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Lignosulfonate as a Strength Additive for Non-Wood Paperboard

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LIGNOSULFONATE AS A STRENGTH ADDITIVE FOR NON-WOOD PAPERBOARD

By

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ABSTRACT

Recycle mills that use old corrugated cardboard (OCC) in their furnish experience difficulties in maintaining the quality of the paperboard produced. Recycle mills using the OCC collect their OCC from many parts of the world. Countries such as China and Japan use rice fibers in the production of corrugated cardboard. Other countries use straw as a fiber source. The end result is that OCC in the United States contains a portion of non-wood fibers as well as the typical wood fibers. Paperboard containing these non-wood fibers typically has lower strength properties than paperboard produced from pure wood fibers. Literature suggests that lignosulfonate compounds can be used as a strength agent for recycled wood fiber paperboards. Calcium lignosulfonate is readily available and is not costly and would prove to be an ideal strength agent for use in recycled paperboard. The objective of this project was to test calcium lignosulfonate as a strength agent in improving the runnability and strength properties on paperboard made from wheat straw paperboard and/or paperboard containing a mixture of wheat straw and wood fibers.

Handsheets ($120 g/m^2$) were prepared on a Noble and Wood handsheet machine. The handsheets from each furnish were then immersed in a bath of calcium lignosulfonate followed by an immersion in kymene. Calcium lignosulfonate levels were varied in the bath in order to control the amount of calcium lignosulfonate applied to each handsheet.

The results show that as far as recycled pulp is concerned, CaLS at 10% is definitely beneficial compared with no CaLS in all strength properties. In the case of straw paperboard, 10% CaLS definitely gives higher strength properties compared with no CaLS (except for burst and Scott bond). Higher CaLS levels (10% or 20%) may be justified only in the case of ring crush. As for mixed fiber paperboard, CaLS seems to yield better strength properties (except in the case of Scott bond and burst). While 10% CaLS still seems to be sufficient, 20% seems to result in better crushing resistance and stiffness. The conclusion of this project is that 10% CaLS yields better strength properties in most of the cases and can be the starting point for further refinement studies.

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INTRODUCTION

Recycle mills that use old corrugated cardboard (OCC) in their furnish experience difficulties in maintaining the quality of the paperboard produced. These difficulties partially are due to the content of non-wood fibers in the OCC used in the stock furnish. Old corrugated cardboard is collected from sources worldwide. Countries such as China and Japan use rice fibers in the production of corrugated cardboard. Other countries use straw as a fiber source. The end result is that OCC in the United States contains a portion of non-wood fibers as well as the typical wood fibers. Paperboard containing these non-wood fibers typically has lower strength properties than paperboard produced from pure wood fibers.

There is no practical way of removing the non-wood fibers contained in the OCC. paper mills add strength agents to increase the strength of the paperboard. These strength agents are oftentimes costly and sometimes ineffective for use on non-wood fibers. A cheap strength agent that is effective with non-wood fibers needs to be implemented to offset the adverse affects these fibers have on the strength properties and runnability of the paper.

LITERATURE REVIEW

Non-wood Fibers

The properties of paper made from non-wood fibers have been a topic of research for many years. During World War II there were severe shortages of fiber. As a result of these shortages extensive research was conducted for an alternate source of fibers. In the Midwest 25 mills were going through great strides to maximize production of straw corrugating material, which approached one million tons in the 1940s. After the war, interest in straw as a fiber source dwindled and eventually ceased to exist. However in 1957 the USDA initiated a study to find new fiber crops; as a result of these studies 6 plants were discovered to be good fiber sources. These plants are kenaf, crotalaria, okra, seshania, sorghum, and bamboo. It was further discovered that kenaf was the best source of fibers and research was done on the applications of kenaf until 1978 when the USDA stopped funding the research. In 1970 the total worldwide production of non-wood plant fibers for pulp was 7.622 million metric tons, which is about 6.7% of the total pulp production at that time. Production of non-wood plant fiber has increased and in 1993 its capacity reached 23.371 million metric tons, which was 11.2% of the total pulp supply. This increase in production works out to a 2.5% increase annually. China is the key country in the production of non-wood fibers. In 1993 China produced 20.736 million metric tons of non-wood fibers for pulp. This is 73.5% of the total production of pulp during that year. (1)

Production of non-wood fibers is expected to increase even more in the future. Due to the increase in the global market, the influx of non-wood packing materials has increased in the U.S. The method by which old corrugated cardboard is collected allows the non-wood cardboard from other countries to mix in with the wood fiber cardboard.

Papers made from non-wood fibers tend to have lower strength properties than those made from wood fibers. When non-wood fibers mix in with the wood OCC furnish, they tend to reduce the strength of the paperboard made with the furnish. To increase the strength of the paperboard, a variety of chemicals are added as strength agents.

Strength Agents

Dry-Strength Additives

Dry strength is a structural property of paper. It is mainly derived from the formation of bonds between fibers as the paper dries. Actual strength of the paper depends on the fiber strength and the strength of the fiber-to-fiber bonds. Dry-strength additives increase the strength of the fiber-to-fiber bonds but not the actual fiber strength. Typically dry-strength is enhanced by refining the fibers. There are a number of forces at work in the fiber-to-fiber bonds. The most prevalent force is hydrogen bonding. For hydrogen bonding to occur, the fiber surfaces must be in molecularly close contact. (2)

Dry-strength additives are typically water-soluble, hydrophilic polymers. They can be either natural or synthetic. The most common dry-strength agents are starch, vegetable gums, carboxymethyl cellulose, and synthetic polymers. Starch is one of the oldest and most widely used dry-strength agent used in papermaking. Starches are usually modified to increase the retention in the paper. Starches act to increase the number of hydrogen bonds and thus increase the dry-strength of the paper. Guar gum is the most commonly used vegetable gum. It is a carbohydrate polymer containing galactose and mannose as the structural building blocks. Vegetable gums increase the dry-strength of the paper by supplementing the natural hemicelluloses in paper bonding. Carboxymethyl cellulose (CMC) is a water-soluble carboxylated derivative of cellulose. The use of CMC as a dry-strength agent is restricted to specialty paper because of the high cost of CMC. Of the synthetic polymers, the most commonly used additive is polyacrylamide (PAM). It is believed that the polar amide groups in the PAM resin form hydrogen bonds with cellulose hydroxyls. These hydrogen bonds are significantly stronger than ordinary cellulose-to-cellulose hydrogen bonds. Other synthetic polymers, such as polyvinyl alcohol and latex, are applicable as dry-strength agents, although there are typically used as surface sizing additives rather than dry-strength additives. (2)

Wet-Strength Additives

Hydrogen bonds are relatively weak inter-atomic forces. They are also water sensitive and easily disrupted by water. The addition of water to dry paper will result in a serious, rapid weakening of fiber-to-fiber hydrogen bonds and a consequential dramatic loss in paper strength and integrity. Various techniques such as wet pressing and refining can be used to limit somewhat the reduction of paper strength on wetting with water. The effect however is very limited; therefore it is typical to boost the wet-strength by the addition of chemical additives. These wet-strength agents can have a temporary effect on the retention of wet-strength. At short rewetting times, wet-strength remains high, but at long rewetting times, the wet-strength decreases dramatically. Wet-strength additive can be permanent as well. Permanent wet-strength agents impart strength to the paper which after an initial decay will retain a residual level of wet-strength during the entirety of rewetting. (3)

The development of wet strength requires one or more of the following attributes: strengthening of existing fiber to fiber bonds, protection of existing bonds from water, formation of water-resistant covalent chemical bonds, and formation of a polymer network that entangles fibers. There are two main wet-strength agents used today. They are urea-formaldehyde and poly (amido-amine)-epichlorohydrin (PAE) (4). Urea formaldehyde reacts with the hydroxyl groups of cellulose to form acetyl structures. These structures are sensitive to water and are therefore used in temporary wet-strength applications. PAE is used as a permanent wet-strength agent. It has found wide use among paper mills for numerous reasons including cost effectiveness, wide versatility, and ease of use. PAE reacts with cellulose to form water-resistant covalent chemical bonds. (3)

Lignosulfonate

Lignosulfonate is a byproduct from the sulfite pulping process. Lignosulfonate consists of a lignin compound coupled with a slufonic acid or a sulfonate unit. Figure 1 shows a diagram of a lignosulfonate molecule.

Calcium lignosulfonate is a brown powder that is highly soluble in water and has a density of 24 lb/ft3. It is produced by the sulfonation of softwood lignin. High purity calcium lignosulfonate from softwood is the most widely used of all lignosulfonates, due to its effectiveness in many applications.

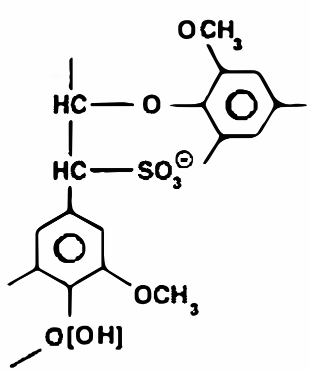

Figure 1. Lignosulfonate Molecule

The Lignin Institute states that lignosulfonates are a very effective and economical adhesive, acting as a binding agent in pellets or compressed materials. Lignosulfonates are used on unpaved roads to reduce the environmental concerns from airborne dust particles and to stabilize the road surface. This binding ability makes it a useful component in a variety of applications such as coal briquettes, ceramics, dust suppressants, particleboard and linoleum paste. (5)

The Lignin Institute further states that lignosulfonates can also be used as a dispersant making it useful for pigments, pesticides, and oil drilling mud. The emulsifying qualities of lignosulfonates make it useful in wax and asphalt emulsions. Lignosulfonates also act as a sequestrant by tying up metal ions, preventing them from reacting with other compounds and becoming insoluble. The metal ions thus stay in solution making lignosulfonates useful in micronutrient systems, cleaning compounds, and water treatment systems for boilers.

Since calcium lignosulfonate is highly soluble in water, contact with a wet surface will leach the CaLS from the treated paper. Several methods are available to prevent the bleeding of chemicals from paperboard. Such methods are to coat the paperboard with a wax or polymer film. However this method is expensive and cumbersome. Another method mentioned by Collias, et al. (4) is to crosslink the water-soluble strength agents. Such crosslinking involves the following: condensation reactions with strong mineral acids, oxidative coupling reactions with hydrogen peroxide, reactions with bis-diazonium salts, reactions with epichlorohydrin, as well as many other reactions. The reactions mentioned above are costly and hazardous to conduct.

Collias, et al. (4) claims that "unexpectedly it was found that an aqueous calcium lignosulfonate solution when mixed together with an aqueous kymene solution exhibits a virtually instantaneous reaction that results in a precipitate". The precipitate formed by the reaction is insoluble in water. This reaction is fast, easy, and cheap to carry out and renders the CaLS treated paperboard resistant to bleeding.

Kymene is a poly (amido-amine) epichlorohydrin. It is commonly used as a wet-strength agent for paper towels. Kymene is used with the CaLS to make the CaLS insoluble in water and to render it less sticky. There are two methods by which kymene interacts with the CaLS in the paperboard. On method is encapsulation. The kymene encapsulates the CaLS attached to the fibers surfaces. The other method is penetration. CaLS absorbs into the fibers pores, when the kymene is applied it also penetrates into the fibers pores and reacts with the CaLS inside the cell wall. (4)

The crosslinking reaction between kymene and calcium lignosulfonate is believed to be due to the sulfonate unit of the CaLS interacting with the azetidinium rings of the kymene, see figure 2. This reaction makes the CaLS insoluble in water and makes the surface of the treated paperboard less sticky.

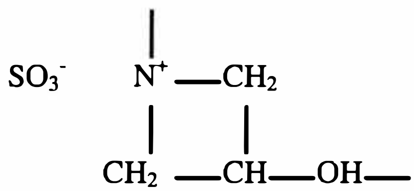

Figure 2. Azetidinium Ring Interacting With Sulfonate Unit Azetidinium Ring Interacting With Sulfonate Unit

OBJECTIVE

Calcium lignosulfonate (CaLS) is a byproduct of the sulfite pulping process. CaLS has been used as an adhesive in applications such as dust suppression and in pellet formation. It is suggested that lignosulfonate compounds can be used as a strength agent for recycled wood fiber paperboards. Calcium lignosulfonate is readily available and is not costly and would prove to be an ideal strength agent for use in recycled paperboard.

It is the objective of this thesis to study the effects calcium lignosulfonate on paperboard made from wheat straw or a mixture of wheat straw and wood fibers. This will help in the determination if CaLS can be used as a strength agent for non-wood paperboards.

EXPERIMENTAL

Experimental Schematic

There are three different pulp furnishes to be tested in this experiment. They are 100% old corrugated cardboard, 100% wheat straw, and a 50/50 mixture of OCC and wheat straw. For each of the pulp furnishes there will be four levels of calcium lignosulfonate - 0%, 10%, 20%, and 30% - applied. After application of CaLS they will be treated with a constant application of kymene. For each of these chemical levels there will be six tests conducted. Each test will be replicated 5 times. Figure 3 shows the experimental schematic for this study.

Twenty handsheets were made from each pulp furnish. The handsheets from each furnish were divided into four groups of five handsheets each. The four groups from each pulp furnish were each treated with a different level of calcium lignosulfonate. Two handsheets of equal weight were taken from each CaLS / furnish combination. From these two handsheets five replicates of each test were conducted.

The experimental design of this experiment is that of a blocked split-split plot. The furnish compositions are the main plots with the concentration of the chemicals being the subplot. The tests conducted are the sub-subplot of the concentration of the chemical treatment.

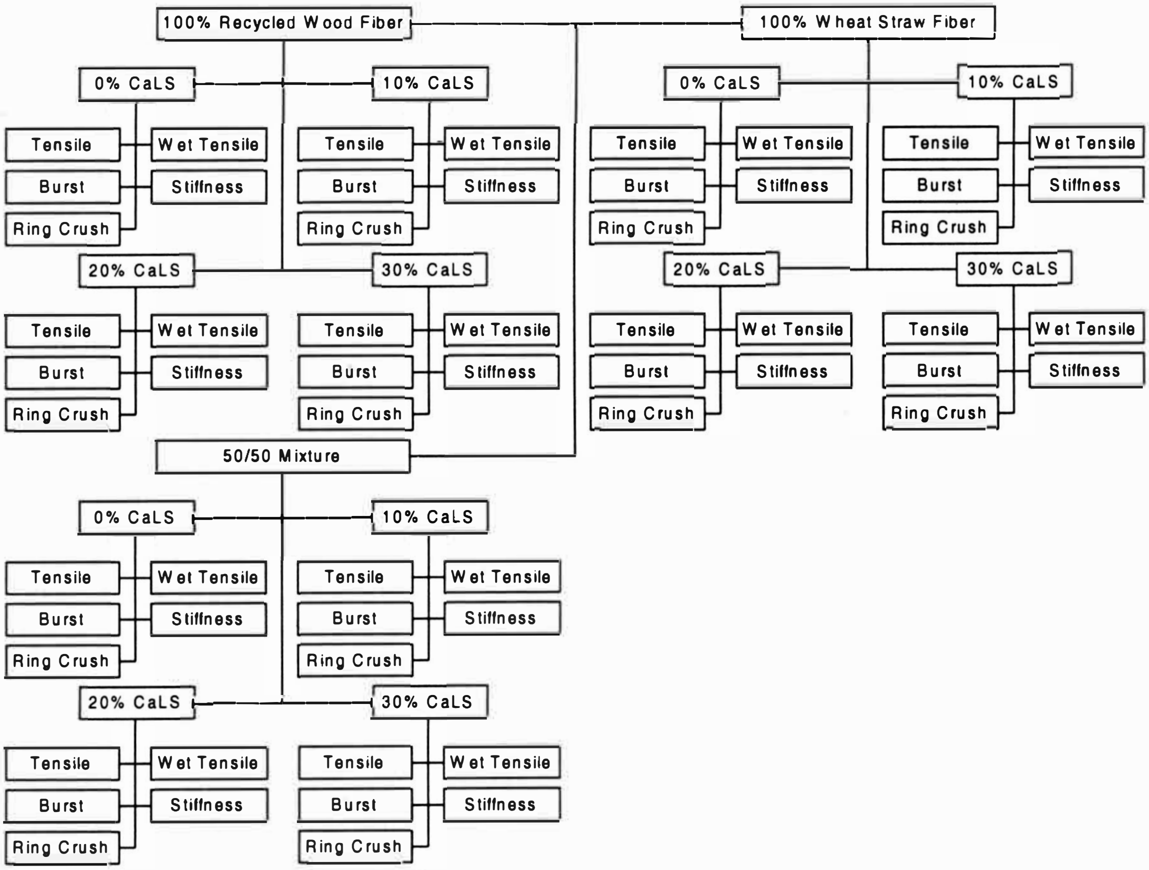

Figure 3. Experimental Schematic

Methodology

Pulp Preparation

Wheat Straw Pulp

The wheat straw pulp was prepared by digesting 250 OD grams of wheat straw in an M and K laboratory digester. First the moisture content of the straw was determined by placing a 10 gram sample in an oven at 102 degrees Celsius for 24 hours. The initial and final weights were recorded and used to calculate the moisture content. A kraft cooking liquor was used for pulping the wheat straw. This liquor was previously prepared and had 189 grams/liter of active alkali and a sulfidity of 15%.

The liquor used was diluted to an active alkali of 12% by using the following formulas:

1. White liquor to dilute = (250grams)(12%)/189 grams/liter = 159 grams white liquor
2. Total amount of dilute white liquor = (5 parts liquid/ 1 part fiber)(250grams fiber) = 1250 mL of dilute white liquor
3. Water to add = 1250mL – water from straw – 159 mL

The dilute kraft liquor and the straw were then placed into the digester and the temperature was set to 165 degrees Celsius. The straw was digested for 30 minutes while the temperature versus time was recorded in order to calculate the H factor. After digestion of the straw, it was cleaned. This was done by flushing the straw fiber with cold water to remove a majority of residual liquor in the pulp. After washing the pulp, it was dispersed by placing the pulp in a commercial blender for 2 minutes at a low speed. Following dispersion the pulp was screened by placing it into a pulsating slotted screen to remove any uncooked fibers. After screening the Canadian standard freeness was determined following TAPPI method T 227 om-93 (6). The screened fiber was then stored in a cold room until further use.

Recycled Fiber Pulp

The recycled fiber pulp was prepared from box clippings. 700 grams of OD recycled fiber was placed into a pulp slusher. 22.7 liters of water was added to dilute the recycled to a consistency of 3%. The pulp was then slushed for 10 minutes. The Canadian standard freeness was measured according to TAPPI method T-227 om-93. The pulp was stored in a plastic 5-gallon bucket in a refrigeration unit until it was used.

Chemical Application

The handsheets were prepared on a Noble and Wood handsheet machine. An average weight of 120-grams/square meter was targeted. Twenty handsheets of equal weight were made from each furnish. Three handsheets from each furnish were then immersed in a bath of calcium lignosulfonate followed by an immersion in kymene. Calcium lignosulfonate levels were varied in the bath in order to control the amount of calcium lignosulfonate applied to each handsheet. The concentration of kymene was kept constant at 12.5% solids. Concentration of CaLS was controlled by determining the amount of water a handsheet would absorb. The weight of the handsheet was then taken and from this weight it was determined the amount of dried CaLS needed for a certain level of chemical addition. The weight of the calcium lignosulfonate was then divided by the amount of water absorbed by the handsheet to determine the concentration of CaLS solution to use. The solution of CaLS was then placed into a 9-inch by 9-inch aluminum tray. The handsheets were then soaked in this solution for 10 seconds and removed from the solution. After drip-drying for 10 seconds the handsheets were then placed into a solution of 12.5% kymene for 3 seconds. To dry the handsheets, they were suspended in the air and allowed to air dry without restraint for 24 hours. When the handsheets were dry, they were placed in an oven at 102 degrees Celsius for 10 minutes to cure the kymene. After chemical treatment the handsheets were stored in a room conditioned according to TAPPI method T 402 om-87, at 50% relative humidity and 70 degrees Fahrenheit until they were tested.

Testing

Two handsheets for each level of chemical addition were taken to be tested. From these two handsheets 15 strips, 152.4mm long and 15mm wide, were cut using a die cutter. One strip, 40mm wide by 152.4 mm long and 5 strips, 38.1mm wide and 70mm long were also cut. These strips were then conditioned using TAPPI method T 402 om-82. All the strips were labeled with their furnish composition and chemical treatment. The following tests were preformed on the relevant samples.

Tensile Strength

Tensile strength testing was conducted using TAPPI method T 494 om-88. Five 15mm wide samples were taken from each furnish and chemical level combination. These sample strips were used instead of the 25mm by 200mm sample strips mentioned in TAPPI method T 494 om-88. All other conditions follow those mentioned in the standard test method. Tensile strength was reported as tensile index in Newton meters per gram.

Wet Tensile Strength

Wet tensile strength testing was conducted using TAPPI method T 456 om-87. Five 15mm wide samples were taken from each furnish and chemical level combination. These sample strips were used instead of the 25mm by 200mm sample strips mentioned in the above method. A one-inch portion of each sample strip was immersed in distilled water at 23 degrees Celsius for 10 seconds. The paper was blotted to remove excess water and them immediately tested. All other conditions follow those mentioned in the standard test method. Tensile strength was reported as tensile index in Newton meters per gram.

Mullen Burst

Mullen Burst testing was conducted using TAPPI method T 403 om-91. One 40mm wide sample was taken from each furnish and chemical level combination. These sample strips were used instead of the 30.5mm sample strips mentioned in the standard method. All other conditions follow those mentioned in the test method. Mullen Burst was reported as burst index in kilopascal square meter per gram.

Ring Crush

Ring crush testing was conducted using TAPPI method T 822 om-92. Five 15mm wide samples were taken from each furnish and chemical level combination. These sample strips were used instead of the 12.7mm by 152.4mm sample strips mentioned in the above method. All other conditions follow those mentioned in the standard test method. Ring crush was reported as force required to crush the 15mm wide sample in kilonewtons cubed meter per gram.

Taber Stiffness

Stiffness was taken using TAPPI method T 489 om-92. Five 38.1mm wide by 70mm long samples were taken from each furnish and chemical level combination. These sample strips were used as mentioned in the standard method. All other conditions follow those mentioned in the standard test method. Tabor stiffness was reported as the force required to bend the sample in millinewton cubed meters per gram.

Scott Bond

Scott bond testing was conducted using TAPPI method T 432 om-91. One 25.4mm wide by 177.8mm long samples were taken from each furnish and chemical level combination. These sample strips were used as mentioned in the standard method. All other conditions follow those mentioned in the test method. Scott bond was reported as the force required to pull the sample apart in joules per gram.

RESULTS AND DISCUSSION

The results are shown below in three sections. Figures 5 through 21 can be found in the appendix. It should be noted that the addition of kymene and calcium lignosulfonate darkened the handsheet and made it brittle. These effects were amplified as the content of CaLS was increased.

Recycled Fiber Paperboard

The tensile index for recycled paperboard can be seen in figure 4 below. There is a statistical increase in the tensile index when the calcium lignosulfonate level was increased from 0% to 10%. A slight increase in tensile index can be noted when the CaLS level increased from 10% to 20%, however this increase is not statistically sound because of the large spread in the data points for the 10% and 20% chemical addition rates. There is no difference in the tensile index when CaLS level increases from 20% to 30%. The only statistically valid result shown in figure 4 is that the paperboard with 0% CaLS level has a lower tensile index than the paperboards with 20% and 30% calcium lignosulfonate levels.

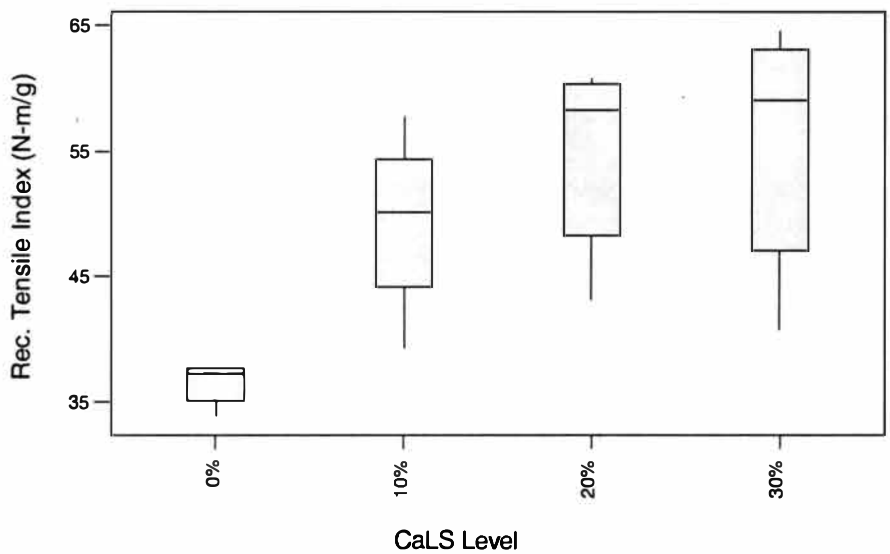

Figure 4. Tensile Index Versus CaLS Level For Recycled Fiber Paperboard

Figure 6 in the appendix shows the wet tensile index for recycled paperboard. This graph shows that the wet tensile index is very low at the 0% calcium lignosulfonate level, much lower than the wet tensile index at 10%, 20%, and 30% CaLS levels. The graph also shows that at 10% CaLS levels the wet tensile index is higher than that at 30% CaLS. No statistical difference between 20% CaLS level and the 10% and 30% levels can be determined because of the large variance in the data points in the 20% CaLS level data points.

Figure 7 shows the stiffness of the recycled paperboard at several levels of CaLS. The graph shows a very definite increase in stiffness as the calcium lignosulfonate level increases. The 30% CaLS level has the highest stiffness value followed by 20%, 10%, and 0% in that order. All of the calcium lignosulfonate addition levels have statistically different stiffness values.

Figure 8 in the appendix shows the burst index for recycled paperboard. This graph shows that the burst index is low at the 0% calcium lignosulfonate level, much lower than those at 10%, 20%, and 30% CaLS levels. The graph also shows that at 30% CaLS, the burst index is higher than that at 20% CaLS. No statistical difference between 10% CaLS level and the 20% and 30% levels can be determined because of the large variance in the data points in the 10% CaLS level data points.

Figure 9 in the appendix shows the ring crush index for recycled paperboard. This graph shows that the ring crush of recycled paperboard containing no CaLS is much lower than that of recycled paperboard containing 10%, 20%, and 30% CaLS levels. There is no statistical difference between recycled board containing 10%, 20%, and 30% CaLS.

Figure 10 in the appendix shows the Scott bond index for recycled paperboard. This graph shows that the wet tensile index is very low at the 30% calcium lignosulfonate level, much lower than the Scott bond index at 10%, 20%, and slightly lower that that at 0% CaLS levels. The graph also shows that there is no statistical difference between the Scott bond index of recycled paperboard at 10% CaLS and the Scott bond index at 20% CaLS.

As far as recycled pulp is concerned, CaLS at 10% is definitely beneficial compared with no CaLS in all strength properties.

Straw Fiber Paperboard

The tensile index for straw paperboard can be seen in figure 11 in the appendix. The graph shows that the tensile index is highest at the 10% calcium lignosulphonate level. There is no statistical difference between the tensile index of straw paperboard at the 0%, 20%, and 30% CaLS levels because of the large amount of variation in the data points.

Figure 12 in the appendix shows the wet tensile index for straw paperboard. This graph shows that the wet tensile index is very low at the 0% calcium lignosulfonate level, much lower than the wet tensile index at 10%, 20%, and 30% CaLS levels. The graph also shows that at 10% CaLS levels the wet tensile index is higher than that at the 20% and 30% CaLS.

Figure 13 shows the stiffness of the straw paperboard at several levels of CaLS. The 10% CaLS level has the highest stiffness value compared to the stiffness of the 0%, 20%, and 30% CaLS levels. The stiffness values are not statistically different for the 0%, 20%, and 30% CaLS levels.

Figure 14 in the appendix shows the burst index for straw paperboard. This graph shows that the burst index is low at the 30% calcium lignosulfonate level, much lower than those at 0%, 10 %, and 20% CaLS levels. The graph also shows that at 0%

CaLS, the burst index is higher than that of the other CaLS. No statistical difference between 10% and 20% CaLS levels can be determined because of the large variance in the data points in the data points.

Figure 15 in the appendix shows the ring crush index for straw paperboard. This graph shows that the ring crush index of straw paperboard containing no CaLS is lower than that of straw paperboard containing 10%, 20% and 30% CaLS levels. The ring crush index of straw paperboard containing 10% CaLS is lower than that of straw paperboard containing 20% and 30% CaLS levels. There is no statistical difference between the straw paperboard containing 20% and 30% CaLS levels.

Figure 16 in the appendix shows the Scott bond index for straw paperboard. This graph shows that the Scott bond index is low at the 20% calcium lignosulfonate level, much lower than the Scott bond index at 0% CaLS and is slightly lower that that at 10% and 30% CaLS levels. The graph also shows that there is no statistical difference between the Scott bond index of straw paperboard at 10% CaLS and the Scott bond index at 30% CaLS.

Except for burst and Scott bond, 10% CaLS definitely gives higher strength properties compared with no CaLS. Higher CaLS levels (10% or 20%) may be justified only in the case of ring crush.

50/50 Mixture Paperboard

The tensile index for the mixture paperboard can be seen in figure 17 in the appendix. The graph shows that the tensile index is higher at the 20% calcium lignosulphonate level than it is at the 0% CaLS level. There is no statistical difference between the tensile index of mixture paperboard at the 0%, 10%, and 30% CaLS levels because of the large amount of variation in the data points.

Figure 18 in the appendix shows the wet tensile index for the mixture paperboard. This graph shows that the wet tensile index is very low at the 0% calcium lignosulfonate level, much lower than the wet tensile index at 10%, 20%, and 30% CaLS levels. The graph also shows that at 30% CaLS levels the wet tensile index is lower than that at the 10% and 20% CaLS.

Figure 19 shows the stiffness of the mixture paperboard at several levels of CaLS. The 30% CaLS level has the highest stiffness value compared to the stiffness of the 0%, 10%, and 20% CaLS levels. The stiffness at 20% is slightly higher than that at the 0% and 10% CaLS levels. The stiffness values are not statistically different for the 0%, and 10% CaLS levels.

Figure 20 in the appendix shows the burst index for the mixture paperboard. This graph shows that the burst index is low at the 30% calcium lignosulfonate level, much lower than those at 0% and 10 % CaLS levels and slightly lower than that of the 20% CaLS level. The graph also shows that at 20% CaLS, the burst index is lower than that of the 0% and 10% CaLS levels. No statistical difference between 0% and 10% CaLS levels can be determined because of the large variance in the data points in the data points.

Figure 21 in the appendix shows the ring crush index for the mixture paperboard. This graph shows that the ring crush index containing no CaLS is lower than that containing 10%, 20% and 30% CaLS. The ring crush of the mixture paperboard containing 10% CaLS is lower than that containing 20% and 30% CaLS. The ring crush index of the mixture paperboard containing 20% CaLS is higher than that containing 30% CaLS.

Figure 22 in the appendix shows the Scott bond index for the mixture paperboard. This graph shows that the Scott bond index decreases as the calcium lignosulfonate level increases. The Scott bond index at the 0% CaLS level is highest followed by the 10%, 20, and 30% levels in that order with the 30% CaLS level being the lowest Scott bond index.

Once again, except in the case of Scott bond and burst, CaLS seems to yield better strength properties. While 10% CaLS seems to be generally sufficient, 20% seems to result in better crushing resistance and stiffness.

CONCLUSIONS

1. Increasing the calcium lignosulfonate levels to 10% in recycled fiber paperboard increases the tensile, wet tensile, burst, ring crush, and Scott bond. The stiffness of recycled paperboard increases as the calcium lignosulfonate level increases to 30%.
2. Increasing the calcium lignosulfonate levels to 10% in straw fiber paperboard increases the tensile, wet tensile, and stiffness. Scott bond and burst decrease as the calcium lignosulfonate levels increase to 30%. Ring crush increase up to an addition of 20% calcium lignosulfonate.
3. The tensile and ring crush of the mixture paperboard increases as the calcium lignosulfonate level increases to 20%. The wet tensile increases as the calcium lignosulfonate level increases to 10%. The stiffness increases as the calcium lignosulfonate level increases to 30%. Scott bond and burst decrease as the calcium lignosulfonate levels increase to 30%.
4. A final conclusion of this project will be that 10% CaLS yields better strength properties in most of the cases and can be the starting point for further refinement studies.

RECOMMENDATIONS

1. The effect kymene alone has on the strength properties of non-wood and wood fibers should be determined under identical conditions. (In this study 0% CaLS also meant no kymene.)
2. A pilot plant trial run with recycled fibers should be conducted to study the runnablity issues.
3. More replicates should be conducted to get a better error estimate.
4. Calcium lignosulfonate should be compared with ammonium lignosulfonate to see if it will reduce the brittleness of the paperboard.

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APPENDIX

Box Plots

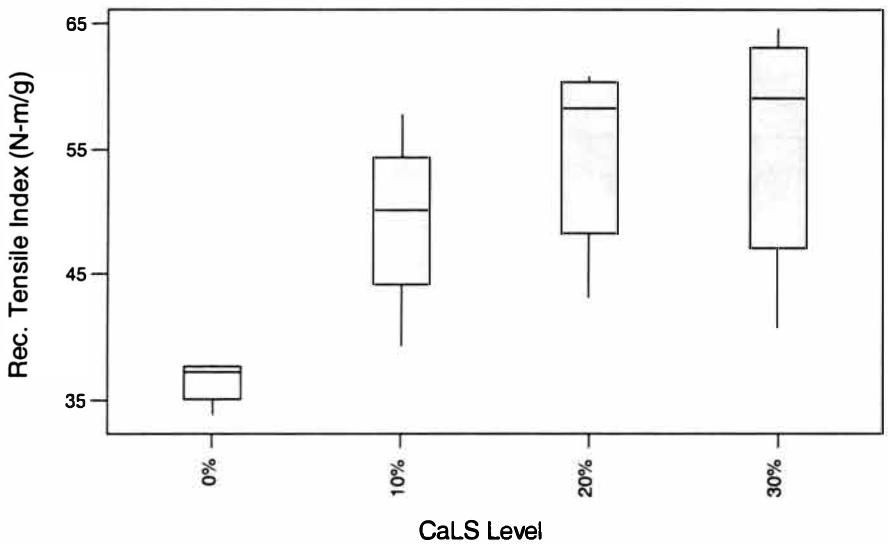

Figure 5. Tensile Index Versus CaLS Level For Recycled Fiber Paperboard

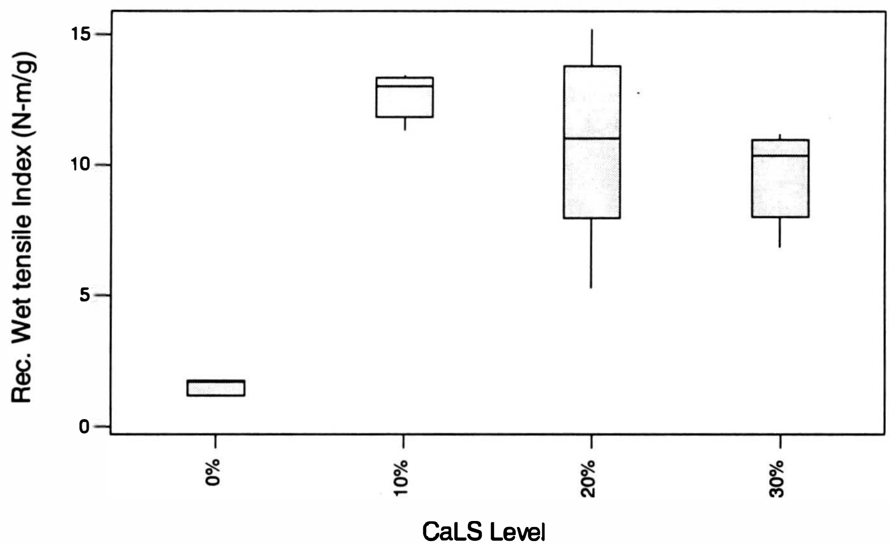

Figure 6. Wet Tensile Index Versus CaLS Level For Recycled Fiber Paperboard

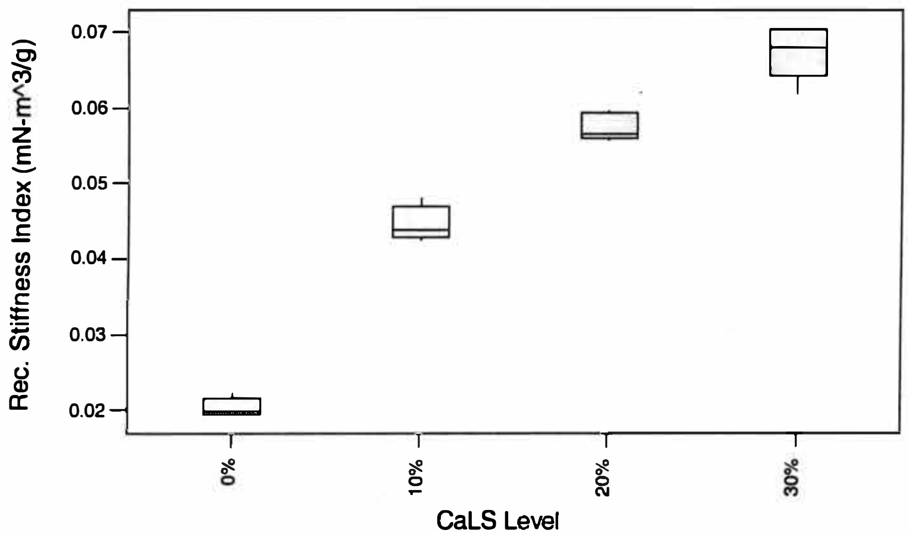

Figure 7. Stiffness Index Versus CaLS Level For Recycled Fiber Paperboard

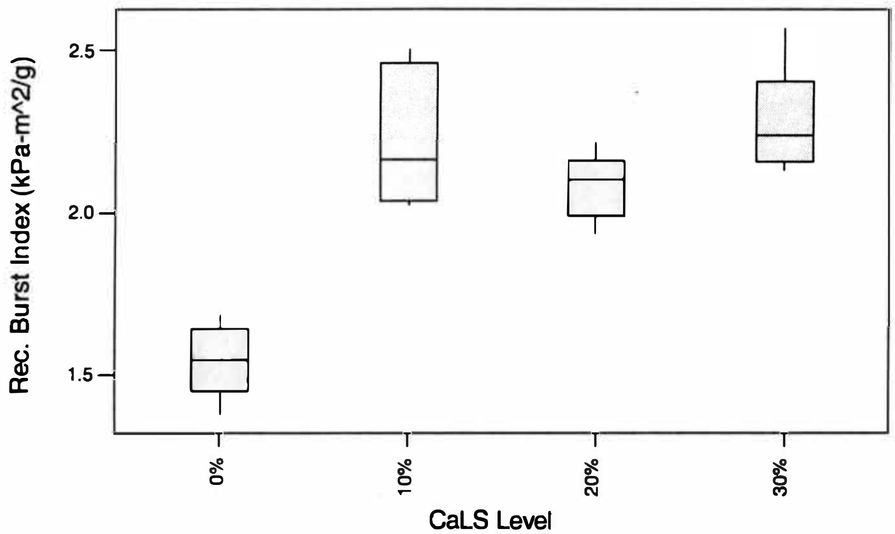

Figure 8. Burst Index Versus CaLS Level For Recycled Fiber Paperboard

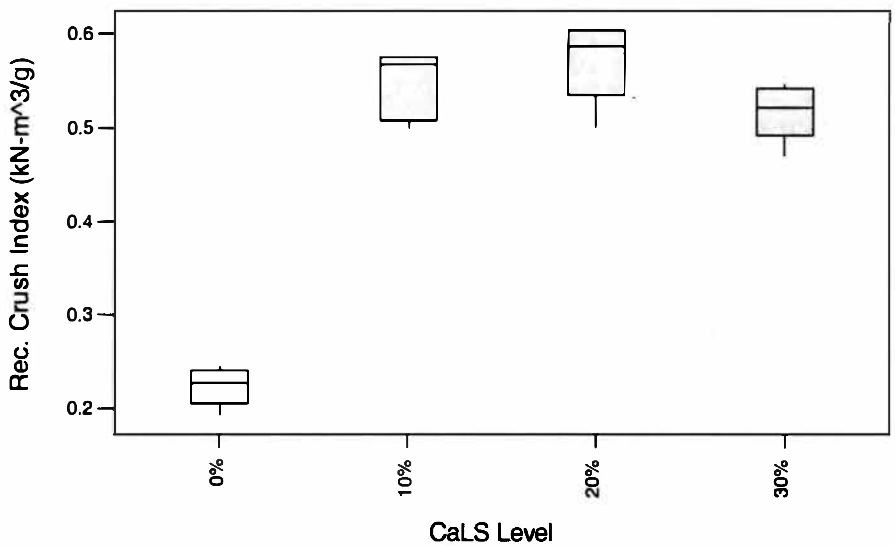

Figure 9. Ring Crush Index Versus CaLS Level For Recycled Fiber Paperboard

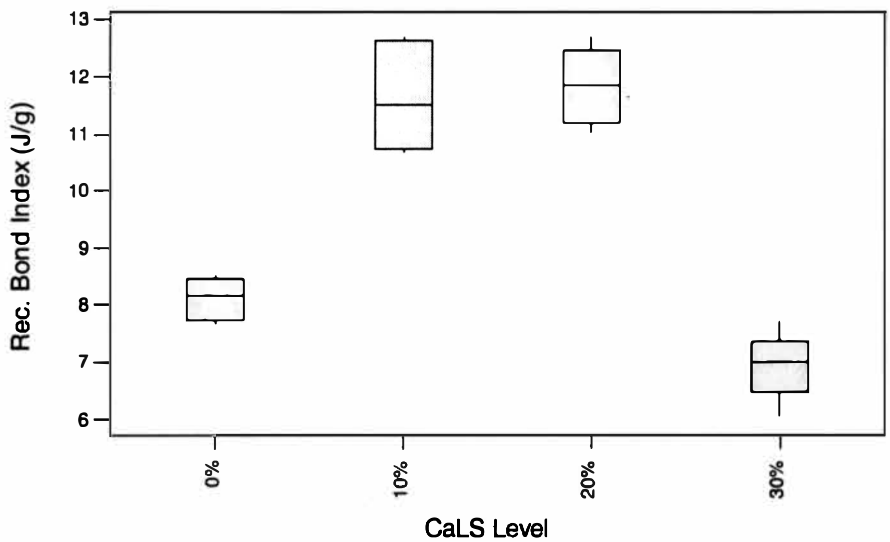

Figure 10. Scott Bond Index Versus CaLS Level For Recycled Fiber Paperboard

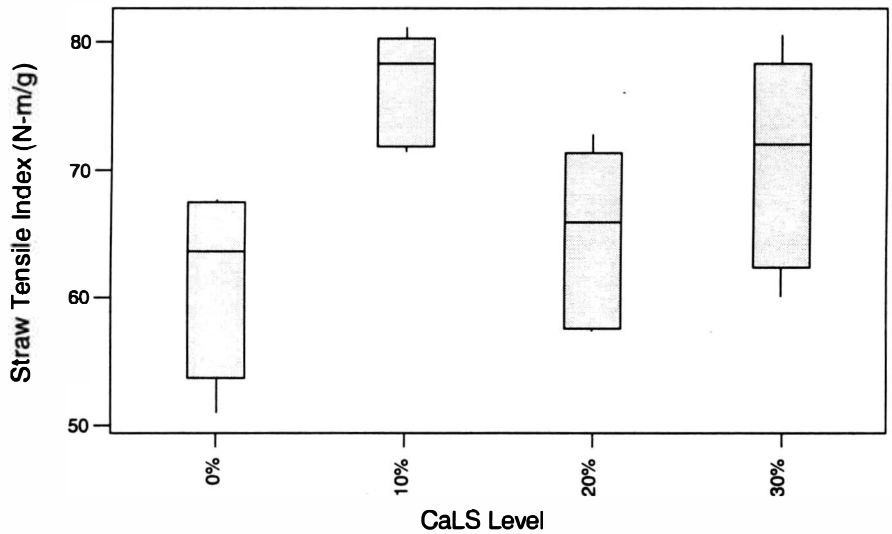

Figure 11. Tensile Index Versus CaLS Level For Straw Fiber Paperboard

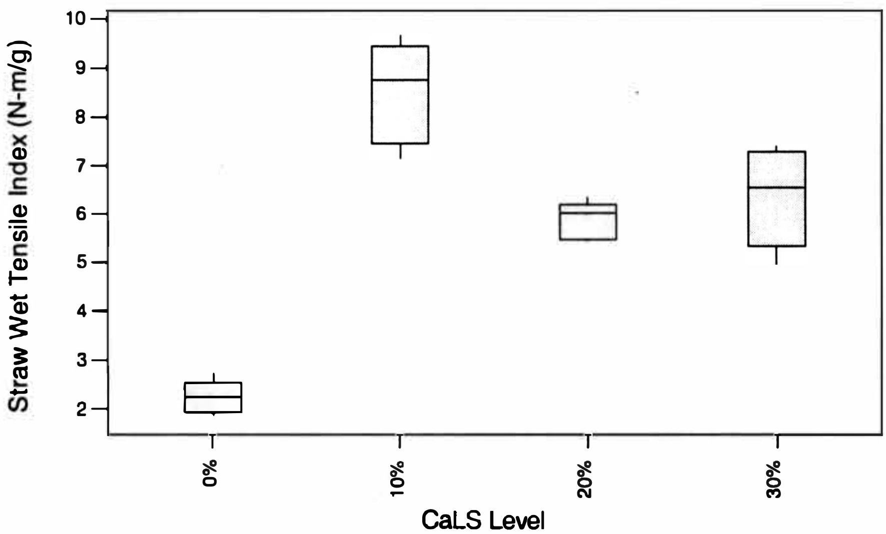

Figure 12. Wet Tensile Index Versus CaLS Level For Straw Fiber Paperboard

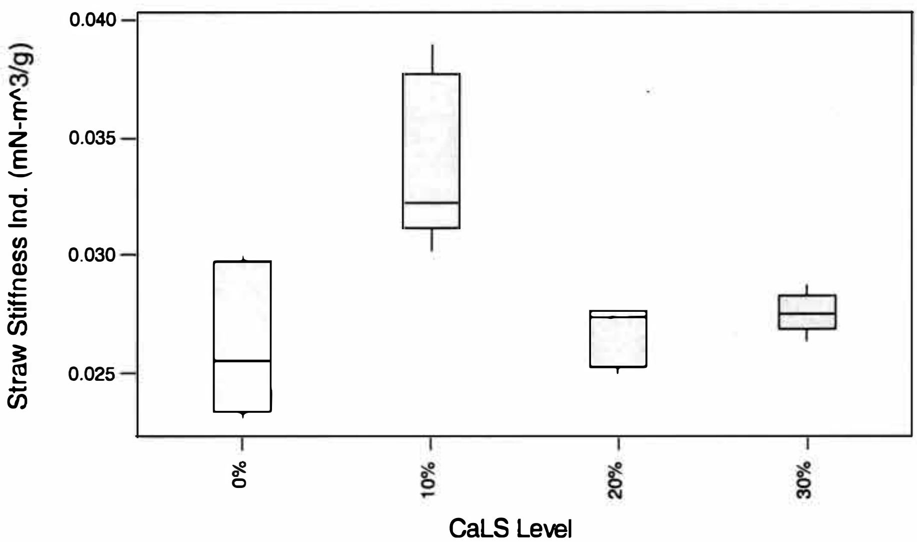

Figure 13. Stiffness Index Versus CaLS Level For Straw Fiber Paperboard

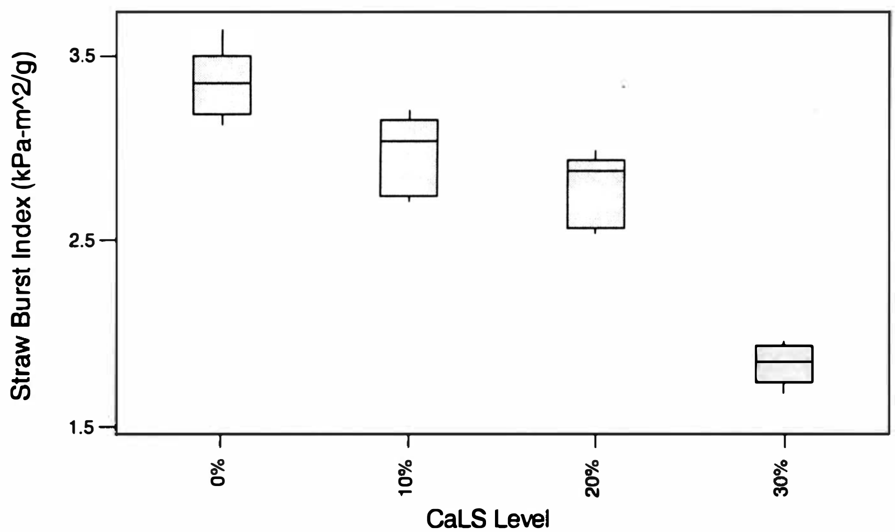

Figure 14. Burst Index Versus CaLS Level For Straw Fiber Paperboard

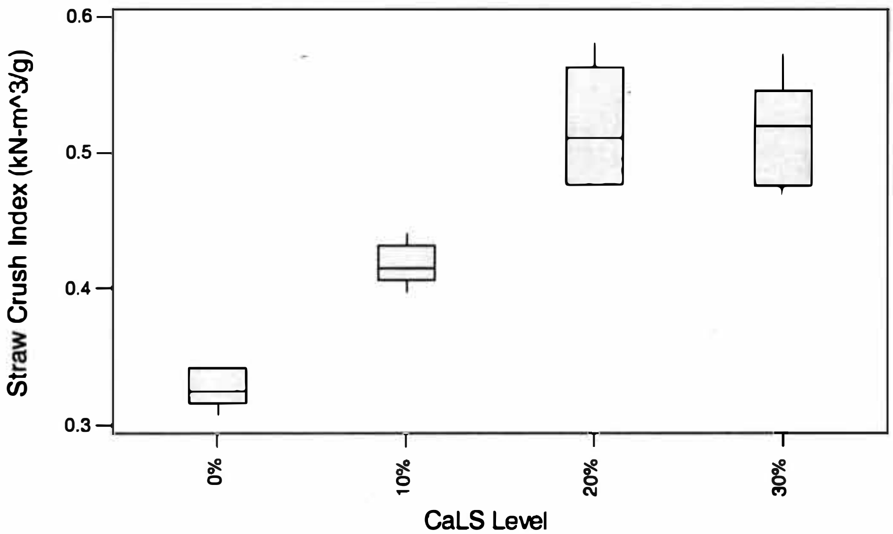

Figure 15. Crush Index Versus CaLS Level For Straw Fiber Paperboard

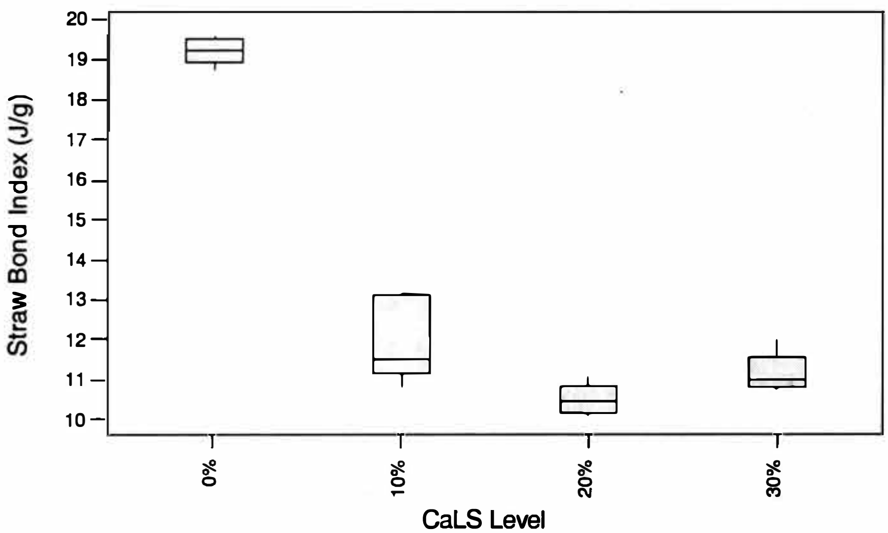

Figure 16. Scott Bond Index Versus CaLS Level For Straw Fiber Paperboard

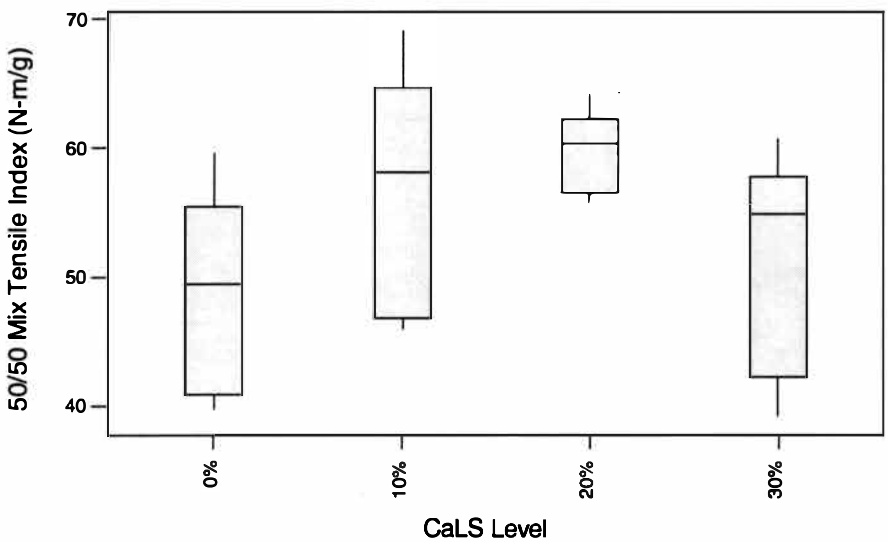

Figure 17. Tensile Index Versus CaLS Level For 50/50 Mix Paperboard

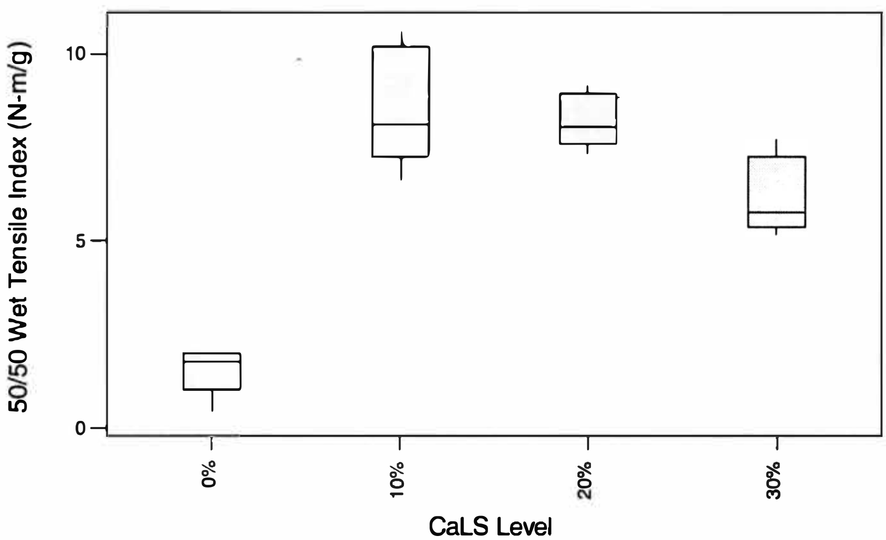

Figure 18. Wet Tensile Index Versus CaLS Level For 50/50 Mix Paperboard

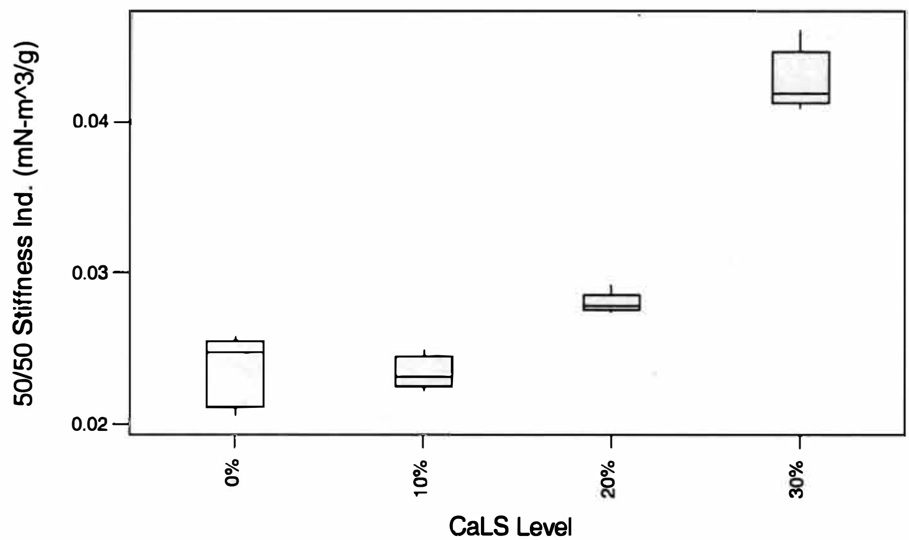

Figure 19. Stiffness Index Versus CaLS Level For 50/50 Mix Paperboard

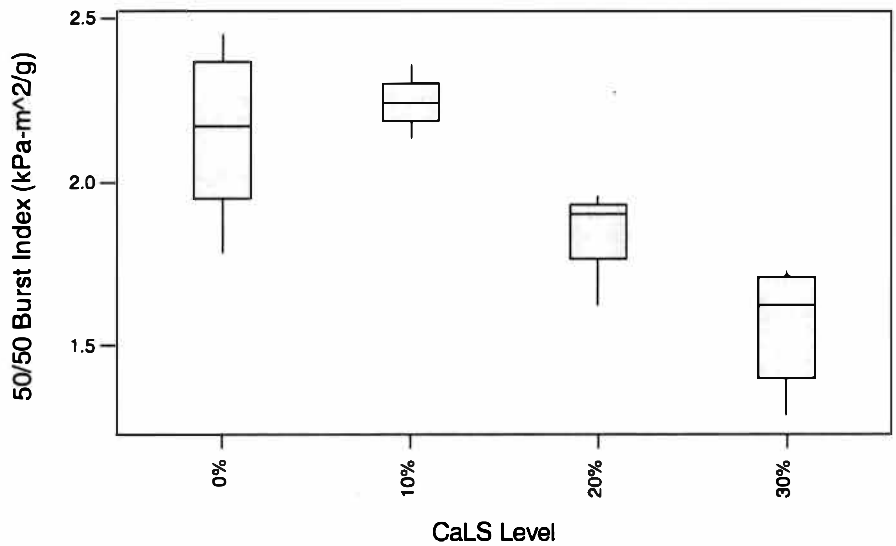

Figure 20. Burst Index Versus CaLS Level For 50/50 Mix Paperboard

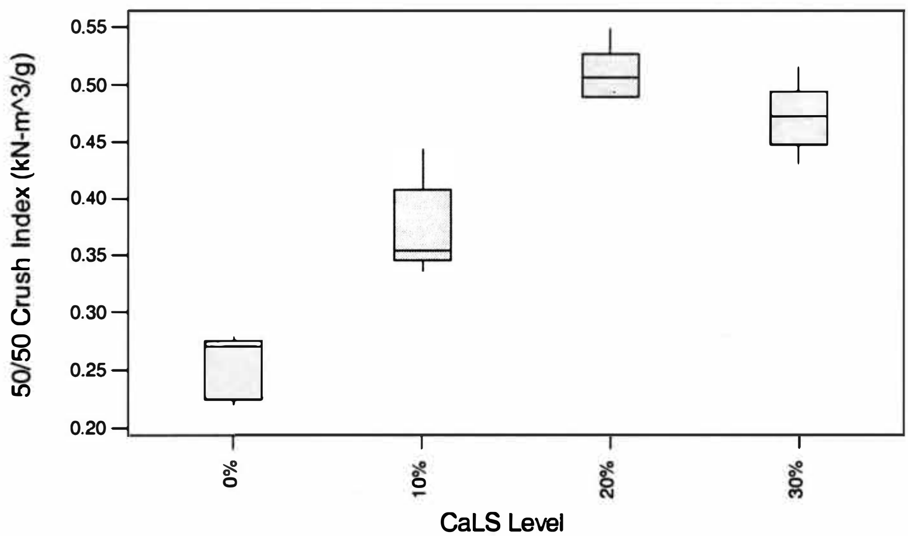

Figure 21. Crush Index Versus CaLS Level For 50/50 Mix Paperboard

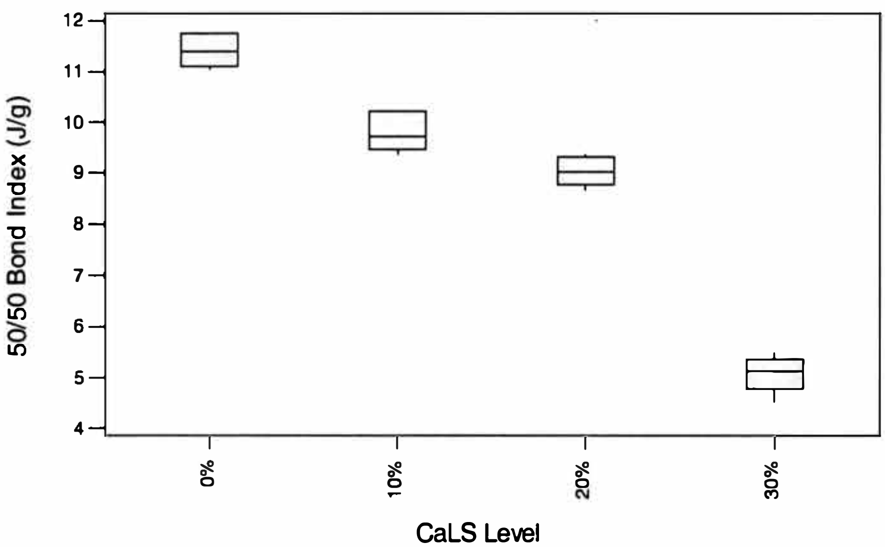

Figure 22. Scott Bond Index Versus CaLS Level For 50/50 Mix Paperboard