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The Effects of Styrene-Butadiene Latex Binder on the Properties of a Coated Sheet

Bryan J. Wiltzius
Western Michigan University

THE EFFECTS OF STYRENE-BUTADIENE LATEX BINDER ON THE PROPERTIES OF A COATED SHEET

BY

Bryan J. Wiltzius

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ABSTRACT

The objective of this thesis proposal is to determine the effect of a varying latex binder on the physical and optical characteristics of a coated sheet with different binder addition levels. A total of nine separate coating formulations were made up of three different styrene to butadiene ratios and three different binder addition levels. The optical properties that were tested include opacity, brightness, paper gloss, and K&N ink absorption. The adhesive properties were evaluated by testing the physical properties of pick strength, abrasion resistance, and wet rub. The porosity and roughness characteristics were also tested.

One liter of each coating formulation was made and ran on the CLC laboratory coater. A fifty pound basis weight base sheet was used. The parameters such as coat weight, percent solids, low shear viscosity, pH, pigment, and drying conditions were held constant at values to ensure good runnability on the CLC and resembling those most commonly used within the industry. The focus of this thesis topic being the binder variable, more specifically styrene-butadiene latex.

The latex was obtained from the Dow chemical company at three different styrene to butadiene ratios within each latex. One formulation contained Dow 617 latex (hard) with a styrene/butadiene ratio of 1.9 and a glass transitional temperature (Tg) of 18 C. The second formulation contained Dow 620 latex (typical) with a styrene/butadiene ratio of 1.7 and a Tg of 12 C. The final formulation contained Dow 679 latex (soft) with a styrene/butadiene ratio of 1.3 and a Tg of -10 C. The amount of latex binder based on dry pigment became another variable. One coating formulation contained the typical 12% binder, one was lower approximately containing 8% binder, and the other was above the typical at 18% binder based on dry pigment.

By altering the latex binder, the properties of the coating formulation itself alters. Certain properties such as film formation, glass transitional temperature, coalescence, and pigment to binder interactions all vary by changing the amount and type of latex. It can be concluded that the hard latex at a lower binder level is desired to achieve optimum optical characteristics while soft latex at a high binder level is desired for optimum binding strength characteristics. A compromise between the two must be achieved while making the proper coating formulation.

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INTRODUCTION

The past decade has shown an incredible rate of growth accompanied by improvements in knowledge and process innovation in the area of paper coating. Today the coating operation is an intricate and necessary part of the whole paper making process. Advancing printing technologies require improved surface quality of the paper sheet. Recently paper coating has become the fastest growing and most concerned area of paper making, with the exception of recycle. The rapid improvement of coating quality and speed is contributed to advances in coating equipment and a better understanding of the coating rheology. Various coating formulations are used to meet the requirements of improved gloss, smoothness, color, printability, and brilliance. (Smook, 1992)

BACKGROUND: A coating formulation may contain over ten ingredients, but they can all be classified into either pigments, binders, or additives. Pigments are the bulk of the coating suspension usually making up eighty to ninety percent of the dry formulation weight. (Smook, 1992) The pigments used are similar to fillers and are mixed with adhesives to hold it onto the paper surface, providing a suitable finish. Pigments are used to improve the optical characteristics, topographical efficiency, ink receptivity and holdout, and printing considerations such as abrasion or dusting (Scheller, 1996).

Additives are any ingredient that is not a pigment, binder, or water that is used to control characteristics. Some additives include defoamers, dispersants, flow modifiers, and preservatives. (Scheller, 1996)

This thesis focuses of the binder group, specifically the synthetic styrene-butadiene latex binder. The function of the binder (adhesive) is to bind the pigment particles firmly to the base sheet surface and to each other. The final dried coating is not a continuos film, but a porous structure of pigment particles cemented together at points of contact. (Smook, 1992) The type of binder and its amount have a strong influence on coating structure because it affects the rate of fluid penetration into the raw stock, the degree of filling between pigment particles, and the rate of drying. (Smook, 1992) Binder is used at the lowest level that is required by the end product because if too much binder is used, the voids begin to fill and potential light scattering capability is lost reducing such optical properties as gloss. Synthetic binders such as latex, are being used more and more over starches and proteins because of the higher optical potential they give to the coated sheet.

SBR latex is made up of two different monomers (styrene and butadiene) at a specific ratio to one another. This ratio is very important because it determines the specific characteristics that the SBR latex brings to the coated sheet. The relevance of this thesis is to determine the unique coated paper properties brought about with a styrene-butadiene (SBR) latex binder that has different ratios of styrene to butadiene.

Styrene is a liquid hydrocarbon (C6H5CH:CH2) used in the making of synthetic rubber and possessing a glass transitional temperature of 100 C. Butadiene is a colorless hydrocarbon gas (C4H6) also used in the making of synthetic rubber and possessing a glass transitional temperature of -80 C.

Previous research and experimentation has been done on the "composite latex", which is latex binder created by varying the styrene and butadiene make up within the latex. Composite latexes are core-shell or two stage structured latexes. It is made by polymerizing a soft monomer mix of styrene and butadiene in the presence of polystyrene, a high-styrene latex seed. Therefore it is composed of both hard and soft polymer phases (Lee, 1982). Hard for improved gloss and soft for improved binding (Sasagawa et. al. 1984). Each composite latex also has its own Tg and minimum film forming temperature which affect the coated sheet characteristics.

The focus of previous research has been limited to the optical properties of the coated sheet, especially gloss. Little documentation has been done on the physical properties of the coated sheet. Little documentation was also found with respect to opacity, brightness, or smoothness; all of which are important characteristics in determining the printability and optical quality of the coated sheet. This thesis project will concentrate on the optical and physical properties of a coated sheet affected by varying the styrene to butadiene ratio in the latex. This is important to the mill to know the type of coating used which will reach the customer's expectations while being economically feasible to make.

The typical styrene-butadiene latex (Dow 620) contains sixty-three percent styrene. A "hard" latex formulation (Dow 617) contains sixty-six percent styrene in the latex. The affects of a hard latex formulation include an open, brittle, easy glossing coating with low strength. A "soft" latex formulation (Dow 679) contains fifty-six percent styrene in the latex. The affects of a soft latex formulation include a soft, flexible, latex film with high elongation and higher strength. Changing the ratio will change the Tg (glass transition temperature) of the latex, its film forming characteristics, coalescence, void fraction, binder migration, and the pigment to binder interactions of the latex monomers. These different latex binder characteristics have the influence and the ability to change the properties of the coated sheet. The knowledge of binder arrangement and the factors that affect it are crucial to the procedure of creating a quality product, and the development of a new product. (Lepoutre, 1992)

This thesis will hopefully show and document the different effects that SBR has on the binding strength properties of: abrasion resistance, wet rub, pick strength, as well as paper gloss, opacity, brightness, and ink absorption. Parker Print porosity and roughness will also be conducted to test for coated paper quality. The coated paper market has become extremely competitive recently, compelling the papermakers to strive for greater production efficiency and higher quality standards. The quality demands of the printers and converters keep increasing so they can increase their own productivity (Yun-Long et. al. 1993).

Latex Characteristics.

The particle size of Latex is roughly 1800 Angstroms. This is small compared to clay which is 20,000 A, and carbonate at 3000 A. The latex particle diameter can range from 1500 to 2000 A. Latex viscosity decreases with increase in particle size (nm). Pick strength and gloss decrease with increase in size. Latex in and of itself is hydrophobic and requires the formation of micelles (Scheller, 1996).

Economically, the solids content plays a major role in latex dispersions. A higher solids content is desired for improved properties, increased production rates, and reduced energy costs. The solids content is limited to the maximum viscosity that will still have good runnability on the coater. A compromise between solids and runnability exists. It is desired to get the highest solids level without interfering with the runnability on the coater.

Latex coatings have a low viscosity for a relatively high solids content making it a desirable binder. (Van Gilder, 1983)

Glass Transitional Temperature.

The glass transitional temperature (Tg) is the temperature where the liquid coating formulation changes from the rubbery state to the glassy state. (Frick and Richter, 1995) The typical Tg range for latex binder is minus thirty-five to thirty-five degrees Celcius. It is expected that as the butadiene level increases within the latex, the Tg will decrease. This is because butadiene has a Tg of about minus eighty degrees Celsius while styrene has a Tg of approximately one hundred degrees Celsius. The glass transitional temperatures of the latex used are eighteen, twelve, and minus ten degrees Celsius for the Dow 617, 620, and 679 respectively. This means that as butadiene content increases, the temperature at which film formation occurs decreases. (Frick and Richter, 1995)

A lower Tg increases the ability and speed of the dispersion's film formation capability, but causes the coating to be soft with a low void fraction. Lower Tg increases film formation and strength; however, the elastic modulus increases with increasing glass transition temperature of the latex. This means that a lower Tg latex will give poorer porosity and gloss but higher film strength and bonding area. This decreases the light scattering potential and is directly related to lower gloss and ink absorption values. (Groves, 1993) Gloss decreases with decreasing glass transitional temperature. (Lepoutre, 1992)

Film Formation.

Film formation and glass transitional temperature go hand in hand. The process of film formation is very important in determining the characteristics of the coating. Film formation occurs when water is evaporated out of the dispersion to the point when all the different particles come into contact with the latex and fuse together. (Joanicot, 1993)

The coating is first applied to the base sheet in a aqueous suspension of pigment and binder. The aqueous form is then changed by evaporation of water and drainage of the formulation into the sheet. This gives a new structure after drying (Lepoutre, 1992) As the water evaporates, the pigment particles are brought closer together up until a point where the repulsion forces due to the electric charges are overcome and a coherent, deformable network is consolidated. (Lepoutre, 1992) Adhesion of the latex on the pigment particles and cohesion of the coating layer are governed by the structure of the latex film.

The film formation process actually occurs in four steps. The first step is concentration which is when particles organize and concentrate by evaporation. The hydrophilic membranes get dispersed in the water. The second step is formation which is contact between particles and filling of voids left the by evaporated water. The third step is coalescence which is the break up of the hydrophilic particles allowing direct contact between cores. The latex cores are fused together causing the cohesion of the coating layer. The last step is interdiffusion which is the interpenetration of the cores of the latex particles. The cores are released form initial confinement and diffuse throughout the film (Joanicot, 1993).

The interdiffusion is called the "ripening stage" which causes the homogeneous film. Interdiffusion cannot take place through membranes, therefore the latex hydrophilic shell, acting as membranes, must be broken up for interdiffusion to occur (Joanicot, 1993).

This process happens very quickly and it is important to the quality of the coating that an order develops between the particles during concentration, they deform into polyhedral cells with shells acting like cell walls, then the membranes break up, and the core polymers mix (Joanicot, 1993). A soft shell and a hard core polymers result in a uniform film (Takahashis et. al. 1984)

A minimum temperature exists when the film will first begin to form. The Tg is usually lower than the minimum film formation temperature. This is important to know in order to determine and regulate the drying conditions of the coating. The minimum film forming temperature of the latex are 17.2 C, 15.6 C, and 7.2 C for the Dow 617, 620, and 679 respectively. This film structure governs the interface between pigment and latex influencing printability. The porous structure of the base sheet is covered by the film making a smoother and more even surface. (Wernett, 1995)

Coalescence.

Coalescence is what causes the film to begin to form. Coalescence is the transformation of the latex binder particles in water, to a dry film, where the latex strength properties are developed. This is mainly due to evaporation.(Wernett, 1995)

The critical point of concentration is when immobilization of solids occurs. As the colloidal interactions between pigment and latex increased, the first critical concentration occurs. As the amount of latex is increased, the second critical concentration occurs. Latex coalescence occurs between these two critical concentrations.

The first critical concentration is assumed to be the immobilization point where no further changes in coating structure occur. The second critical concentration is the "true" immobilization point. (Lepoutre, 1992) A lower critical concentration results in a bulkier dry coating.

The drying conditions significantly affect coalescence of the latex and its ability to spread over the pigment surfaces. Coalescence occurs while water is still present. (Lepoutre, 1992) Extended coalescence causes disruption of the structure of the latex particle walls due to the aging or increasing temperature above the glass transition temperature. (Ming, 1995)

Void Fraction.

The optical properties are especially affected by the coating void fraction which changes as the styrene to butadiene ratio changes. The more styrene that is in the latex, the higher the coating void fraction becomes. This is desirable because a higher void fraction gives more light scattering potential, therefore improving gloss.(Penson, 1993)

One important component in paper coating that is usually overlooked is air. The porous, air filled structure of the coating has a strong influence on the optical, mechanical, and fluid absorption properties. (Lepoutre, 1992) The less binder used, the higher the void fraction. Increasing addition of binder always brought about a decrease in gloss until the critical pigment volume concentration (CPVC) was reached.

Binder Migration

Binder migration and its film forming capability is mainly affected by the drying conditions, which determine the uniformity of absorbency of the coating formulation. Binder migration occurs in two directions, either into the base sheet due to drainage of the aqueous phase (until the critical point has been reached), or towards the surface of the base sheet as water evaporates (Lepoutre, 1992) This means that the state of the sheet surface at the time it enters the dryer section is critical to binder migration. Unfortunately the distribution of coating thickness varies along with the absorbency rate at different areas on the sheet. Therefore the coating on the base sheet does not reach the dryers at the same concentration throughout the sheet surface giving a non uniform film. (Lepoutre, 1992) This poor coating structure affects the rate at which a freshly applied ink film sets. The values of ink absorbency, gloss, and print mottle reflect the uniformity of the coating structure. (Penson, 1993)

Pigment / Binder Interactions.

The binding strength of the latex is determined by the pigment binder interactions. The pigment to binder interactions are dependent on the particle surface structure (core and shell make up) which in turn determines the affinity of the latex to the pigment surface. (Wernett, 1995)

Latex particles are made up of a core and a shell (Figure 1). The core should be hard to resist shrinkage and the shell should be soft to give bonding strength. A composite latex designed to have harder polymer in the core phase and softer polymer in the shell phase gives improved pick strength and stiffness. (Takahashi and Matsumoto, 1984) For high gloss enamel paper there should be a hard core for reduced shrinkage and soft shell for better adhesion. For low gloss matte paper there should be a soft core for high shrinkage.

figure 1

Optical, physical, and fluid absorption properties are all functions of different interfaces of the coating and substrate. The light scattering efficiency is determined by the magnitude of difference between the refractive indexes across an interface. Adhesion and coating strength is determined by the interaction of the pigment / binder interface. The rate of coating absorption is determined by the contact angle at the liquid / solid interface. (Lepoutre, 1992)

The importance of this thesis is based on determining the beneficial and undesirable effects of a changing styrene to butadiene ratio on the characteristics of coated sheets. The basic goals that will hopefully be accomplished will be to find out what styrene - butadiene ratio gives the best optical and adhesive (surface) sheet characteristics, and to find out the effects that an increasing amount of SBR latex in the coating dispersion has on the coated sheet characteristics. Generally as the amount of binder in a coating dispersion increases, the optical properties of gloss, opacity, brightness, and ink transfer decrease while pick resistance increases. (Fernandez, 1983) Strength and elongation increased with increased binder content.

The optimum coating is usually one with as high a void volume as possible and with voids of the right size. Smoothness is also usually a requirement for quality printing and to achieve this, the volumetric roughness is filled with dry coating. Shrinkage during drying can be minimized by using as low a binder level as possible. (Lepoutre, 1992)

The experiment will show if an increase in certain optical characteristics means a decline in certain physical characteristics. These properties are very important to the customer and the grade of paper required. A compromise between coated sheet characteristics may have to be reached.

The objective of this thesis is to see if a higher binder level at a higher percent styrene will give optimum binding strength and optical brilliance, or if the reverse is true. A lower binder level at a higher percent butadiene may give optimum binding strength and optical brilliance.

There are many benefits which may come about upon completion of this thesis. Some critical information may be obtained on the knowledge of varying SBR latex and the influence it has on the coated sheet characteristics. Percent solids, Tg, film formation, void fraction, binder migration, and pigment / binder interactions are all factors of the SBR latex that can have a direct affect on sheet properties. It also determines the effects of a changing styrene-butadiene binder level on coated sheet characteristics. Hopefully this thesis will generate greater knowledge about latex binder composition and its effects on the characteristics of the coated sheet.

EXPERIMENTAL DESIGN / METHODOLOGY

The coating formulations were run on the cylindrical laboratory coater (CLC). The CLC is a high speed laboratory coater which helps to predict the coating performance at high shears, simulating an actual mill size coater. (Eklund, 1988)

The formulations were made similar to following a recipe. The formulation sheet is placed in the appendix. The latex binder level and styrene to butadiene ratios are the only two things that change in the experiment. One liter (300 g. dry material) of each coating was made and used to coat a fifty pound base sheet on the CLC at 2000 feet per minute. The CLC dries the coating application by means of infrared radiation. The drying variable was held constant throughout the experiment. Each coating dispersion had a coat weight of 10 g/m^2 ($\pm$ .2 g/m^2) and a percent solids of 62% ($\pm$ 1%). A low shear viscosity was adjusted within the range of 1200 to 1400 cP using Union Carbide Polyphobe 205 thickener as needed. The viscosity was measured on a Brookfield viscometer at 100 rpm using spindle #5. The pH was adjusted to approximately 8.5 using 5% NaOH for good runnability on the CLC. The clay to ground carbonate ratio was maintained at 80 to 20. The exact values for percent solids, viscosity, pH, and coat weight of each latex dispersion is placed in the appendix.

The first three formulations contain 8% binder based on dry pigment, but the styrene to butadiene ratio varied (soft, typical, and hard). The next three formulations contained 12% binder, and the last three contained 18% binder based on dry pigment and containing the three different styrene to butadiene ratios. The three different Dow latexes used were 617 at 66% styrene, 620 at 63% styrene, and 679 at 56% styrene. Each latex was used in the three different binder level additions giving a total of nine runs.

CLC

The CLC (cylindrical laboratory coater) is a high speed blade coater which provides low cost research and experimentation in order to search for improvements of the coated sheet. These improvements include new product development and coating rheology. (R.W. Eklund, 1988) The CLC can operate at speeds from 200 to 4000 feet per minute. The CLC is used to predict coating and product performance before a pilot or production run. The CLC requires at least one liter (300 grams dry weight) of coating and a base sheet 38 inches wide by 10 feet long. (Eklund, 1988)

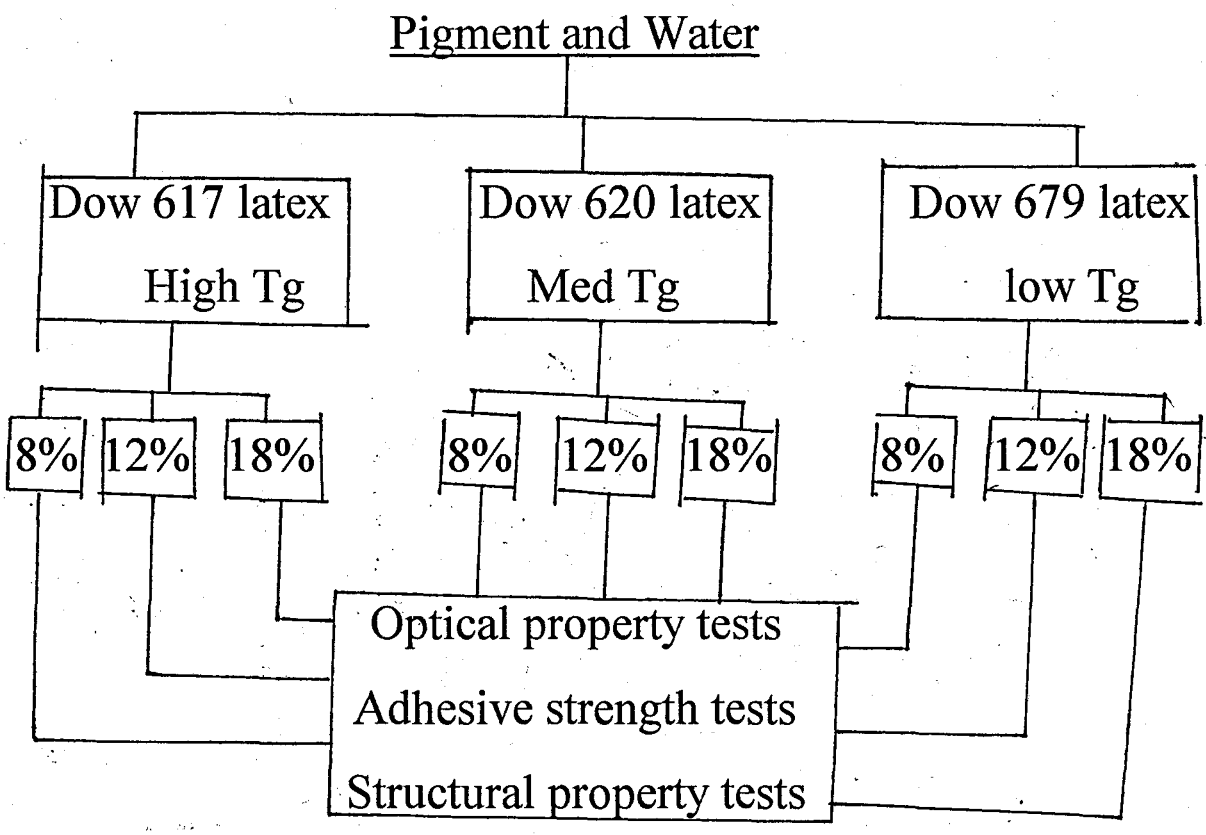
Steps: Tape base sheet to drum, then place the pond on the pond carriage. The pond is then locked in the carriage and filled with the coating. Next the safety cover is closed and the coating begins. (Eklund, 1988)

Experimentation has been done and there is evidence that the CLC coater and a high speed short dwell pilot coater give similar coating performances. There is no significant difference in gloss, opacity, roughness, or Parker Print smoothness. (Eklund, 86) The cylindrical laboratory coater is proven to be a reliable, repeatable and flexible high speed blade coater. (Eklund, 1988)

The samples were placed in the conditioning room for one day before testing. All the testing was done in the WMU laboratory. The results of the physical and optical testing were carried out according to Tappi standards and recorded. The physical testing included wet rub, abrasion resistance, IGT pick strength, smoothness, and roughness. The optical testing consisted of gloss, brightness, opacity, and K&N ink absorption.

EXPERIMENTAL DESIGN

Experimental Conditions & Flowchart:



Optical property tests - Opacity, Brightness, Gloss, K&N Ink absorption

Adhesive strenght tests - Taber Abrasion, IGT Pick, Wet Rub

Structural property tests - Parker Print porosity and roughness

RESULTS

OPTIMUM (BEST) CONDITIONS

OPACITY	BRIGHTNESS	GLOSS	K&N INK	POROSITY
8% 617	18% 617	18% 617	18% 679	8% 620
12% 620	12% 617	12% 617	18% 620	8% 617
8% 620	8% 617	8% 617	12% 679	8% 679

ABRASION	WET RUB	IGT PICK	ROUGHNESS
18% 679	18% 620	18% 620	12% 620
18% 620	12% 620	18% 679	18% 617
12% 620	18%679	18% 617	12% 679

UNDESIRED (WORST) CONDITIONS

OPACITY	BRIGHTNESS	GLOSS	K&N INK	POROSITY
8% 679	18% 620	18% 679	12% 617	18% 679
18% 617	18% 679	8% 679	8% 617	18% 620
12% 617	12% 620	12% 679	8% 679	12% 679

ABRASION	WET RUB	IGT PICK	ROUGHNESS
12% 617	8% 617	8% 617	8% 679
8% 617	8% 679	8% 620	8% 620
18% 617	12% 617	12% 617	8% 617

Best overall conditions: 18% binder Dow 617 (low butadiene)

Worst overall conditions: 8% binder Dow 617

DISCUSSION

The results that are analyzed in the first part of the discussion will be the optical characteristics of the coated sheet. These characteristics include opacity, brightness, gloss, and K&N ink absorption. The last part of the discussion will analyze the results of the testing done to determine the coatings binding adhesion strength. The testing that was done in this area includes wet rub, abrasion resistance, and IGT pick. The Parker Print porosity and roughness was also done on each of the samples to compliment or further explain the results that occurred. All data will be represented with graphs or figures to make an easy comparison between the different types of coating dispersions that were used.

The coating dispersions that were made and the conditions at which they were run on the coater were chosen to best fit the normal, run of the mill, conditions. The main focus of this thesis is the binder portion of the coating dispersion. The other portions of the coating dispersions and other process variables during the coating runs were held constant in order to isolate the type and level of latex binder that was used (SBR) and its effects on the coated sheet.

As mentioned earlier, nine different coating formulations were made and ran on the CLC coater. Three separate coatings were made with three different styrene-butadiene ratios within the latex binder. These three coatings were ran at a low, normal, and high binder percentage within the coating dispersion itself for a total of nine runs. The CLC was chosen in order to best represent the speed and shear forces that are present in industrial coater.

OPTICAL BRILLIANCE:

Before the discussion of the optical characteristics which occurred after the testing of the different coated sheets, an understanding of the critical pigment volume concentration (CPVC) must be developed. The critical pigment volume concentration is the point where the voids in the coating are filled with binder which occurs as the pigment volume concentration (PVC) decreases. PVC is equal to the pigment volume divided by the pigment volume plus the binder volume.

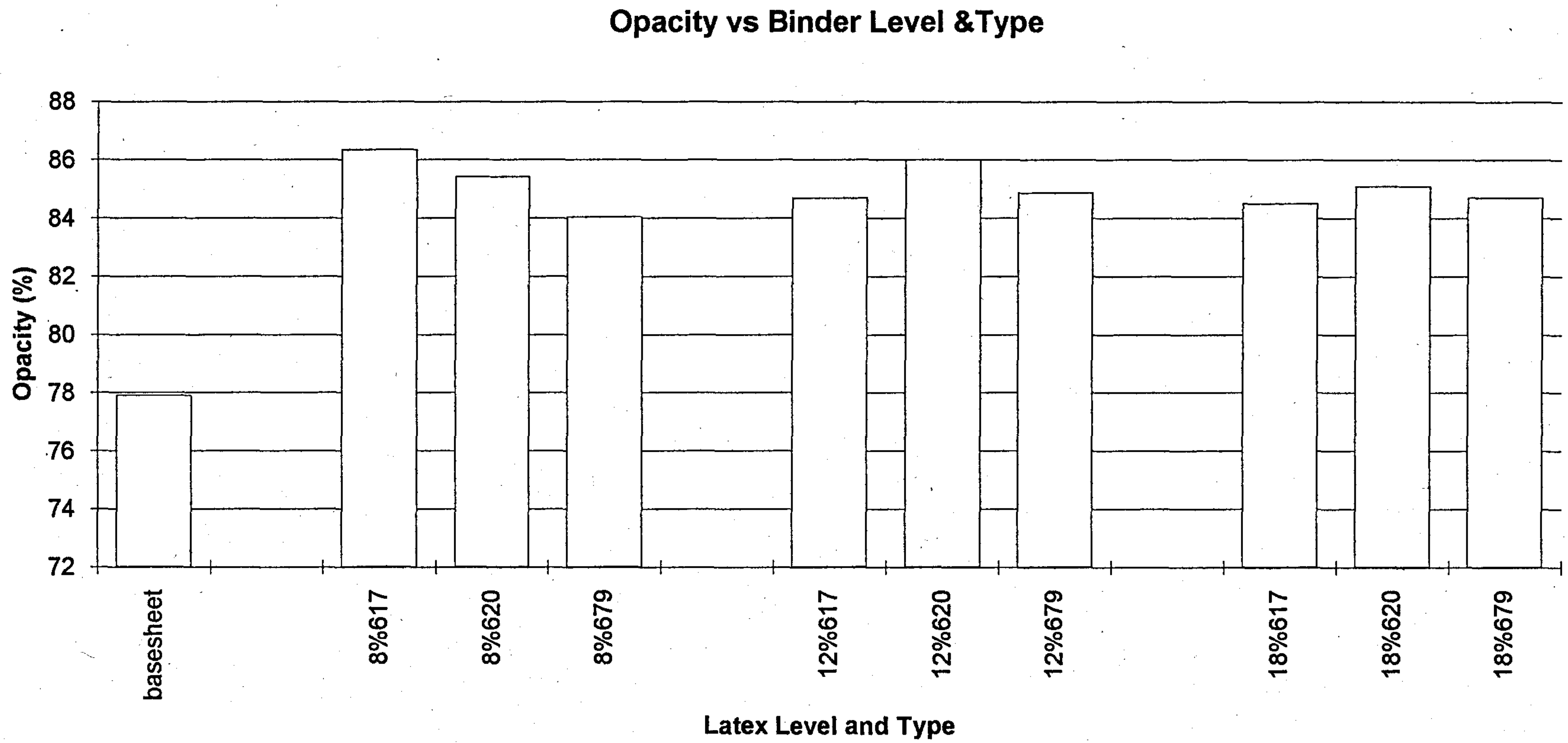
As the PVC rises through the CPVC a sharp change in coating properties is observed (Abell, 1992). Below the CPVC the coating contains little void volume and may have high gloss and good abrasion resistance. This often occurs in paint. Above the CPVC the coating contains significant void volume opening up the structure meaning a less dense, more porous coating. The opacity varies depending on the amount of voids in the coating, or how near the coating is to the CPVC. This region can bring about high opacity because of the light scattering in the micro-voids. After the CPVC has been reached, a small increase in PVC gives a proportionally larger effect on porosity. The PVC can be raised by simply removing binder from the formulation improving porosity but also weakening the coating strength.

There are also two critical concentrations which occur during the drying process which are important in the development of the coated properties. A lower critical concentration results in a bulkier dry coating (Lepoutre, 1992) The first critical concentration (FCC) occurs when the immobilization of solids occurs. This happens as the colloidal interactions between pigment and latex increases. During the FCC, the gloss drops as the solids becomes high enough for a pigment structure to form.

The second critical concentration (SCC) is the "true" immobilization point. There is no further movement between pigment and latex after the SCC, at this point all binder migration has stopped. At the SCC the opacity rises sharply as air voids begin to develop in the drying film. As the amount of latex is increased, the SCC increases also.

OPACITY: Opacity is the property of a sheet or coating which obstructs the passage of light and prevents one from seeing objects through the sheet on the other side (Lavigne) It was measured using Tappi Standards by the contrast ratio between the reflectance value of a single sheet backed by a non-reflecting black surface and that of a pile of sheets of the same material (Smook, 1992) The results of the opacity test are shown in chart 1 on the next page. The two different variables that affect the opacity values are total binder level, and the butadiene level (softness). A hard latex is one with a low level of butadiene and a soft latex has a higher level of butadiene.

The results of the opacity test were rather hard to explain and somewhat unexpected. The lower levels of butadiene binders should give a coating with high void fraction which increases the light scattering ability of the sheet and in turn increases the opacity. The void fraction should decrease with an increasing butadiene content. This is explained in terms of binder film shrinkage as the coating coalesced upon drying. As butadiene in the coating increases, so does the film shrinkage in the film formation process. The lower binder levels should also give higher opacity values because when there is less binder, the coating is more above the CPVC meaning more void volume that



Opacity vs Binder Level &Type
88
86
84
82
80
78
76
74
72
Opacity (%)
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

opens up the coating structure. The opacity should increase because of more light scattering in the more numerous micro-voids (Abell, 1992).

It is noted that the opacity of the base sheet was enhanced greatly by the coating. This is expected because one of the reasons to coat a base sheet is to improve the optical properties, including opacity. The data showed that at the twelve and eighteen percent binder all the opacity values were very similar. The increasing butadiene content had little affect on the opacity at both of these binder levels. The coatings at the twelve and eighteen percent binder possesses about an 85% opacity value meaning that there are air voids in the coating, but that there is very little change in the void fraction from twelve to eighteen percent binder and there is little change in the void fraction as the butadiene content increases from thirty-four to forty-four percent.

At the eight percent binder level there is a nice decreasing trend as the butadiene content increases. This makes sense because at the hard, high Tg coating there is less film shrinkage and more air voids causing a higher opacity. As the butadiene increases the Tg decreases and there is more film shrinkage giving a more flexible, less porous coating. This means there is less air voids and a lower light scattering ability. The eight percent binder level shows these trends nicely. The best opacity value occurred at the lowest binder level and butadiene content which is expected.

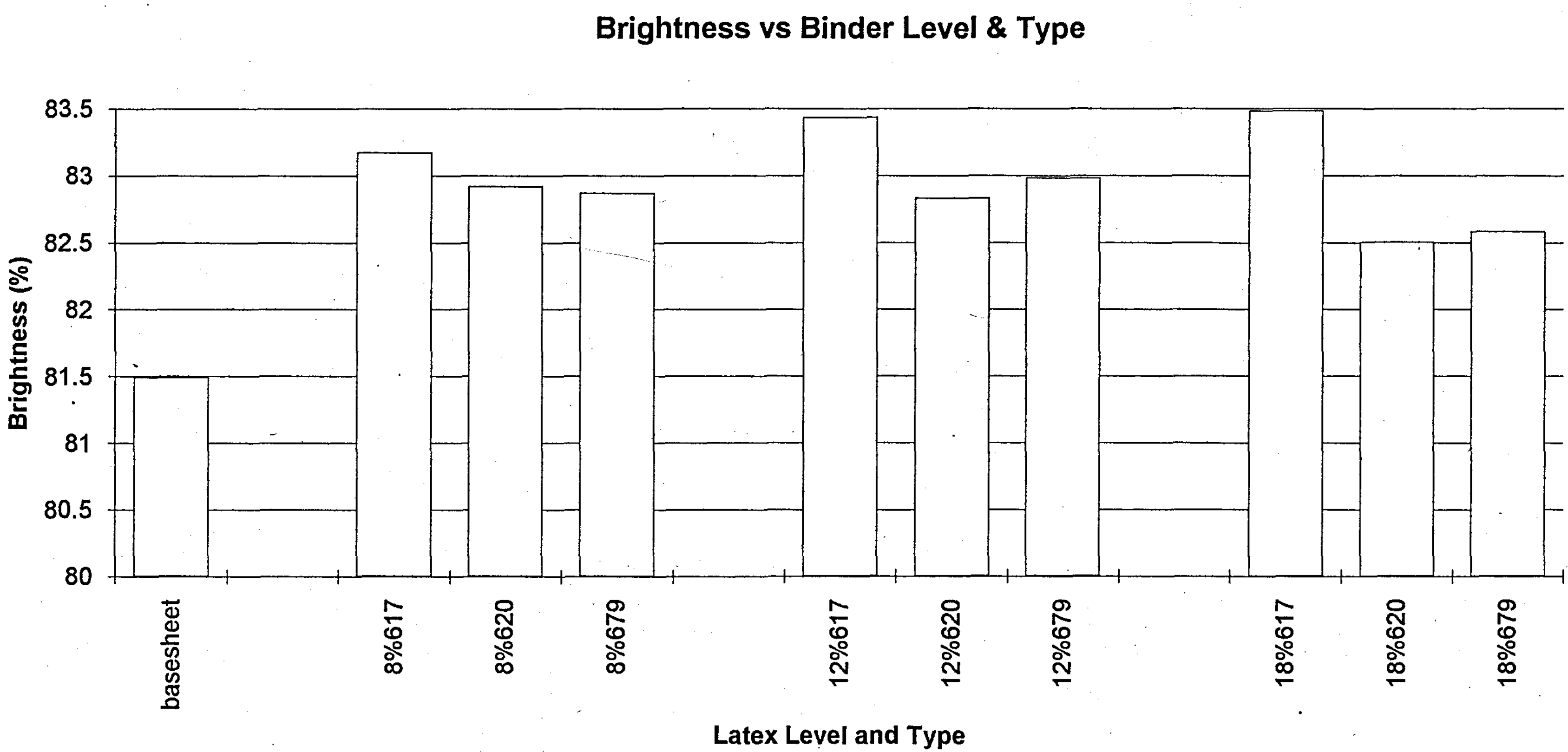
It is also noted from chart 1 that although the opacity values did differ, they only varied by a slight margin. When comparing the butadiene content variations and the binder level variations, it can be seen that the all opacity values remained within a two percent range from 84% - 86% opacity. This would seem to imply that the butadiene content and binder level only play a minimal role in determining the opacity of the sheet.

The porosity data gives an idea of the void fraction of the coated sheet and this can be used to help explain the opacity trends. As the porosity of the coated sheet increases, so should the opacity. When looking at the porosity data (chart 8) it was found out that there is a slight decreasing trend in porosity as both the binder and butadiene level increase as there should be. The opacity values should follow this trend, however, the porosity values for the twelve and eighteen percent binder are very similar complementing the similar values of opacity at these binder levels.

BRIGHTNESS: Brightness is a measure of the reflectance value, relative to a standard, in the blue region of the visible spectrum (Smook, 1992). Brightness is a measure of the whiteness of the sheet. Brightness, like opacity, originate from the scattering of light and its absorption. The light scattering capability is obtained from the difference in refractive index between pigment and binder (Lepoutre, 1992) The brightness values are a little less than the opacity values and should follow the opacity trends.

As void fraction increases, the light scattering capability increases, which in turn should increase the brightness also. This means that a lower level of both butadiene and binder level should result in a higher brightness value. The brightness test was carried out according to Tappi standards on a brightness meter.

The results of the brightness test are shown in chart 2 which is the graph on the next page. It can be seen that the coating improved the brightness of the base sheet. This



Brightness vs Binder Level & Type
83.5
83
82.5
82
81.5
81
80.5
80
Brightness (%)
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

is expected because one of the properties of a coated sheet is enhanced optical values which include brightness.

The data showed that the butadiene (or styrene) content played a more important role than did binder level when determining brightness. The results showed that the lowest butadiene content, in all three binder levels, had the highest values. This implies that the amount of butadiene in the latex plays an overriding role in determine the brightness when compared to the binder level. For the medium and high butadiene content the brightness values decreased when the binder level increased. This is expected.

The lowest brightness values occurred at the eighteen percent binder with a high butadiene content. This makes sense because at the high binder and butadiene content, the coating is softer (more flexible) resulting in less void fraction. As the void fraction decreases the brightness value should decrease with it, and it does here.

The highest brightness values occurred at the low butadiene level with the best values occurring at eighteen percent binder level, then twelve, and then the eight percent consecutively. This is somewhat unexpected, ideally the reverse should happen with the 8% binder being the brightest sheet. The results may be due to the increased styrene content. When the butadiene is decreased, the styrene content is increased. Styrene has a high Tg and makes the coating "hard" resulting in a film with less shrinkage and more air voids. This means the sheet is more porous giving it higher light scattering capability. In the 18% binder, there is more styrene in the coating formulation than there is in the eight percent binder which may give the sheet a higher brightness.

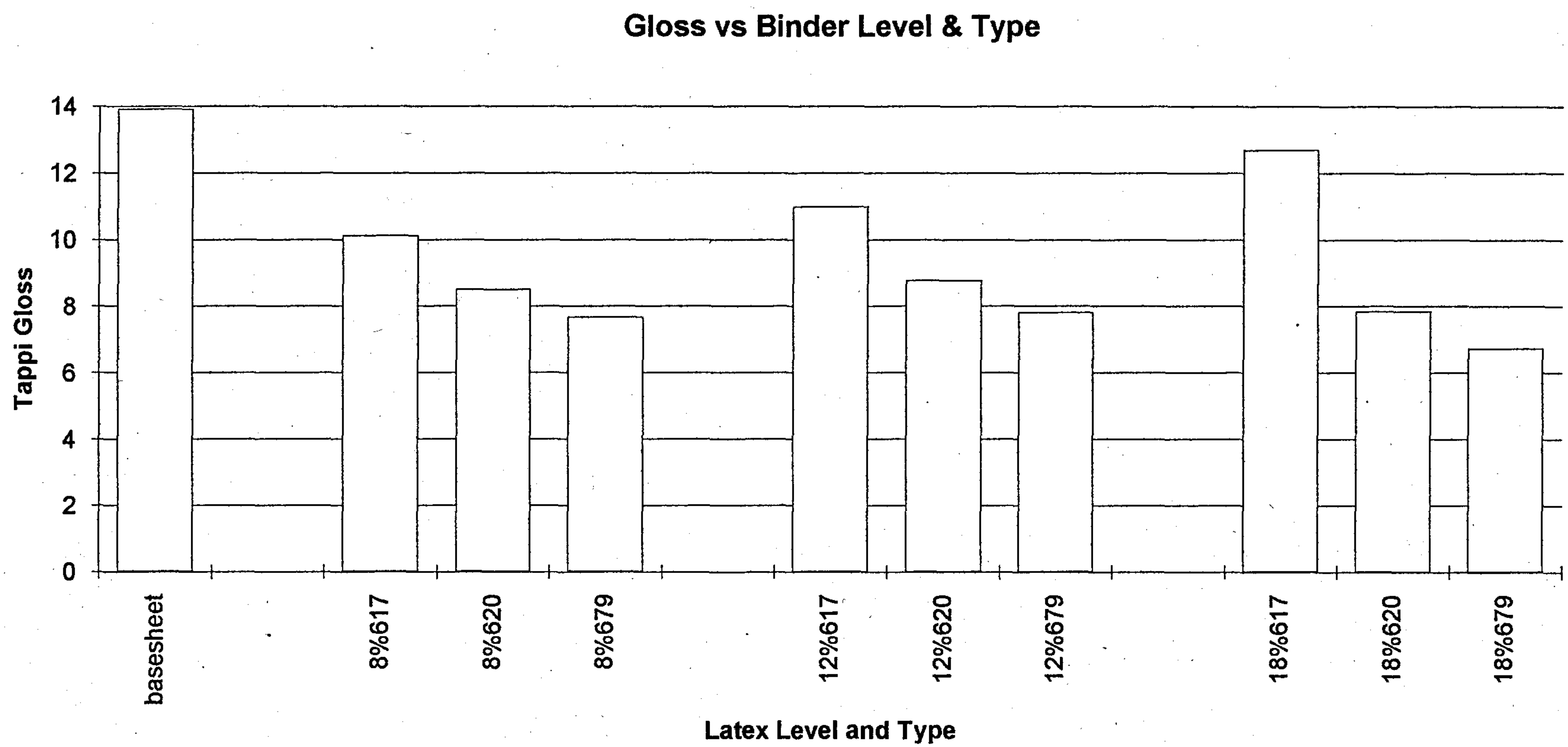
Brightness is a measurement of whiteness and another reason that eighteen percent binder had the highest brightness value may be because of the color influence that the styrene has. Styrene is a liquid and may add more whiteness to the coating which means an increased amount of styrene would result in a whiter sheet.

Once the styrene level in the latex drops below a certain point then the binder level takes over as the overriding variable. This explains why at the medium and low styrene content the brightness decreases with an increasing binder level.

GLOSS: Gloss is the property a surface has of reflecting light specularly, similarly to a mirror (Lavigne, 1996). Gloss is defined as the ratio of specularly reflected light to incident light and is a function of roughness. The gloss test was carried out according to Tappi standards which describes the specular gloss of paper at 75 degrees.

Gloss is the most important sheet characteristic of high quality coated sheets. Styrene butadiene latex is often used as the binder in grades such as magazine paper because of its improved response to gloss. High gloss gives the sheet a finished or polished look. Gloss is often measured after supercalendering because it increases the gloss values drastically. Supercalendering was not taken into account as a variable in this thesis.

The results of the gloss test are very similar to those of the brightness test. The data from the gloss test is graphed and placed on the next page in chart 3. Generally, a hard, low butadiene latex will give a higher gloss value due to its higher Tg. The gloss of coated papers usually increases with coat weight. An increasing amount of binder should


Gloss vs Binder Level & Type
Tappi Gloss
0
2
4
6
8
10
12
14
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

decrease the gloss value until the CPVC is met because more air filled voids become replaced with binder.

The data revealed that the overriding variable here was the butadiene content. An expected decreasing trend is seen as the butadiene content increased within all three binder levels. There were very slight decreases in gloss values as the binder level increased. There was a larger decrease in gloss values as the butadiene content increased.

There is a large change in gloss values between the low and medium butadiene content latexes and a small change in gloss values between the medium and high butadiene content latexes. Gloss decreases as a function of shrinkage (Lepoutre, 1992). A high butadiene latex undergoes more film shrinkage in the drying process than a low butadiene latex. This shrinkage damages the smoothness and gloss of a film (Abell, 1992). Hard latexes shrink least giving better gloss values (Lee, 1982). A low butadiene mix provides a high gloss and remains relatively constant as the butadiene was increased until a certain point where the gloss sharply declined. It then levels off again at a lower value as the butadiene content is increased further. This is explained in terms of binder film shrinkage as the binder coalesced (Groves et. al 1993). This suggests that there is a larger change in shrinkage between the Dow latex 617 and 620 and than there is between the 620 and 679.

A hard formulation, low butadiene content (high styrene) has a higher Tg and provides an open, brittle, and easy glossing coating. As mentioned earlier, high styrene latex should give the best gloss values because of its greater Tg (Fernandez,et.at 1983) The lower levels of butadiene (glassy state) should give the coating a higher void fraction and in turn higher gloss (Groves et. al. 1993).

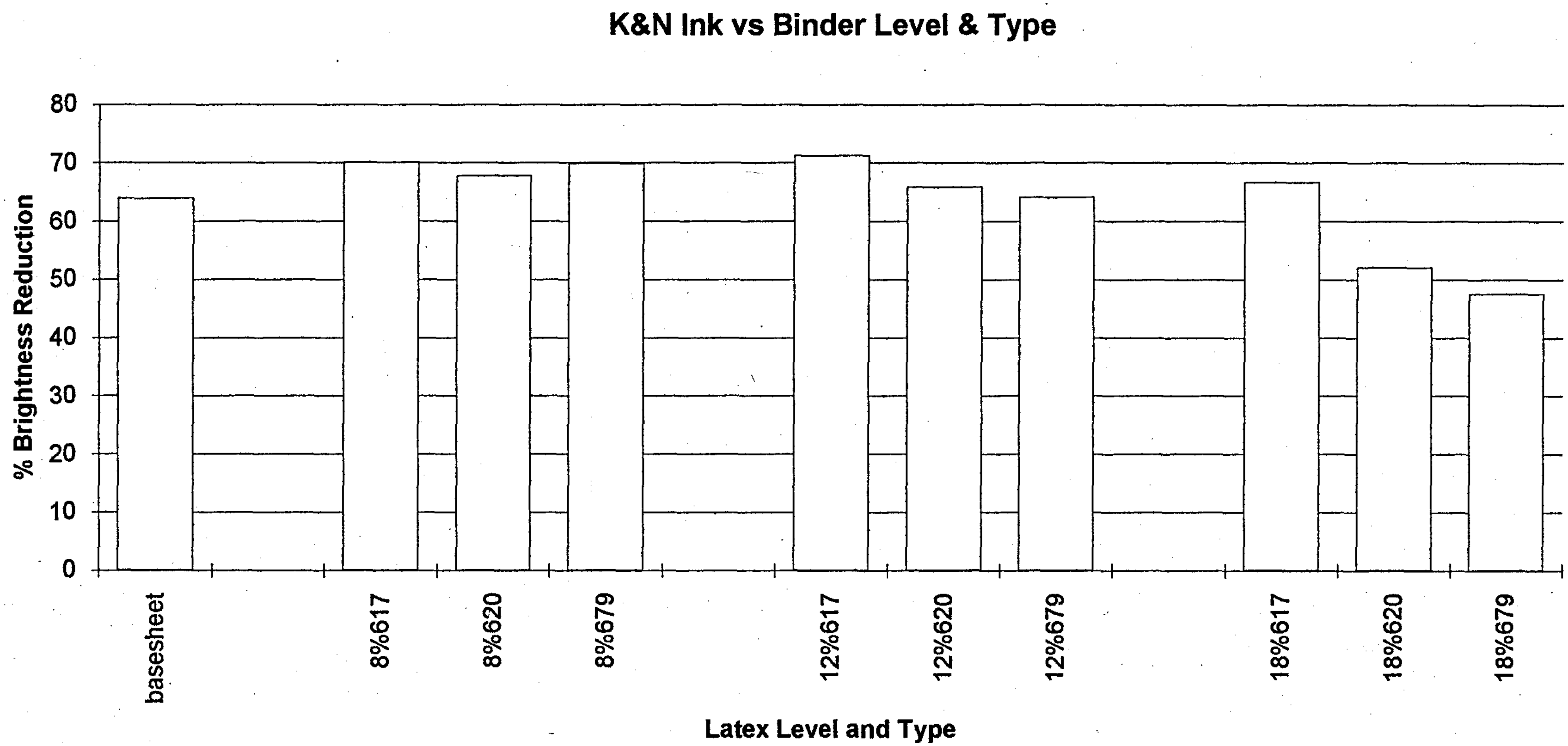
Chart 3 reveals that the best gloss values occurred with the latexes that contain the lowest amount of butadiene. The worst gloss values occurred at the highest butadiene level latexes. The highest gloss value occurred at the eighteen percent binder followed by the twelve percent binder and then the eight percent binder consecutively. This is similar to what happened in the brightness test. Ideally this order should be reversed with the eight percent binder having the highest gloss value because the shrinkage during drying can be minimized by using a lower binder level (Lepoutre, 1992). This shows that low butadiene content is more critical to gloss than the binder level. Another reason that the eighteen percent binder had higher gloss values may be because of its slightly higher coat weight. A higher coat weight usually means more fiber coverage and in turn increases light reflectance. Although the difference here in coat weight is less than half of a gram and should really play no role in the difference in the gloss values.

The eighteen percent binder also was a smoother sheet when compared to the other two binder levels. A smoother sheet also results in higher gloss. Gloss is dependent on both smoothness and void volume.

It was interesting to note that the base sheet, which had no coating applied to it, possessed the highest gloss values. This is unexpected because the coating should increase the gloss values. The gloss improves tremendously upon supercalendering. If the sheets were supercalendered, the gloss values would far exceed the base sheet values. The gloss values of the coated sheet should however be higher than the uncoated base sheet. Maybe the much more porous base sheet caused the gloss values to exceed those of the base sheet.

K&N INK: The K&N Ink test measures brightness reduction and in turn determines the amount of ink absorption on a coated sheet. The test was carried out according to Tappi standards. The brightness was taken of each sample before the K&N ink TK-1 was spread on the sample. The ink was allowed to set for two minutes before the excess ink was wiped off. The brightness was then taken again and the percentage of brightness reduction was recorded. The optimum values of the K&N Ink test depends on what is desired for that particular sheet. Sometimes ink absorption is desired and sometimes it is not. Usually the sheet with the lowest brightness reduction is more desired, as it was in this thesis. The K&N Ink test, because of its simplicity may not give a true picture of coating absorption performance (Lepoutre, 1992). K&N Ink may also be used as a measure of printability.

The results of the K&N Ink test were graphed and placed on the next page in chart 4. Surface roughness is a significant factor in determining ink penetration. Soft, flexible latex with a higher butadiene content (lower Tg) provide a higher quality sheet as a function of smoothness and compressibility (Fernandez et. al. 1983). Porosity plays a role in determining the ink setting speed. A porous sheet provides quicker ink setting (Lepoutre). The penetration of ink is controlled by porosity and the interfaces within layers between pigment surfaces and latex film surfaces (Joanicot et.al. 1993) The hard polymer content or low butadiene latex should give higher K&N ink receptivity and higher brightness reduction. The absorbency increases at lower butadiene contents due to the more open coating structure (Groves et. al. 1993). This means that the low butadiene latex has a higher brightness reduction therefore absorbing more of the ink.


K&N Ink vs Binder Level & Type
80
70
60
50
40
30
20
10
0
% Brightness Reduction
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

The same thing can be said as the binder level increases. As the binder level increases, the void fraction decreases and less of the ink gets absorbed resulting in less brightness reduction. This situation may be considered optimal or unacceptable depending on the grade and end use of the product.

According to chart 4, the results of the K&N Ink test follow these trends nicely. The lower butadiene content latexes exhibit the most ink absorption and the highest brightness reduction values. The eighteen percent binder with the high butadiene content gave the lowest brightness reduction values while the eight percent low butadiene latex gave the highest brightness reduction values. The K&N Ink trends follow the porosity trends nicely also (chart 8), implying that porosity is definitely a factor in determining ink absorption.

When comparing the K&N ink results of the base sheet to the coated sheet, it is noted that the base sheet exhibited values very similar to those of the coated sheet. This is unexpected due to the fact that the base sheet is so much more porous than the coated sheet that it should absorb much more ink and have a much higher brightness reduction value. This was not the case however and the base sheet's brightness reduction values imitated those of the coated sheet.

BINDING STRENGTH (ADHESION)

With the printing speed always on the rise, the demand for a coated sheet with good abrasion and pick resistance is on the rise also. The ease and strength of the film that is formed determines the binding strength of the coating to the base sheet. Film formation depends on time and temperature (Fernandez, 1983). These two process variables were held constant for all the runs. During the drying process, the latex structure shifts from discrete particles in water to a dry film where the strength properties of the latex are developed (Abell, 1992). Another key factor in determining the adhesion and coating strength is the pigment / binder interactions.

The binding strength of the coating depends on the adhesion of minerals, fillers, and cellulose. Adhesion is defined as a steady attachment due to molecular forces exerted across the surface of unlike liquids and/or solids which resist separation (Lepoutre, 1992).

Adhesion of the coating to the substrate takes place in three ways during the coating process. Electrostatic- at any boundary layer an electrical double layer is produced and the attraction of the electrical forces (charges) play an important in the strength of adhesion. Diffusion- the interdiffusion of chain segments take place during the film formation process. There are no clear interfaces, but there is a transition region. Absorption- intimate contact is necessary for intermolecular forces of attraction and the development of bonds (Lepoutre, 1992)

The main function of the binder is to give the coating its strength. Coating strength and flexibility should increase with an increasing binder content. This is because as more binder is added the void fraction is decreased. They should also increase with an increasing butadiene content. This is because a lower Tg gives a more flexible coating also resulting in a decreased void fraction. A lower Tg also means a lower minimum film forming temperature meaning that the coating undergoes coalescence at an earlier stage of drying usually resulting in a stronger film.

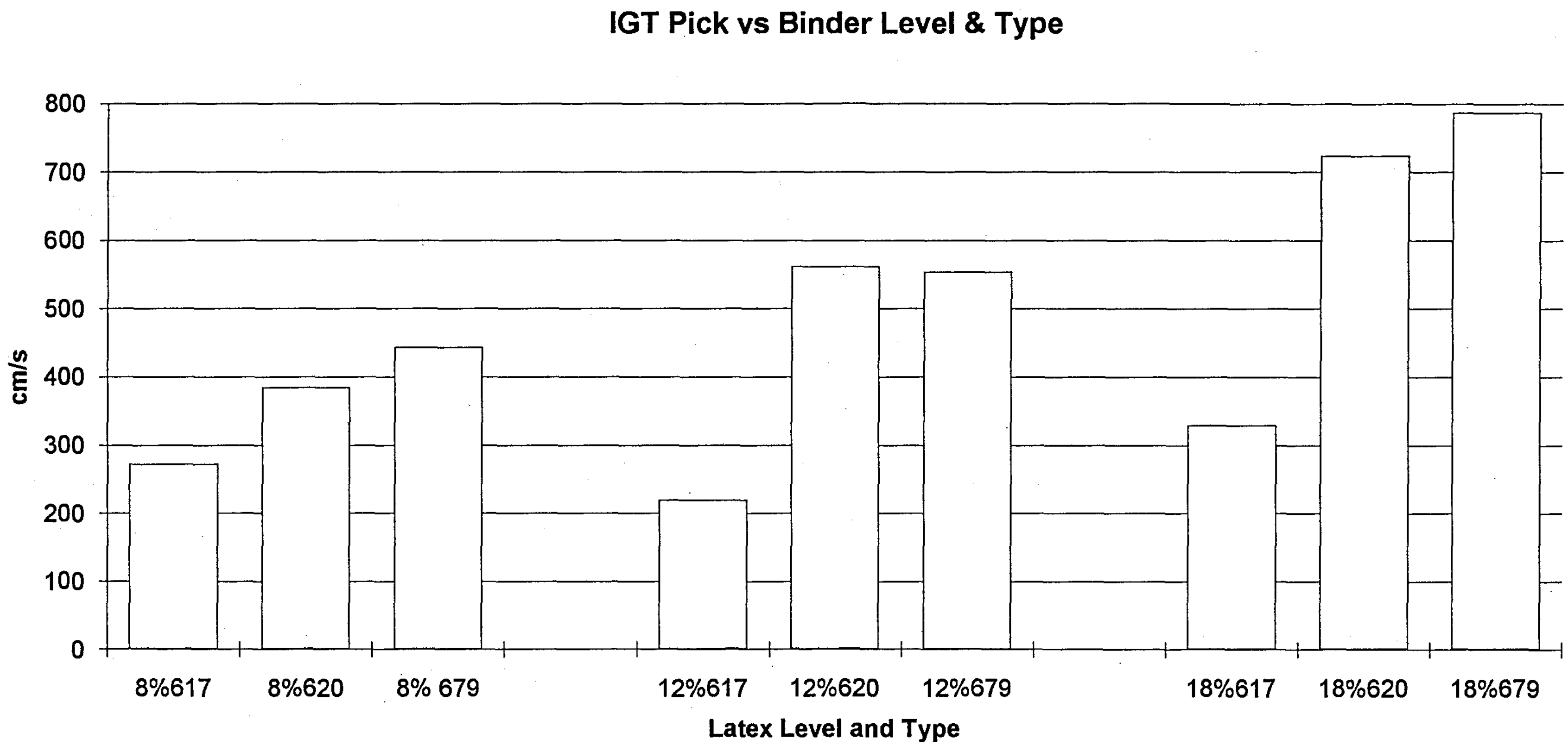
Three tests were performed to determine the binding strength of the coating. These three tests are IGT pick, Taber abrasion, and wet rub. All of these tests were carried out according to Tappi standards.

IGT Pick: The IGT pick test occurs at the fiber interface, not in the coating. The IGT pick test was carried out using a medium viscosity fluid with an application force of 35 kgf. The acceleration was set at 2 m/s^2.

The pick strength is controlled by the latex gel content. Generally as a rule, a high gel content provides better picking strength. Higher gel results in smaller pores improving the pick strength. Gel content is a measurement of the amount of residue when the film of the latex is dissolved in an organic solvent (Yamawaki et.al. 1991). There are other factors that play a role in determining pick strength also.

The pick strength, referring to the coatings resistance to pick away from the base sheet, should increase with an increasing butadiene content while the void fraction and Tg decrease. The pick strength should decrease with an increase in hard polymer content because a hard latex cannot form a film as easily or as strong as a soft latex (Sasagawa et. al. 1984). A porous structure should cause poor picking strength. In order to achieve good pick strength, the latex should provide a tight structure and small pores.

The results of the IGT pick test are graphed and placed on the next page in chart 5. The results follow the ideal trends for an increasing binder and butadiene content. It is shown that as the butadiene content and percent binder increase, the IGT pick strength increases also, as it should.


IGT Pick vs Binder Level & Type
800
700
600
500
400
300
200
100
0
cm/s
8%617
8%620
8% 679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

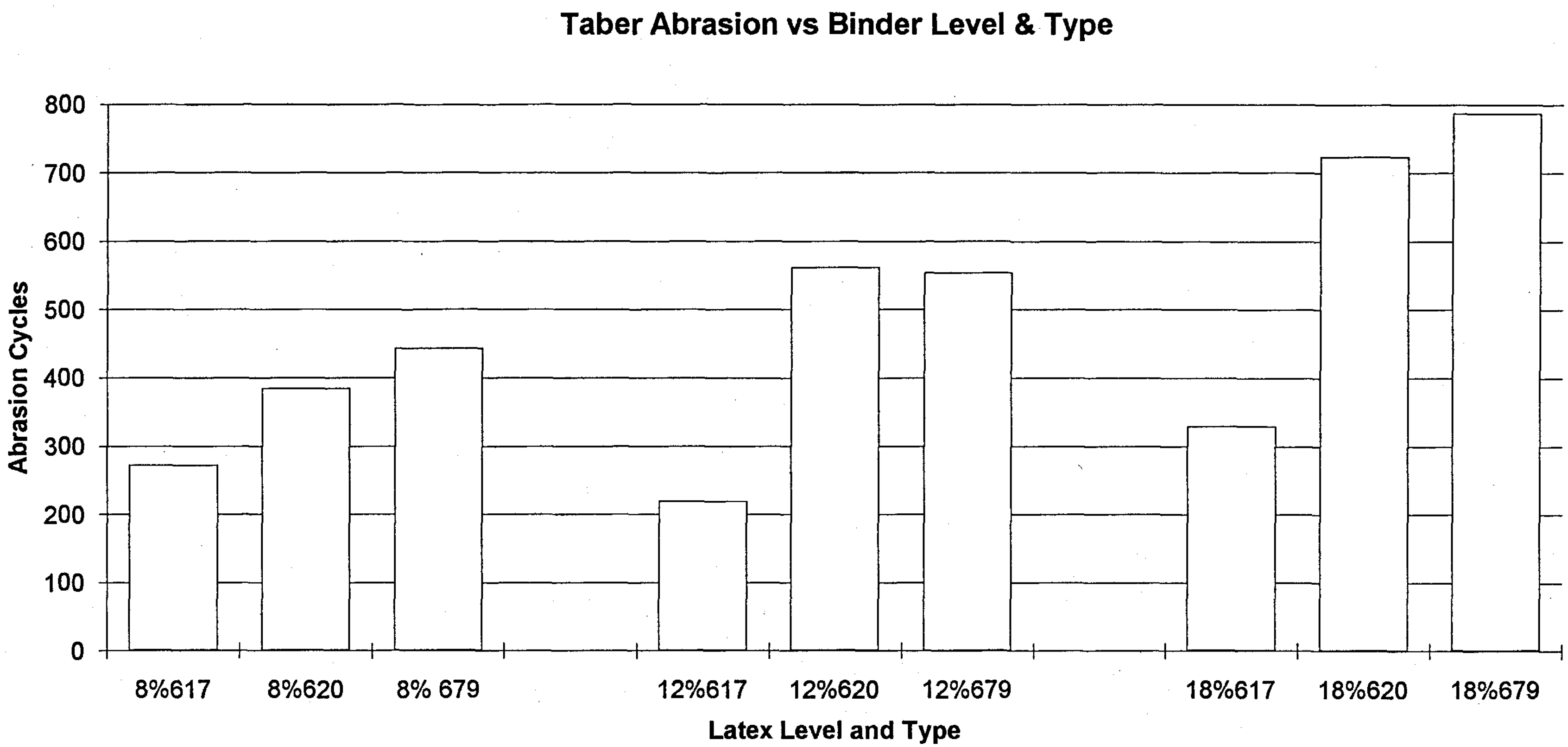
It is hard to distinguish if the butadiene content or the total binder level play a more important role in determining pick strength. When looking at the graph the incremental increase in pick strength is almost equal when observing the increase in butadiene and total binder. It does appear that there is a larger increase in pick strength when going from the twelve percent binder level to the eighteen percent. This implies that binder level plays a slightly more important factor in determining pick strength. The eight percent binder level possessed the lowest pick strength values while the eighteen percent binder level possessed the highest pick strength values. Within each binder level the high butadiene content latex possessed the highest pick strength value. This is expected also because the correlation between pick strength and porosity. The results of the pick test follow the porosity trends nicely (chart 8) in that as the porosity value decreases, the IGT pick strength increases.

TABER ABRASION: Abrasion resistance strength is now an important printing consideration due to the high speed of the printing process today. The Taber abrasion test is similar to the IGT pick test in that it tests the binding strength of the coating to the base sheet. A sample of the coated sheet was placed on a turn table where two abrasive wheels rotate on the sample as the turn table revolves. The number of cycles were counted until the coating began to wear off and paper fibers could actually be seen where the coating was worn right off the sample. The sample was weighed before and after the test to determine how much coating was removed by the abrasion. The test continued until .022 $\pm$ .005 grams of coating was removed. Then the number of cycles it took was recorded.

This test actually measures the amount of abrasion that a sheet can endure before the coating begins to peel away from the base sheet.

A higher binder content increases the binding strength of the coating therefore, the latex formulations with the higher percent binder should provide the higher abrasion strength. The coating abrasion strength means the resistance to peel or flake away upon prolonged exposure to abrasion. The strength and elongation of the film increase with an increase in binder content (Lepoutre, 1992). A higher butadiene content should also provide improved abrasion strength compared to a lower butadiene content. This is because a higher butadiene content provides a softer, stronger, more flexible coating by a reduced Tg. A high butadiene content coating is stronger and more flexible because of its higher bonding area due to its low Tg. Higher binder level and butadiene content usually indicate a less porous more tight coating structure that is more resistant to flaking off the base sheet while abrasion is present.

The results of the Taper abrasion test are graphed and placed on the next page in chart 6. The abrasion resistance comes from the strength of the coalesced latex film (Abell, 1992). It can be seen from the data that there is a large jump in abrasion strength between the low butadiene content and the medium butadiene content latex. This is because with an increase in butadiene, the latex film dries quicker usually resulting in a stronger adhesive binder. This data shows that there is a definite drop off point between the medium and low butadiene content latex (Dow 620, 617 respectively), but not as drastic a drop off between the high and medium butadiene content latex (Dow 679, 620 respectively). This implies a large step change between latex with thirty-four and thirty-


Taber Abrasion vs Binder Level & Type
Abrasion Cycles
800
700
600
500
400
300
200
100
0
8%617
8%620
8% 679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

seven percent butadiene and then a leveling off affect when the butadiene is increased beyond thirty-seven percent.

There is also quite drastic changes in abrasion strength between binder levels. A substantial increase in abrasion strength is observed as the binder level is increased from eight to twelve to eighteen percent binder. This implies that binder level plays an important role in determining abrasion resistance. This is especially seen in the high butadiene content latex. An increase of over one hundred cycles is seen in the high butadiene content latex between eight and twelve percent binder level, and then again between the twelve and eighteen percent binder level.

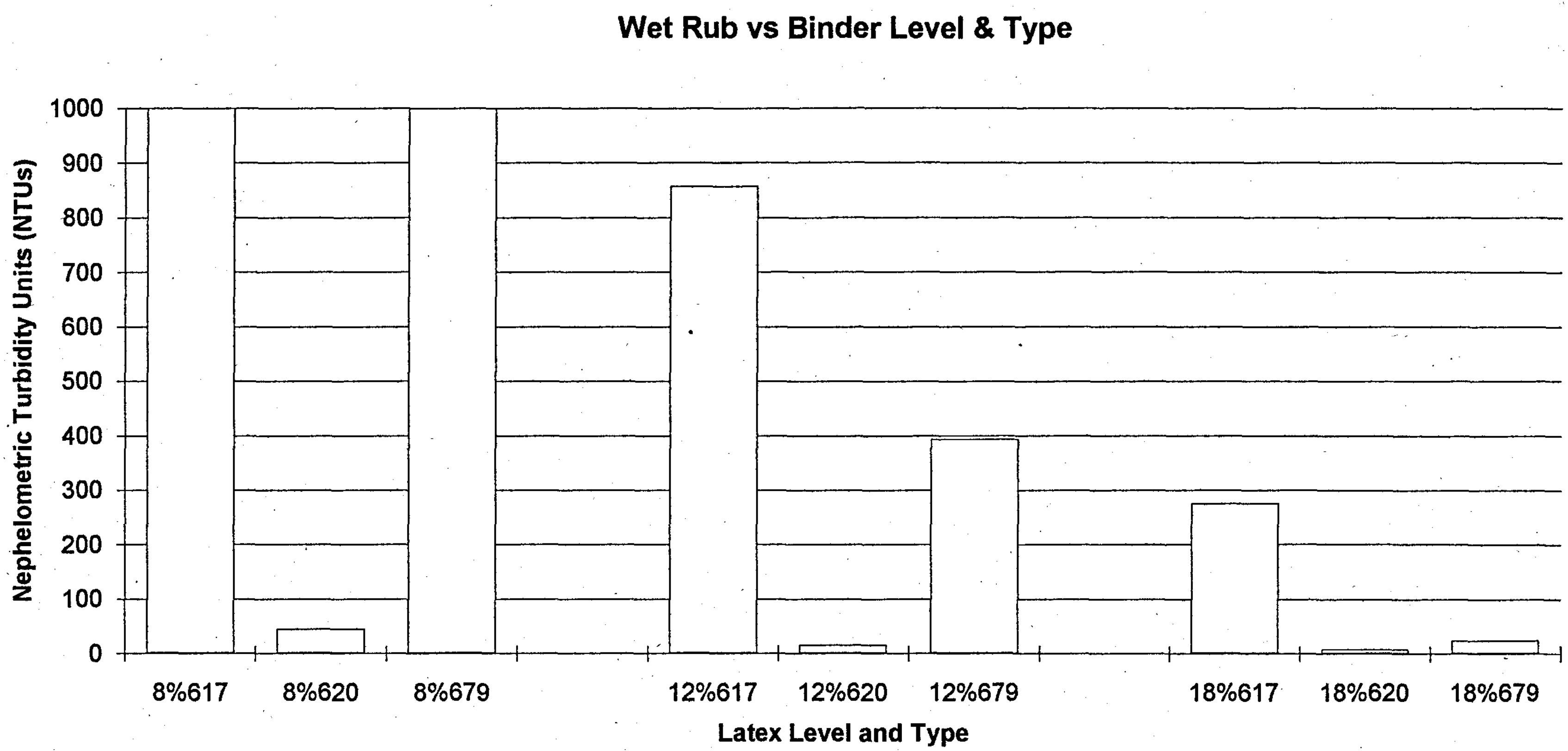
These trends also follow the porosity value trends (chart 8) but seem to be more drastic. It is seen that as the porosity values decrease, the abrasion strength increases. This makes sense because of the tighter coating structure represented by lower porosity values. This implies that the porosity may also play a role in the abrasion strength of the coating.

WET RUB: The wet rub tests the binding strength of the coating after it has been re-wetted. A sample strip is attached to a spindle which comes into contact with a rotating wheel that is partly submerged in water. When the sample spindle is in contact with the wheel, a motor is turned on which rotates the wheel at a constant velocity and because the sample spindle is in contact with the driven wheel, it rotates in the opposite direction. The driven wheel is constantly moistened and cleaned by the reservoir of distilled water that the driven wheel is partially submerged in. This test had a duration of one minute. When the test was over, the reservoir water was placed in a test tube and the turbidity of that water was measured. The turbidity was measured in Nephelometric Turbidity Units (NTUs). As the coating was wore off of the sample by the wet driven wheel, it caused the reservoir to become more turbid or cloudy. The lower the NTU value of the reservoir water, the more resistant the coating was to wet rub. The receiver water is desired to be more transparent because this means the coating has a stronger resistance from being rubbed off while wet.

There was little information found on the wet rub test and the effects of butadiene content and binder level on that test. It is known that a higher butadiene content and binder level offer a stronger coating resistance to abrasion and pick, so it is hypothesized that they would also provide stronger wet rub resistance. The results of the wet rub test are graphed and placed on the next page in chart 7.

According to the data it was discovered that there is a sharp decline in turbidity units as the binder level rose. This is true for all butadiene contents. This implies that binder level plays an important role in the determination of wet rub values for various coatings. This was hypothesized and expected.

As the butadiene level rose within each binder level, a different trend was observed. As the butadiene content was raised from a low to high level, the graph was shaped like a U with the medium butadiene content (Dow 620) giving the lowest turbidity values and therefore the best wet rub resistance. This implies that the medium, or normal, butadiene content (37%) is the optimum butadiene content for wet rub resistance. In all the binder levels, the low butadiene content latex gave the poorest wet rub values. This makes sense because a low butadiene latex gives a stiff, brittle coating with low adhesive



Wet Rub vs Binder Level & Type
Nephelometric Turbidity Units (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

strength. The turbidity of the high butadiene latex was significantly lower than the low butadiene latex, yet still more turbid than the medium butadiene level latex.

The results of the wet rub test show that the optimum butadiene content is thirty-seven percent. Any butadiene level higher or lower will result in a decrease in the wet rub resistance. This may be because the water breaks down the adhesiveness of the butadiene, when it is present in a higher content, causing the coating to wash out in the reservoir. The level of carboxylation of the individual latex may have also played a role in determining the wet rub values. A higher level of carboxylation would be more reactive with water. However, all the latexes used should have been at the same low level of carboxylation. The optimum wet rub resistance was shown to occur at eighteen percent binder with a medium butadiene content. The poorest wet rub resistance occurred at eight percent binder with a low butadiene content.

STRUCTURAL CHARACTERISTICS

The structural characteristics of porosity and roughness were tested on the samples not only to determine the effects that butadiene content and binder level have on them, but also to help clarify the other optical binding characteristics of the coated sheet. Both porosity and roughness (smoothness) are very important in determining ink transfer and overall printability. Higher porosity corresponds to higher ink settling speed. The optimum coated sheet should have good porosity values by having a large number of small size pores which also give good smoothness values (Sasagawa et. al. 1984). There are definitely some correlations between porosity and roughness to the other sheet characteristics as was discussed earlier.

PARKER PRINT POROSITY: It is expected that latex with a higher Tg (low butadiene content) will give a more porous coating. This is because the higher Tg causes the coating to become stiffer more brittle and contain more pores during the drying process. A low butadiene latex causes an increase in the void fraction of the coating. This increase in void fraction offers more light scattering potential which is desirable for enhanced optical properties.

If the coating contains a high butadiene content then the coating is soft and flexible resulting in less pores and film shrinkage during drying. A high Tg latex does not pack as dense as a low Tg latex resulting in more pores before the bulk of the drying takes place. These pores get enlarged during the film shrinkage which occurs in the drying process. Void fraction is expected to decrease with an increase in butadiene content. This is controlled by coating shrinkage upon drying and in turn related to film formation (Groves et. al 1993).

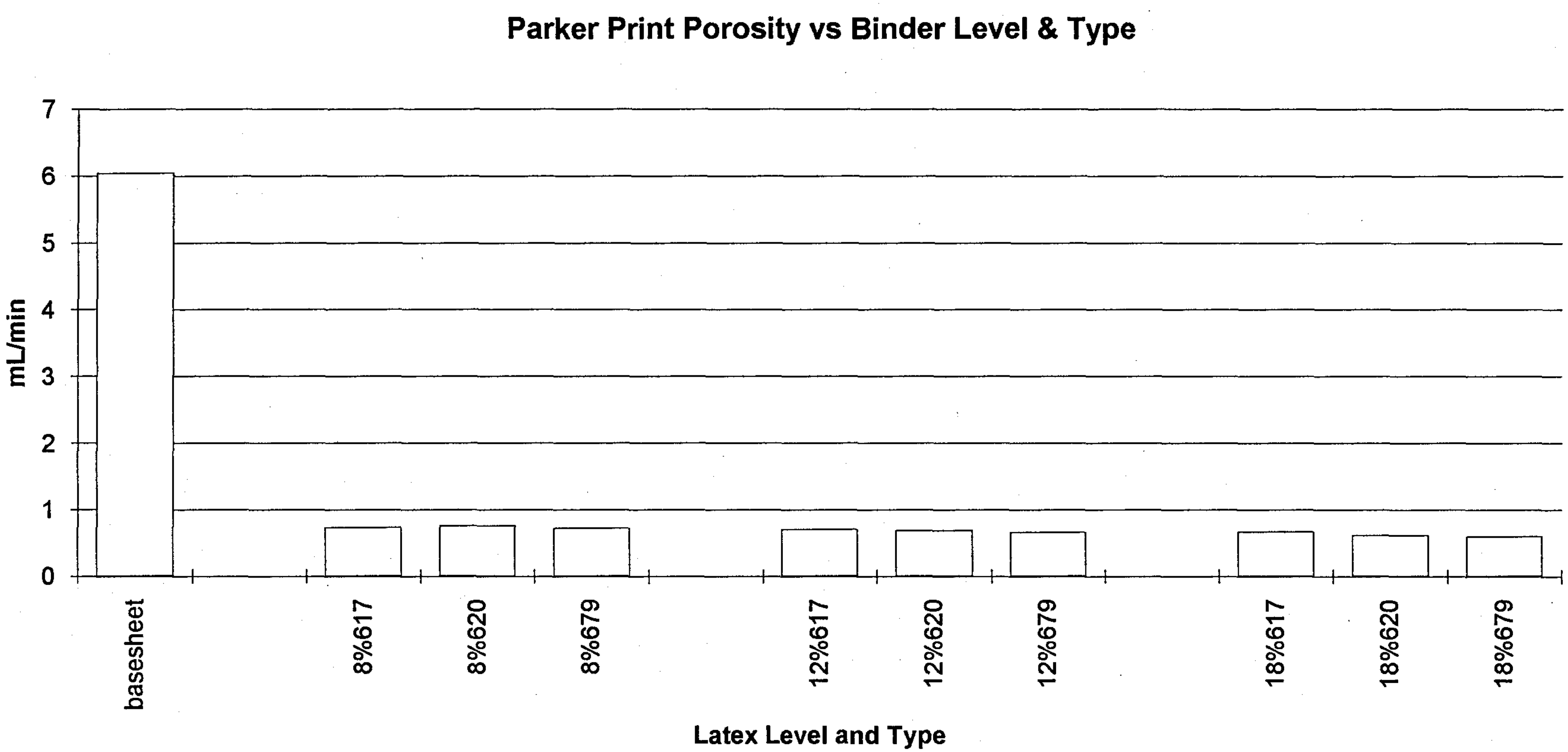
The less binder that is used in the coating also results in higher void fraction and therefore porosity (Lepoutre, 1992). The porosity of the base sheet is much higher than that of the coated sheet. This is because the coating tends to cover the void areas of the base sheet reducing the porosity and improving the smoothness. The porosity measurement of the coated sheet measures the porosity of the coating more so than that of the base sheet. The final dried coating is actually a porous structure of pigment particles that are cemented together at points of contact by the binder (Smook, 1992). This porous structure can begin to fill if the voids are filled in by an excess amount of binder reducing the porosity.

The data from the results of the Parker Print porosity test are graphed and placed on the next page in chart 8. It is expected that as the butadiene content and binder level increase, the porosity of the coated sheet will decrease.

The base sheet shows the best porosity value which makes sense because after the sheet is coated the pores get covered by the latex films. The highest porosity values occur at the three eight percent binder latex formulations and the poorest porosity values all occur at the eighteen percent binder level. This implies that the binder level is the overriding effect on porosity. The high butadiene content coating at eight percent binder has a higher porosity value than the low butadiene content coating at twelve percent and so on. This further illustrates the dominance that binder level has on porosity.

The best porosity value occurred at the medium butadiene content eight percent binder level. This is a little bit higher than the low butadiene content eight percent binder, more than likely due to the slightly lower coat weight. A lower coat weight will result in a higher porosity. The resulting data of the rest of the coating formulations follow the expected trends nicely. The porosity decreased in the binder levels as the butadiene content increased. This is expected. The binder level, having an important effect on porosity, caused the porosity values to significantly decrease as the level of binder increased from 8% to 12% to 18%.

PARKER PRINT ROUGHNESS: The degree of roughness is related to the level of fiber bonding and stresses within the sheet (Yun-Long et. al 1993). The Parker Print method tests roughness of the sheet in units of microns. The lower the roughness value is, the smoother the sheet. Here, the structural characteristic will be in terms of smoothness.



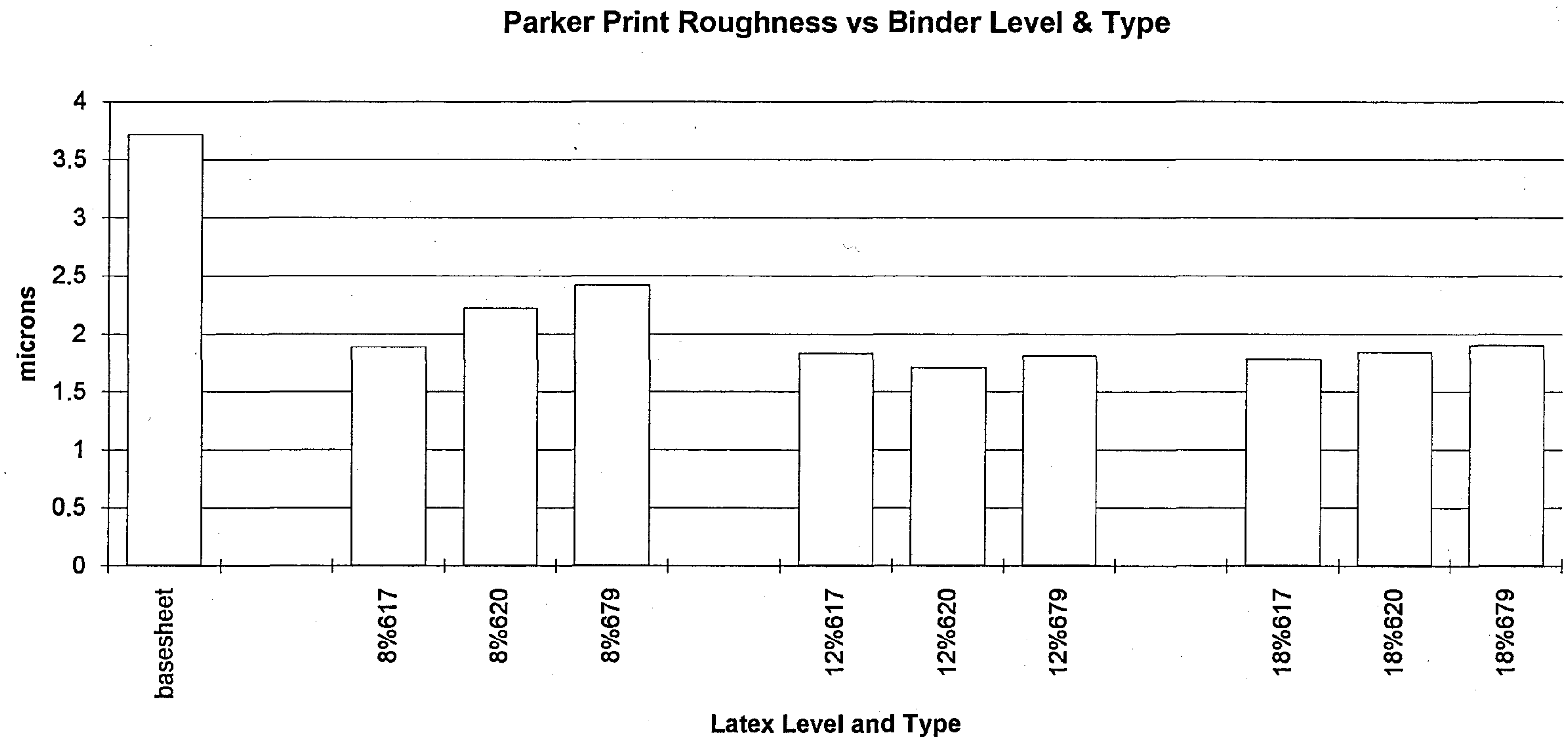
Parker Print Porosity vs Binder Level & Type
mL/min
7
6
5
4
3
2
1
0
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

The coating is applied to cover the void areas of the base sheet, providing a smoother, more even surfaced sheet enhancing the quality of printability. It is important to realize that no coating formulation can compensate for a poor, extremely rough raw stock base sheet (Smook, 1992).

The gloss values are partially dependent on the smoothness of the sheet. As macroscopic smoothness increases, the gloss increases. Smoothness or eveness of the coating is strongly influenced by film shrinkage which is affected by binder migration and pigment / binder interactions.

Latex with good film formability tends to coalesce and forms a film more easily in the coating layer at an earlier stage of drying corresponding to a lower Tg or higher butadiene content. The early film formation is bad because the solids immobilize sooner giving a disorder of pigments which result in rough coating layer surface (Sasagawa et. al 1984)

The data of the results of the Parker Print roughness test are graphed and placed on the next page in chart 9. It can be seen from the graph that the base sheet possessed the lowest smoothness value. This makes sense because one of the reasons for coating a base sheet is to improve its smoothness. The smoothness increased drastically after the sheet was coated. Overall, all the coated sheets possessed very high smoothness. The smoothest sheets seemed to occur at the twelve percent binder level, this implies that twelve percent binder is the optimum level for smoothness and twelve percent is the normal binder content in most coatings. This may be because the twelve percent binder may provide the best binder migration resulting in a more even coating surface when it



Parker Print Roughness vs Binder Level & Type
4
3.5
3
2.5
2
1.5
1
0.5
0
microns
basesheet
8%617
8%620
8%679
12%617
12%620
12%679
18%617
18%620
18%679
Latex Level and Type

entered the drying section. The twelve percent binder provided adequate adhesion to the base sheet at the minimal amount of binder resulting in less shrinkage.

The eight percent binder level gave the poorest smoothness values or the roughest sheet. This may be because the low binder level did not adhere the coating to the base sheet well enough resulting in poor base sheet coverage and a rougher sheet. The 18% binder level smoothness values were slightly lower but very similar to the twelve percent binder level. They may be slightly lower because a higher binder level results in more film shrinkage. When the film shrinks the surface becomes uneven resulting in a rougher sheet. There is very little difference in smoothness when going from twelve to eighteen percent binder for all three butadiene levels. There is a noticeable increase in smoothness when going from eight to twelve percent binder, especially in the medium and high butadiene content latexes. This implies an increase in smoothness until the twelve percent binder level is reached then a leveling off effect takes place.

When the butadiene content increased, the general trend was a rougher resulting sheet. This is because a higher butadiene content has a lower Tg and lower minimum film forming temperature. A lower film forming temp means that the film forms more quickly and is exposed to more heat resulting to a disorder of pigment particles and a rougher sheet. The optimum smoothness value occurred at the medium binder level and the medium butadiene content. An increase or decrease in either binder level or butadiene content may result in a less smooth sheet.

CONCLUSIONS

The conclusions to this thesis project will hopefully be used as reference in future experimentation, or an insight to binder development in the industry. There were definite trends in data as the styrene to butadiene ratio changed and also when the binder level changed. By varying the ratio of the SBR latex in which they are used to make the coating, the coaters have a great deal of latitude in adjusting overall binder and coating properties to fit their needs (Abell, 1992).

The most desirable optical properties of gloss, brightness, porosity, and opacity are all interdependent (Lee, 1982). They are all affected by the varying latex binder in the coating formulation. It can be seen that for the optical properties of opacity, brightness, and gloss, there is a general decrease in values as the butadiene content increased.

The opacity of the eight percent binder level showed a steady decrease in value as the butadiene content increased. The opacity values for the twelve and eighteen percent binder level stayed relatively constant and their values were very similar even as the butadiene content rose. The binder level seemed to play an important role in opacity because once twelve percent binder was reached, the opacity values did not change much even as butadiene content increased. It is important to note that all the opacity values were very similar indicating that is was only slightly affected by the variations in butadiene content and binder level.

The brightness property showed a definite decrease in value as the butadiene content increased. When the binder level was increased the brightness values decreased also. However for the low butadiene content latex, the brightness values increased as the binder level increased. The other latexes all decreased as the binder level increased.

The gloss value trends were identical to those of the brightness value trends. There was a definite decrease in gloss values as the butadiene content increased in all three binder levels. It was seen however that as the binder level increased so did the gloss values for the low butadiene content latex. The medium and high butadiene content latexes both decreased in gloss value as the binder level increased.

The K&N ink absorption test showed expected trends. As the butadiene content increased, percent brightness reduction decreased indicating less ink absorption. It can also be seen that as the binder level increased, the percent brightness reduction decreased also. This is because of the less porous sheet.

When the binding strength of the coating was tested, different trends appeared in the data. A higher butadiene content and an increased binder level seemed to offer improved coating adhesion to the base sheet. It can be seen that generally as the butadiene content and binder level was increased, the strength properties of IGT pick, Taber abrasion, and wet rub increased.

The Taber abrasion test showed definite increases in strength values as the butadiene content increased throughout all three binder levels. A drastic jump in abrasion resistance occurred between the low butadiene content and the medium butadiene content latex suggesting that butadiene content plays an important role in abrasion strength. There was a little step increase in abrasion strength when going from the medium to high butadiene content implying a type of threshold point at thirty-seven percent butadiene.

The data also showed that the binder level played just as important a factor as the butadiene content. The abrasion strength values underwent a large increase between the binder level increase from eight to eighteen percent.

The IGT pick resistance test had results similar to the Taber abrasion results but not as drastic. It can be seen that as the butadiene content increased, the IGT pick strength increased during all three binder levels. It can also be seen that as the binder level increased so did the pick strength. A higher increased in pick strength when the binder level was increased, implying that and increase in binder level is a more influencing factor than an increase in butadiene content.

The results of the wet rub test were uniquely different than those of the other binder strength test. The wet rub test showed the strongest wet rub resistance occurred at the medium butadiene content in all three binder levels. It showed that the wet rub strength increased drastically from the low to the medium butadiene content latex, then decreased drastically when going from the medium to the high butadiene content latex. This implies that at thirty-seven percent butadiene, there is a peak as far as wet rub strength goes because a higher or lower level of butadiene will cause a decrease in wet rub strength. A sharp increase in wet rub strength occurred as the binder level increased from the eight to the twelve percent and again from the twelve to the eighteen percent binder. This sharp increase in value implies that binder level is a major factor in improving wet rub strength because as the binder level increased so did the wet rub strength.

The structural properties of porosity and roughness were also tested to complement the optical and adhesive properties of the coated sheet. It can be seen from the results of the porosity test that as the butadiene content increased, the porosity value decreased in all three binder levels. It can also be seen that as the binder level increased, the porosity value decreased within all three butadiene content latexes. The decrease in porosity was similar when comparing it against the changing butadiene content and binder level.

The results of the roughness test showed that as the butadiene content increased so did the roughness causing a less smooth sheet. A very smooth sheet was made when the base sheet was coated with all the various coatings and there roughness values were all very similar. An increase in smoothness occurred between the eight and twelve percent binder level and then leveled off because the smoothness values of the twelve and eighteen percent binder were very similar. This implies that once the twelve percent binder level was reached, the smoothness became relatively unaffected by increasing the binder level more to eighteen percent.

Overall it can be stated that a low butadiene content latex provides a higher Tg resulting in a more open, brittle, and easy glossing coating. The high butadiene content latex provides a lower Tg resulting improved film formation and adhesive strength. A higher Tg will also require more energy for drying in order for the film to fully develop.

When looking at all the results it can be stated that the binder level is definitely the overriding factor in determining the binder strength properties. The better strength properties occurred at the higher binder level. When looking at the optical brilliance of the coated sheet it can be stated that the butadiene content plays just as important a factor as the binder level. Therefore when comparing all the data, the eighteen percent low butadiene content (Dow 617) provides the best all around coated sheet properties. It is understood that the twelve percent medium butadiene content latex (Dow 620)is the most common type of latex binder coating formulation. The medium butadiene content latex at the medium binder level probably provides the best coated sheet properties for its price. Economically it may not be as feasible to make coating dispersions at eighteen percent binder, even though it provides better sheet properties. The increase in coated sheet quality may not overcome the increase in cost which would occur to make best coating formulation.

It is important to realize that no coating formulation can compensate for a poor raw stock base sheet. A quality coated sheet can only be produced from a quality base sheet free from defects.

RECOMMENDATIONS

The need for further research and experimentation exists due to the ever increasing demand for a high quality coated sheet. This thesis work can open the door for further study in many different ways. It is important to isolate one variable and optimize it because it is hard to determine the final effects on a coated sheet if many different variables are involved.

Instead of concentrating on binder level and type, the pigment portion of the coating dispersion could be isolated. Type of pigment and its optimum substitution could be studied to find more information about the coated sheet.

Further study can be done by actually printing the coated sheet. This would help determine the effects that a varying styrene-butadiene ratio and binder level has on the printability of the coated sheet. Print gloss and ink resolution could be tested after the samples were printed to give a value of the printability and quality of the coated sheet.

Another area for further research would be to study the effects of supercalendering on the various coated sheets. That would help determine which styrene-butadiene ratio and binder level has the best and most desired response to supercalendering.

The technology now exits to make latex coating that possesses any desired glass transitional temperature. This would make it possible to test the extremes of the Tg and its effects on the coated sheet. One test that could be done is the yellowing of the sheet as it ages or gets exposed to ultra violet light.

The other variables of printing the sheet, or supercalendering the sheet are just some of the many different variables in addition to the variable of binder level and type that can be tested to determine any detrimental effects on the coated sheet. Maybe a breakthrough will occur that will take the coating paper process by storm.

LITERATURE CITED

Abell, Steven. "Reinforced Film Binder Creates New Coating Structure." 1992 Tappi Coating Conference. pg 95-103.

Eklund, R.W. and H.A. LeBlanc and D.G. Halley "The Cylindrical Laboratory Coater (CLC)--A New High Speed blade Coater for the Laboratory." 1988 Tappi Coating Conference. pg 81-87.

Fernandez, J. "Binder Influence on Rotogravure Printability" 1983 Tappi Coating Conference. pg 137-153.

Frick, B. and D Richter. "The Microscopic Basis of the Glass Transition in Polymers from Neutron Scattering Studies." Science. March 31, 1995. vol 267. pg 1939-1945.

Groves, R. and J. Penson. "Styrene-Butadiene Latex Binders and Coating Structure." 1993 Tappi Coating Conference. pg 187-194.

Joanicot, M. "Structure of Latex Films." 1993 Tappi Coating Conference. pg 175-184.

Landes, Chester and Leonard Kroll. Paper Coating Additives. McDaniel Printing Co. Atlanta, GA 1978.

Lavigne, John. Paper Industry Instrumentation. Foxboro Company. Foxboro, MA 1996.

Lee, D.I. "Development of High Gloss Paper Coating Latexes." 1982 Tappi Coating Conference. pg 125-135.

Lepoutre, P. "Adhesion and Cohesion in Paper Coatings." 1992 Tappi Coating Conference. pg 1-4.

Ming, Y. "Latex Particle Behavior in Paper Coating examined by Low Voltage Scanning Electron Microscopy" 1995 Tappi Coating Conference pg 391-394.

Sasagawa, Yasuhiko and Akira Tsuji. "The Effects of Latex Properties on Paper Coating Structure." 1984 Tappi Coating Conference. pg 93-103.

Scheller, Brian. "Paper 342 Course Packet" Coating Process 1996. Western Michigan University Copy Desk.

Smook, G.A. Handbook for Pulp & Paper Technologists. Angus Wilde Publications, Bellingham, WA. 1992.

Takahashi, K. and K. Matsumoto. "A New Composite SBR for Paper Coating." 1984 Tappi Coating Conference. pg 27-35.

Van Gilder, R.L. "High Solids Latexes for Paper Coatings." 1983 Tappi Coating Conference. pg 123-134.

Wernett, P.C. and N. Sanders. "Direct Measurement of the Strength of Coating Pigment Binder Interactions" 1995 Tappi Coating Conference. pg 407-416.

Yamawaki, Kazumasa. "The Improvement of SB-Latex for Web Offset Coated Paper." 1991 Tappi Coating Conference. pg 199-204.

Yun-Long, Pan and Joseph Borovsky. "Effect of Papermaking and Coating variables on offset print quality." 1993 Tappi Coating Conference. pg 105-108.

APPENDIX

The appendix contains information about the Dow latexes that were used in this experiment, the average values resulting from each of the tests, the coating formulation makeup, and the properties of each coating formulation.

Dow Latex Characteristics: The following information is unique to the type of latex that was received from the Dow Corporation. All latex possessed a low level of carboxylation.

	617	620	679
Tg	18 C	12 C	-10 C
Minimum film forming temp.	17.2 C	15.6 C	7.2 C
Percent Styrene (styrene:butadiene)	66 (1: .5)	63 (1: .6)	56 (1: .8)

Optical Brilliance: The following tests were completed to test the optical properties of the coated sheet. Fifteen runs were made for each test and the average value was calculated along with the standard deviation.

Binder	OPACITY(%)		BRIGHTNESS(%)		GLOSS(Tappi)		K&N INK(%)	
Formulation	Avg	SD	Avg	SD	Avg	SD	Avg	SD
8% 617	86.35	.47	83.17	.09	10.11	.3	70.2	
8% 620	85.42	.45	82.92	.15	8.50	.74	67.8	
8% 679	84.05	.57	82.87	.11	7.67	.35	69.9	
12% 617	84.69	.35	83.43	.15	10.99	.58	71.3	
12% 620	86.01	.56	82.83	.11	8.77	.43	65.9	
12% 679	84.88	.39	82.98	.12	7.81	.44	64.2	
18% 617	84.51	.51	83.48	.15	12.69	.68	66.7	
18% 620	85.10	.46	82.50	.27	7.84	.26	52.1	
18% 679	84.71	.71	82.58	.21	6.73	.53	47.6	
base sheet	77.9	.66	81.49	.35	13.9	.65	64.0	

Adhesion / Binding Strength: The following tests were completed to test the binding strength of the coating to the base sheet. Five runs were done for each test and the average value was calculated along with the standard deviation.

Binder Formulation	WET RUB(NTU) Avg	WET RUB(NTU) SD	ABRASION(Cycles) Avg	ABRASION(Cycles) SD	IGT PICK(cm/s) Avg	IGT PICK(cm/s) SD
8% 617	>>1000		272	28	139	11.2
8% 620	45	4.9	384	11	157	4.7
8% 679	>>1000		443	30	164	7.8
12% 617	857	48	219	21	158	8.9
12% 620	15.75	.43	562	9	176	15.8
12% 679	392.5	39.6	554	29	180	11.7
18% 617	275	42	329	38	200	9.2
18% 620	7.8	.78	724	11	215	4.2
18 % 679	24.25	.83	787	23	210	4.3

note: The average coating loss from the Taper Abrasion test was .022g with a standard deviation of .005

Structural Characteristics: The following tests were completed to test the structural characteristics of the coating on the base sheet. Fifteen runs were done for each test and the average value and standard deviation were calculated.

Binder Formulation	POROSITY(ml/min) Avg	POROSITY(ml/min) SD	ROUGHNESS(microns) Avg	ROUGHNESS(microns) SD
8% 617	.73	.06	1.89	.11
8% 620	.76	.04	2.22	.16
8% 679	.72	.04	2.42	.14
12% 617	.71	.07	1.83	.07
12% 620	.69	.05	1.71	.07
12% 679	.66	.06	1.81	.05
18% 617	.67	.04	1.78	.08
18% 620	.62	.05	1.84	.07
18% 679	.60	.05	1.90	.09
base sheet	6.04	1.07	3.72	.21

COATING FORMULATION
MAKE-UP CHART

8% binder

Ingredient	pph	% solid	wet weight	total addition for 3000g OD
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 617	8	49.2	16.3	489
water			17.4	521.8
total	108		156.8	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 620	8	50	16	480
water			17.7	531
total	108		156.5	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 679	8	49	16.3	489
water			17.4	521.8
total	108		156.8	

12% binder

Ingredient	pph	% solids	wet weight	total addition for a 3000g OD
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 617	12	49.2	24.4	732
water			15.7	471
total	112		164.9	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 620	12	50	24	720
water			16.1	483
total	112		164.5	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 679	12	49	24.5	735
water			15.6	468
total	112		165	

18% binder

Ingredient	pph	% solids	wet weight	total addition for a 3000g OD
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 617	18	49.2	36.6	1098
water			13.2	396
total	118		177.1	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 620	18	50	36	1080
water			13.8	414
total	118		176.5	
clay	80	72	111.1	3333.3
gr. carbonate	20	68	29.4	882.4
latex 679	18	49	36.7	1101
water			13.1	393
total	118		177.2	

COATING FORMULATION PROPERTIES

8% Binder

<u>Dow 617</u>

percent solids	62.3%
viscosity	1344 cP
pH	8.87
coat weight	9.82 g/m^2
RUN # E	

<u>Dow 620</u>

percent solids	62.7%
viscosity	1225 cP
pH	8.68
coat weight	9.86 g/m^2
RUN # H	

<u>Dow 679</u>

percent solids	62.6%
viscosity	1205 cP
pH	8.55
coat weight	9.96 g/m^2
RUN # F	

12% Binder

<u>Dow 617</u>

percent solids	61.6%
viscosity	1280 cP
pH	8.66
coat weight	9.80 g/m^2
RUN # D	

<u>Dow 620</u>

percent solids	62.1%
viscosity	1312 cP
pH	8.55
coat weight	10.09 g/m^2
RUN # I	

Dow 679
percent solids 61.9%
viscosity 1365 cP
pH 8.5
coat weight 9.81 g/m^2
RUN # G

18% Binder

Dow 617
percent solids 61.1%
viscosity 1384 cP
pH 8.46
coat weight 10.17 g/m^2
RUN # A

Dow 620
percent solids 60.3%
viscosity 1386 cP
pH 8.85
coat weight 9.88 g/m^2
RUN # B

Dow 679
percent solids 61.0%
viscosity 1250 cP
pH 8.47
coat weight 9.84 g/m^2
RUN # C

ALL COATING DISPERSIONS UNDERWENT THE FOLLOWING CONDITIONS:

Union Carbide Polyphobe 205 used as a thickener to bring the viscosity up to 1200cP
5% NaOH used to adjust pH to 8.5
CLC ran at 2000 feet per minute
Brookfield viscosity spindle #5 at 100 rpm.