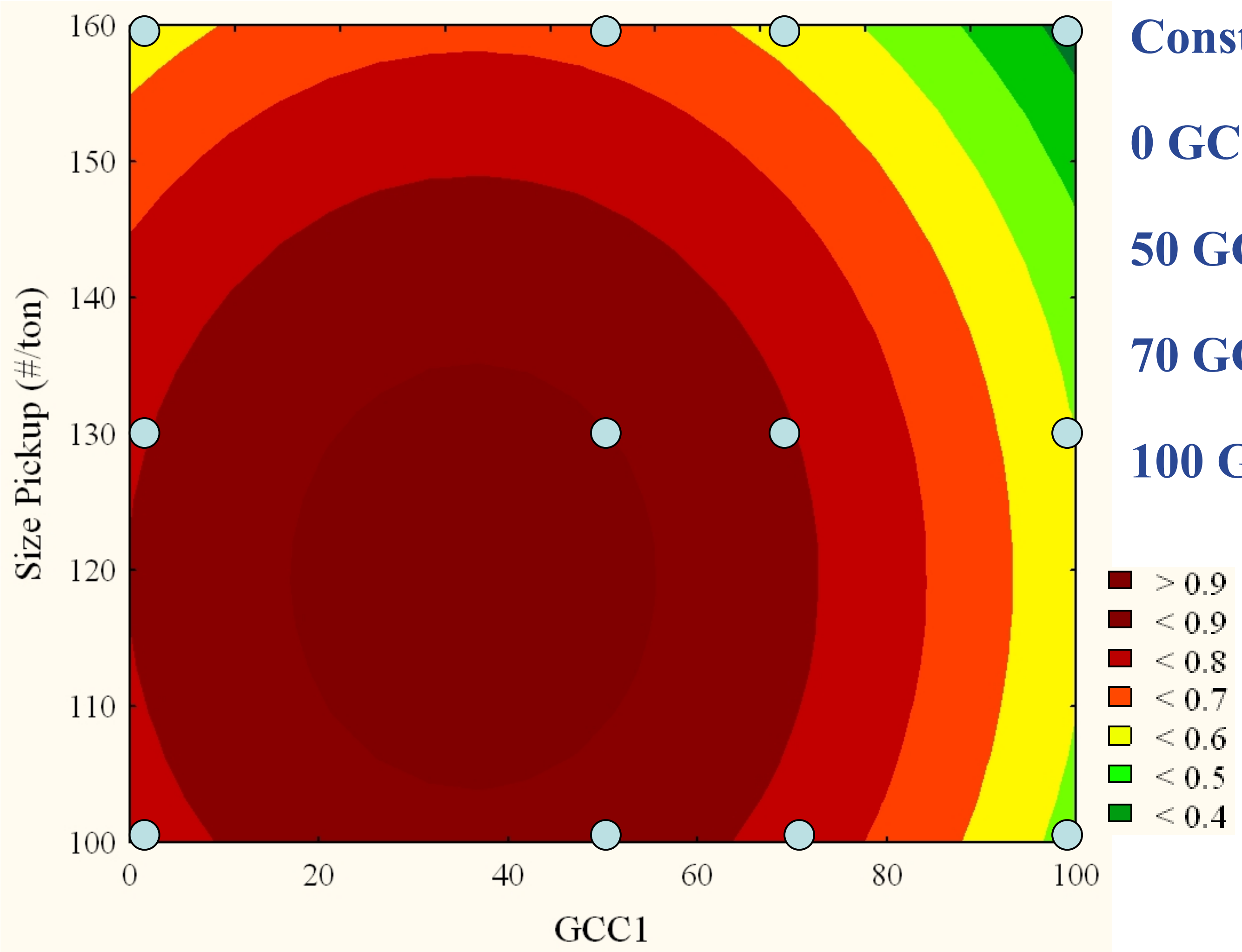
Coating	IPI 1/2" Grooved Rod Type	Tube Pressure top / bottom (k pascals)	Calender Temperature (°C)	Moisture (%)	Size Pickup (#/ton)	Size Pickup (g/m^2)	Finished Basis Weight (#/3000 sq.ft.)	Finished Basis Weight (g/m^2)
Clear Size	Lox003	138 / 138	33.3	3.6	84.5	3.2	47.2	76.9
	004	179 / 172	33.3	4	111.5	4.3	47.9	78.0
	005	138 / 145	33.3	3.4	134.5	5.3	48.4	78.9
	004	152 / 152	31.7	4.8	85.9	4.1	58.8	95.7
	005	345 / 345	33.3	4.9	132.0	6.4	59.6	97.0
	005	172 / 152	*	5.6	144.9	7.1	60.1	97.8
GCC1	33	200 / 207	33.3	3	101.8	3.6	43.2	70.4
	Lox003	352 / 345	33.3	4.5	139.9	5.0	44.2	72.0
	Lox003	138 / 145	33.3	4.4	152.5	5.5	44.6	72.5
	Lox003	138 / 159	33.3	3.1	82.9	4.0	58.7	95.6
	004	186 / 193	33.3	5.7	130.9	6.3	59.5	96.9
	005	159 / 152	33.3	4.9	151.3	7.4	60.3	98.2
GCC2	33	214 / 221	33.3	3.2	95.9	3.5	44.4	72.3
	Lox003	338 / 345	33.3	4	136.4	5.0	44.7	72.8
	Lox003	138 / 138	33.3	5.4	164.8	6.0	45.0	73.2
	Lox003	138 / 138	33.3	3.7	87.1	4.1	58.3	94.9
	004	159 / 159	33.3	4.4	119.7	5.8	59.2	96.4
	005	145 / 145	33.3	5.4	146.3	7.1	59.9	97.6
30 GCC1 70 KaolinA	33	179 / 179	35	4.5	95.9	3.7	47.1	76.7
	Lox003	345 / 345	34.4	3.9	110.7	4.3	47.8	77.9
	Lox003	131 / 145	34.4	5.7	145.8	5.7	48.2	78.5
	Lox003	131 / 138	35.6	4	88.4	4.2	58.1	94.6
	004	165 / 186	35	4.5	123.2	6.0	59.4	96.7
	005	138 / 138	35	5.6	156.3	7.6	60.1	97.8
50 GCC1 50 KaolinA	33	172 / 179	36.1	2.4	82.2	3.2	47.8	77.8
	Lox003	352 / 338	36.1	3.2	118.0	4.5	47.1	76.7
	Lox003	131 / 138	36.1	4.8	144.9	5.7	48.6	79.0
	Lox003	131 / 138	35.6	4.2	97.7	4.7	58.8	95.7
	004	165 / 152	35.6	3.8	119.5	5.8	59.5	96.8
	005	124 / 138	35.6	4.2	143.0	7.0	60.4	98.4
30 GCC1 70 KaolinB	33	179 / 186	36.7	3.6	88.0	3.4	47.3	77.0
	Lox003	345 / 352	36.7	3.1	110.9	4.3	48.0	78.2
	Lox003	138 / 138	36.7	4.8	139.0	5.5	48.8	79.4
	Lox003	207 / 207	37.2	4.6	99.7	4.8	59.4	96.6
	004	207 / 234	37.2	4.1	128.8	6.3	60.1	97.9
	005	131 / 145	37.2	4.6	155.3	7.7	60.7	98.8

Each sizing was applied:

at three pickup levels

onto two different weight basestocks

Response of Bending Resistance to Size Pickup and GCC Level



Constant 100 parts starch

0 GCC → Starch only

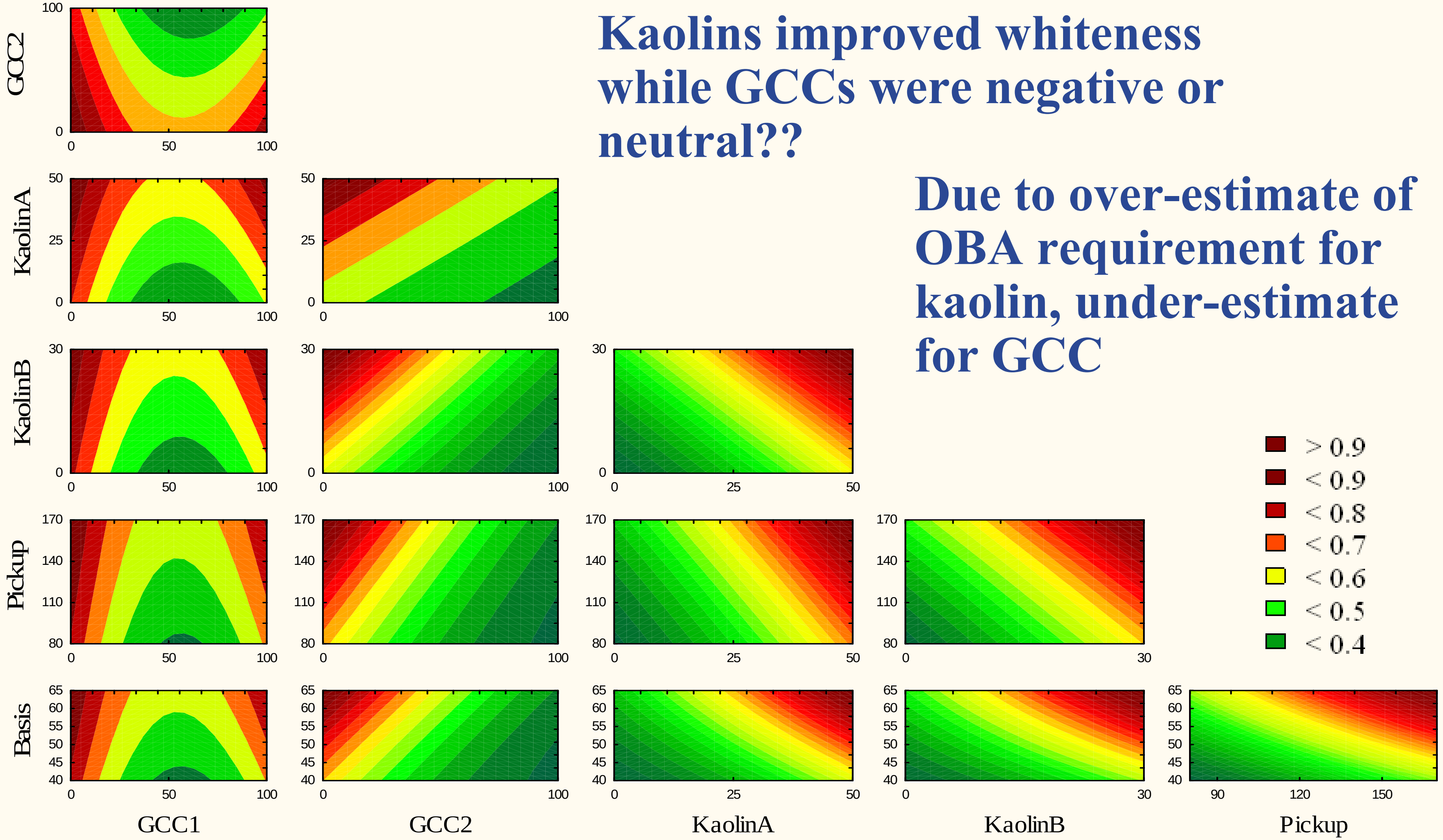
50 GCC → 50 Kaolin

70 GCC → 30 Kaolin

100 GCC → 0 Kaolin

Optimum GCC level corresponds to systems that include kaolin

Whiteness Responses to Basis Weight, Size Pickup and Pigmentation Types and Levels



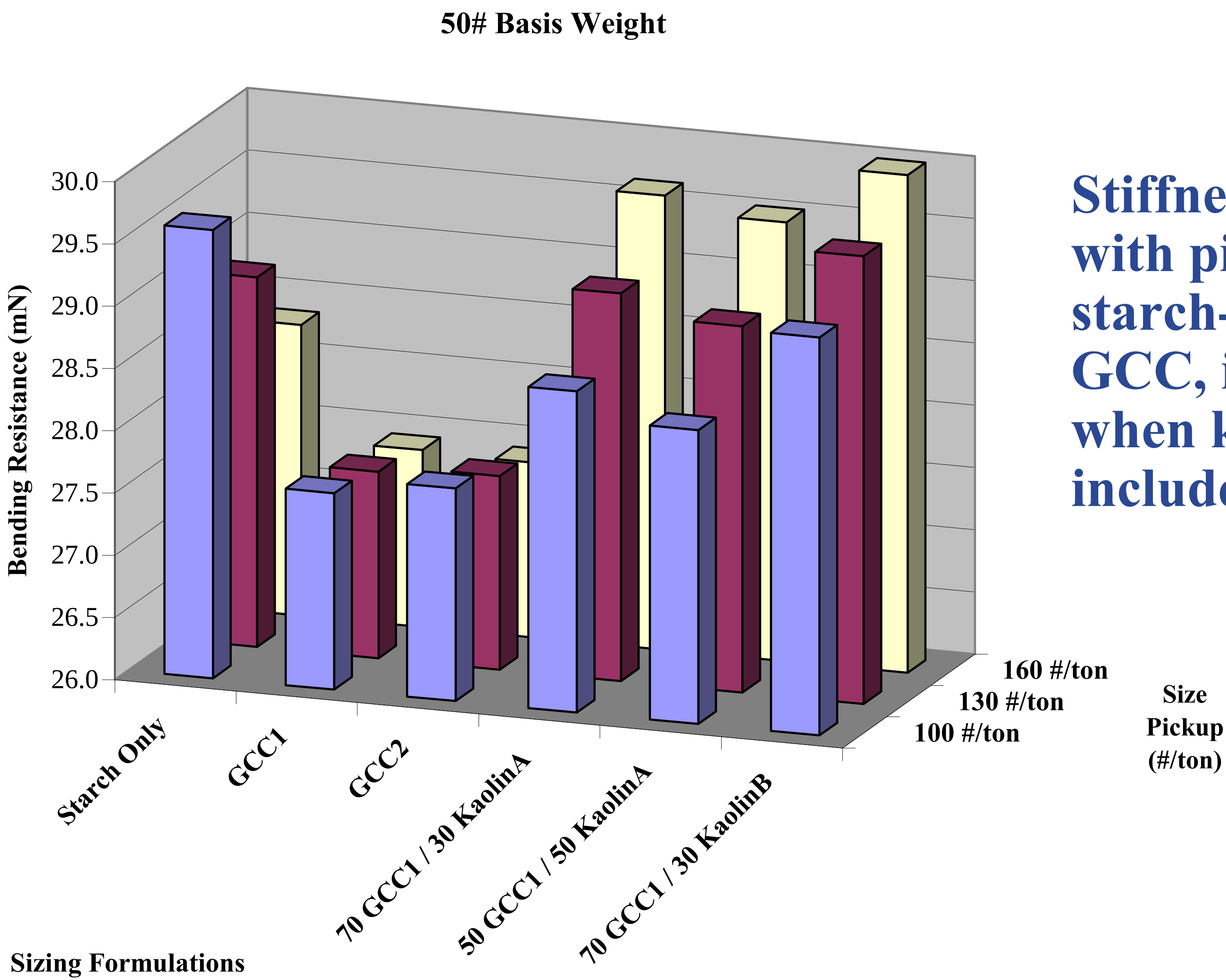
Kaolins improved whiteness while GCCs were negative or neutral??

Due to over-estimate of OBA requirement for kaolin, under-estimate for GCC

Summary of Response Surface Regression Results

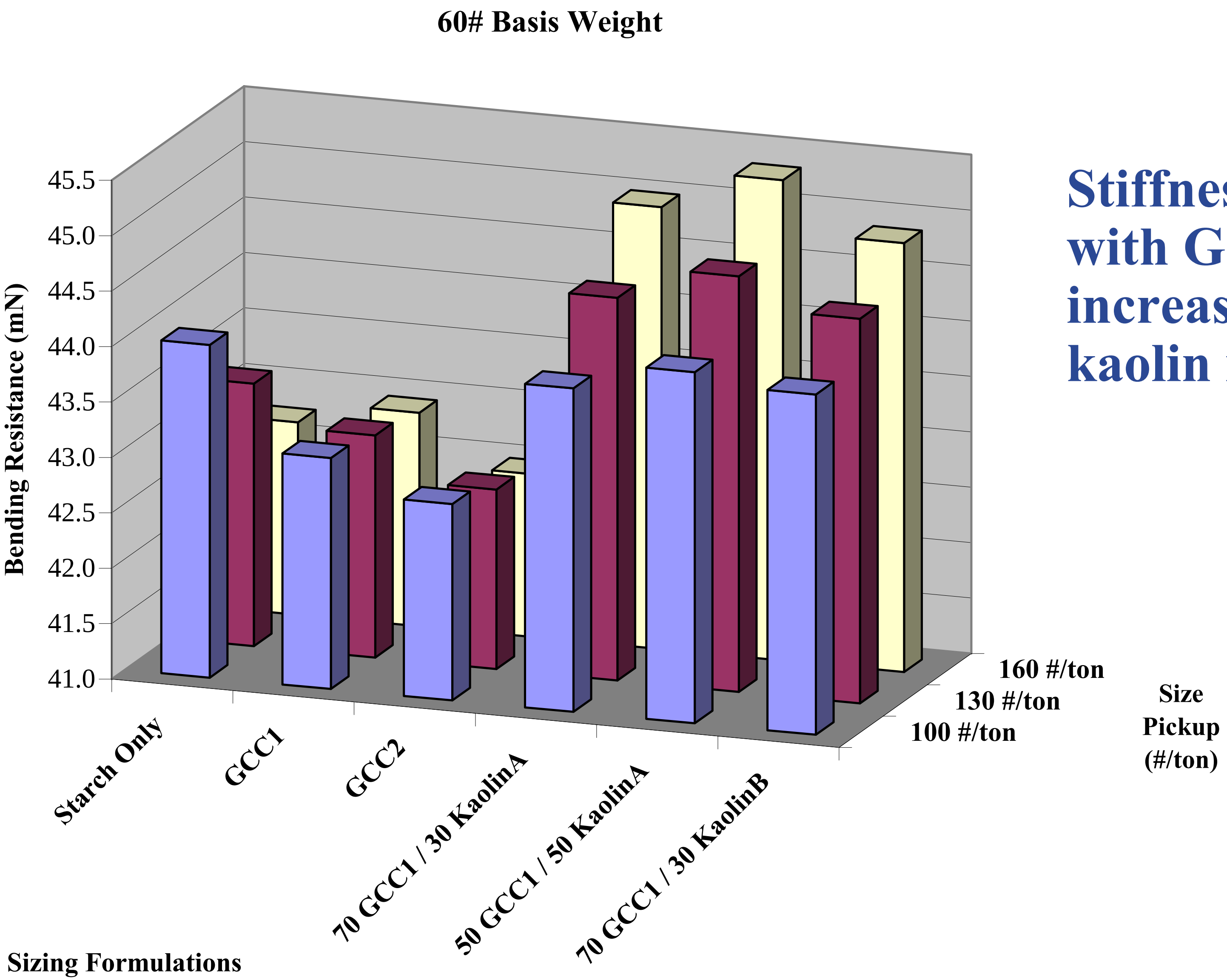
Measurement	Adjusted R^2	D o G	Basis	Pickup	GCC1	GCC2	KaolinA	KaolinB
Brightness	0.82	+	-	+	+/-	=	+	+
Opacity	0.99	+	+	-	+	+	+	+
Caliper	0.97	+	+	-	+	=	=	-
Formation	0.89	+	+/-	-	+	+	=	=
Bending Resistance	0.98	+	+	+/-	+/-	-	=	=
Sheffield	0.44	-	+/-	+	+	+	+	=
Pick	0.97	+	+/-	+	-	-	-	=
Whiteness	0.98	+	+	+	+/-	-	+	+
Low Pressure Gurley	0.87	+	+	+	=	+	+	+
Hercules Sizing	0.89	+	+	+	=	+	+	=
Hunter b	0.98	-	+	+	-	-	=	=
Tensile Peak Load	0.98	+	+	+	-	-	-	-
Tensile Energy Absorption	0.95	+	+	+	+/-	-	=	=
Tensile Elongation	0.91	+	+	+	+/-	-	=	=
Scott Bond	0.90	+	=	+	+/-	-	-	=
Burst	0.96	+	+	+	-	-	-	-
Tear	0.98	+	+	-	+/-	+	=	=
+'s			+12	+12	+4	+6	+6	+4
-'s			-1	-4	-4	-9	-4	-3
overall			+11	+8	0	-3	+2	+1

Bending Resistance @ 50 #/ream



Stiffness decreases with pickup for starch-only and GCC, increases when kaolin is included

Bending Resistance @ 60 #/ream



Stiffness decreases with GCC-only, increases when kaolin is included

Reduced Stiffness with Increased Starch?

- It seems counterintuitive that stiffness is decreased with increased starch pickup
  - Starch is considered to be quite stiff
- This may be due to reduction in caliper when size pickup is increased at constant basis weight
  - Stiffness goes as the cube of the caliper
- For less stiff sizing system such as starch only, or starch with GCC, stiffness may decline when size pickup is increased at constant basis weight
- For stiffer sizing systems, using platy kaolin, increased stiffness of “I-beam flanges” may offset caliper reduction

Bending Resistance-based Wet End Basis Weight Reduction Potentials with Kaolin in Sizing

Control Cases 100 # size / ton paper	70 GCC1: 30 KaolinA			50 GCC1: 50 KaolinA			70 GCC1: 30 KaolinB		
	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction	Size Pickup (#/ton)	Basis (#)	% Fiber Reduction
Clear Size 50# basis	157	50	**3.0**	164	50	**3.4**	160	49.7	**3.7**
Clear Size 60# basis	160	59.4	**4.1**	160	59.2	**4.4**	160	59.4	**4.1**
1 Starch: 1 GCC1 50# basis	160	48.7	**5.7**	160	48.8	**5.5**	160	48.4	**6.3**
1 Starch: 1 GCC1 60# basis	160	58.8	**5.1**	160	58.6	**5.4**	160	58.6	**5.4**

Conclusions

- Including kaolin in pigmented size on uncoated woodfree can improve stiffness while reducing wet end basis weight
  - Especially in comparison to GCC-only pigmented size
- Kaolin color difference from fiber/GCC is easily overcome by minor adjustment to OBA level
- Fine, platy KaolinB had best fiber replacement potential
- Delaminated KaolinA has best economics
- Coarse GCC is definitely inferior to Fine GCC