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Effects of white-water closure on the physical properties of linerboard

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Abstract

Mills are reducing their consumption of fresh water by recycling process waters. As the supply of fresh water to the paper machine decreases, there is a buildup of detrimental substances in the white water, a situation that is heightened when recycled fibers are added to the mix. These detrimental substances include both cationic and anionic species. The effects of these substances on linerboard strength were measured on laboratory handsheets made on a Formette Dynamique. A partial-factorial design of experiments was used to investigate the effects of calcium, sodium, lignin, xylan, pH, and fines on the physical properties (burst strength, ring crush, and *z*-directional tensile strength) of linerboard. Water quality was controlled to simulate average conditions in an open mill and a closed mill. Higher levels of calcium and sodium reduced sheet strength, while the presence of anionic organic substances actually improved the physical properties. The increased level of fines in the recycled white water had the largest impact, improving the strength of the board.

Application: Laboratory results suggest that closure of the white-water circuit on the paper machine will not reduce linerboard strength.

Introduction

The pulp and paper industry continues to look into mill closure as a means of reducing water consumption, in particular white-water closure around the paper machine. Contaminant levels increase when white-water streams are closed. The contaminants include organic, inorganic, cationic, and anionic substances, and detailed discussion about these contaminants can be found in the literature *(1–7)*. Typical contaminant levels of common species for linerboard mills are listed in **Table I** *(4, 8–10)*. The effects of these contaminants on the physical properties of paper, specifically linerboard, have not been discussed in sufficient detail. For example, Dexter *(2)* presented a table that qualitatively assessed the effects of contaminants on the physical properties of linerboard. The table suggested both positive and negative benefits of closure on the physical properties. However, this table gave only a qualitative description of the results. Even though many mills have operated under zero discharge for over 25 years, "there appears to be a need for quantitative information defining the impact on product quality which may result due to closure of the water system" *(1)*.

I. Typical average contaminant levels in linerboard mills

	Open system Virgin fiber	Open system Recycled fiber	Zero discharge Recycled fiber
Lignin, ppm	214	77	914
Carbohydrates, ppm	N/A	N/A	2930
Sodium, ppm	533	381	5000
Calcium, ppm	144	335	141
Aluminum, ppm	3.4	2.0	10
Magnesium, ppm	43	56	64
Manganese, ppm	1.6	1	0.4
Fines, %	20.1	14.5	30

The wet-end chemistry in traditional linerboard mills was a relatively simple acid and alum system. However, today's mills are trying to run with as much recycled fibers as possible. One of the consequences of using recycled furnish is a loss in strength, which can be balanced by adding starch to improve dry strength. Furthermore, some linerboard mills add clay or other fillers to the top layer to improve appearance, printability, or opacity. Thus wet-end chemistry and paper properties for current linerboard mills are quite different from the traditional acid and alum system.

The literature contains several works addressing the impact of closure on papermaking *(11–14)*, and the qualitative consequences and results of white-water closure are generally well understood. Nevertheless, there is little information regarding specific quantitative examples. Of course, like most of the research in the paper area, many of the systems are machine specific, so results can vary from machine to machine or from region to region. Clearly, there is a need for more generic studies. In this work, the effects of water closure were studied by testing linerboard handsheets produced at various degrees of closure. The handsheets were produced on a Formette Dynamique, which can produce multi-ply sheets with fibers aligned in the machine direction, similar to that of commercially produced linerboard. Although these handsheets are different from the papers produced on a commercial machine, the laboratory results provide a valid basis for predicting the effects of water closure on the physical properties of mass-produced papers.

Experimental

Materials, equipment, and procedures

A Georgia linerboard mill supplied furnish for these experiments. The furnish was obtained right after the refiners at approximately 4% consistency. The mill produces two-ply linerboard on a dual-headbox paper machine. The top furnish was 100% virgin, while the bottom furnish was 65% virgin and 35% OCC (old corrugating container). To simulate the white-water closure, different amounts of inorganic salts and organic components were added in the diluted furnishes. The organic components added to the furnish were model lignin (Indulin C, Westvaco) and xylan (Fisher). Calcium chloride and sodium chloride (Fisher) were used to adjust the cationic levels in the furnish. The pH was adjusted with sulfuric acid and sodium hydroxide. Alum (Fisher) was added to the furnish as required. Tap water was used to dilute the furnish.

The fines contents in the furnishes were adjusted with a concentrated solution of fines. The fines were generated by rinsing furnish in a DDJ (dynamic drainage jar) with a 200-mesh screen. The fines solution was concentrated by allowing the original filtrate to settle overnight. The top layer of water was removed, and the fines were concentrated. The fines contents were 7.77%, 7.32%, and 13.92% for the original top virgin, bottom virgin, and recycled OCC, respectively.

The furnish, stored in a cold room, was allowed to come to room temperature before use. Each experiment began by weighing out the necessary amount of furnish. The furnish was then diluted with tap water to approximately 0.5% consistency. Model lignin (Indulin C), xylan, calcium, sodium, fines, and alum were added at prescribed dosages. An anionic polymer (Perform, BetzDearborn) was added (0.5 lb/ton) in accordance with the mill from which the samples originated. This polymer was thought to be a drainage and retention aid. The pH was adjusted to the desired value. Both the top and bottom furnishes were treated similarly.

A Formette Dynamique was used to make two-ply directional handsheets. The bottom sheet comprised 80% of the target basis weight of the two-ply sheet of 205 g/m^2. The bottom furnish was poured into the Formette, and then the bottom sheet was made. When the sheet was almost finished, the top furnish was added and the top sheet formed. The Formette ran at 1500 m/min, with the pump pressure at 1.5 bar. The bottom furnish contained 35% recycled OCC, while the top sheet was 100% virgin fiber. Once finished, the sheets were removed and dried in a Johnson drum dryer at 15 psi of steam pressure. The sheets were then removed and conditioned before testing. The physical properties (burst strength, ring crush, and *z*-directional tensile strength) were measure according to TAPPI test methods.

Experimental design

This work utilized a partial-factorial experimental design to determine the effects of water closure on the physical properties of linerboard handsheets. Six variables of interest, along with their added amounts, can be seen in **Table II**. This work grouped the two most prevalent cationic species together, i.e., the levels of sodium and calcium were changed at the same time. The same procedure was followed for the anionic organic compounds.

The partial-factorial design of experiments was resolution V, which allowed interpretation of two-way interactions. The design called for 16 experiments, and four additional center points were run to determine the error and to test for curvature. **Table III** details the experimental runs.

II. Experimental variables

	Factors	
–1	0	+1

Cationic, ppm			
Ca	100	250	400
Na	500	2250	5000
Anionic, ppm			
Lignin	25	100	175
Xylan	50	325	600
Alum, ppm	13	15	18
Fines, %	8	10	12
pH	5.0	5.5	6.0

III. Experimental design

Run order	Metal ions	Organic anionic substances	Fines	Alum	pH
1	1	–1	1	1	–1
2	0	0	0	0	0
3	1	–1	–1	1	1
4	0	0	0	0	0
5	1	–1	1	–1	1
6	–1	1	1	–1	1
7	–1	1	1	1	–1
8	0	0	0	0	0
9	1	1	1	1	1
10	–1	–1	–1	1	–1
11	–1	–1	1	–1	–1
12	1	1	–1	–1	1
13	1	1	–1	1	–1
14	–1	–1	–1	–1	1
15	–1	–1	1	1	1
16	1	1	1	–1	–1
17	1	–1	–1	–1	–1
18	–1	1	–1	1	1
19	0	0	0	0	0
20	–1	1	–1	–1	–1

Results and discussion

Burst strength

Table IV lists the *p*-values for each of the main effects and two-way interactions for burst. The *p*-value is a statistical evaluation of the likelihood that the result is not statistically significant. If a confidence level of 95% is selected, a *p*-value of 0.05 or less is considered statistically significant. Whenever there are two-way interactions present, it is necessary to discuss the interactions first. A two-way interaction implies that the factors in question behave differently together than they do when they are separate. This is basically an indication of positive or negative synergy. The results in Table IV show that the organic anionic substances, fines, and pH were the only significant factors at 95% confidence. The metal ions and alum were significant at roughly 94% confidence. Only two interactions were significant at the 95% confidence level: organic anionic substances–pH and alum–pH.

IV. *p*-values for burst

Factors	*p*-value
Main effects	
Metal ions	0.051
Organic anionic substances	<0.001
Fines	<0.001
Alum	0.056
pH	0.048
Two-way interactions	
Organic anionic substances–pH	0.002
Alum–pH	0.014

Figure 1 shows the two-way interaction between alum and pH. At pH 6, the alum dosage had no effect on the burst. However, at pH 5, increasing the alum decreased the burst. The negative effect of increasing alum concentration at acid pH was also observed by Allen *(15)*. The reason for this difference is definitely related to the charge and structure characteristic of aluminum ions at different pH. However, more work is needed to fully understand the mechanism of alum effects on burst strength at different pH.

1. Effect of two-way interactions (pH–alum) on burst

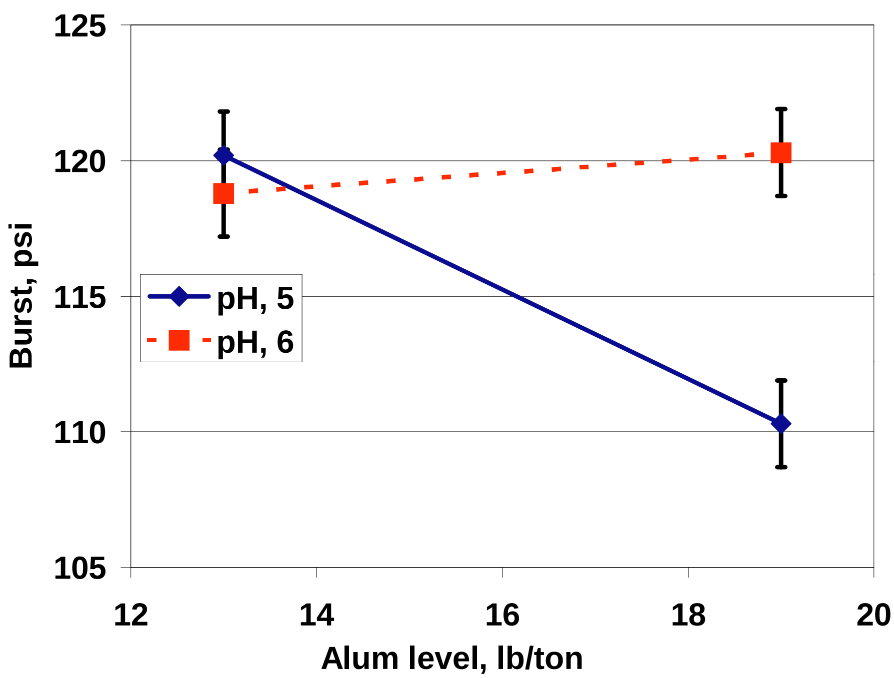
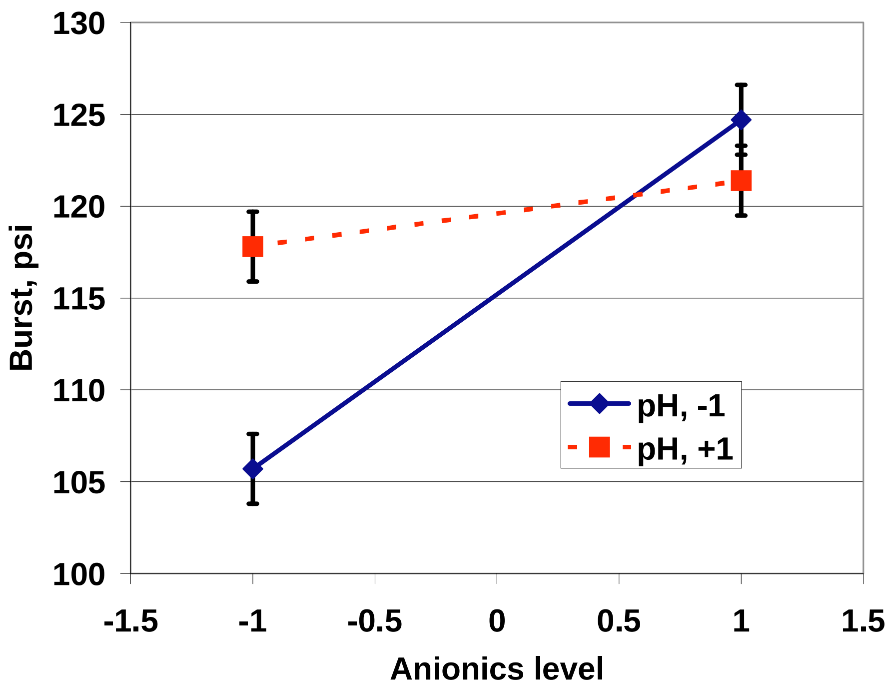
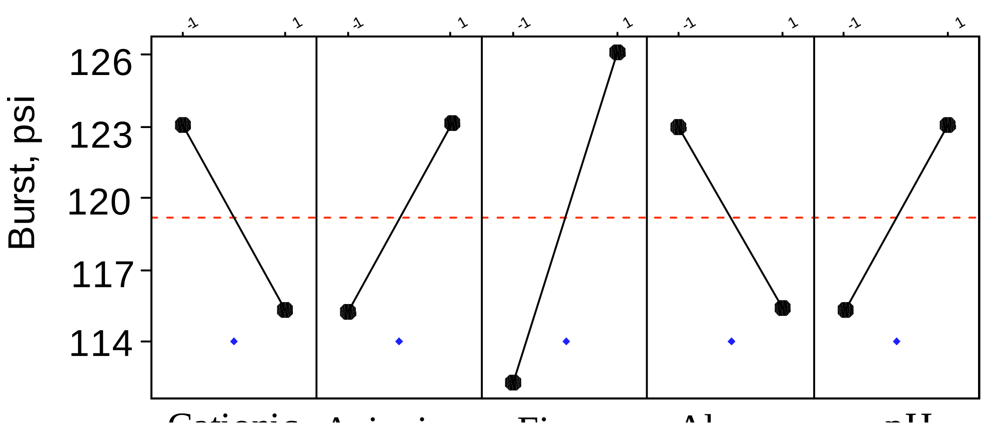


Figure 2 indicates that the effects of the anionic organic substances are dependent upon the pH as well. At pH 5, increasing the anionic organic substances greatly increased the burst from 105 to 125 psi. At pH 6, however, the addition of more organic substances to the system had a negligible effect on burst strength. The anionic materials are more ionized at pH 6 than 5. **Figure 3** summarizes the main effects of contaminants on burst strength. It can be seen that the organic anionic substances, fines, and pH increased burst, while alum and other metal ions (sodium and calcium) had a slightly negative impact.



2. Effect of two-way interaction (pH–organic anionic substances) on burst



3. Effect of simulated closure on burst

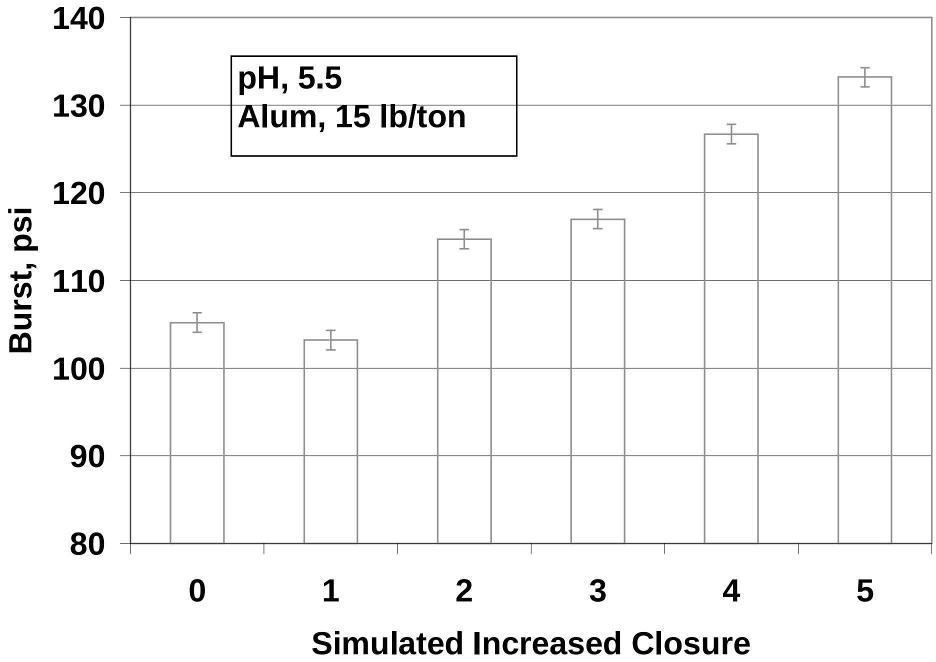
Both positive and negative effects of organic substances on burst and tensile strength have been reported in the literature. Researchers such as Auhorn *et al. (6)*, Springer *et al. (16)*, and Lindström *et al. (17)* have indicated that sheet strength can decrease when organics are present in the white water. In contrast, many others *(18–20)* have indicated that sheet strength is improved by increasing dissolved organics. These opposing results may in part result from differences in the types of pulp and organics used. It is well known that some organics generated from wood, such as hemicellulose and xylan, can improve the paper strength, while some others, such as fatty acids, can result in a loss in paper strength. The levels of organic substances added also give different effects. Springer *(16)* mentioned that two mechanisms are involved in the strength effects of organic contaminants. One results in a strength loss and the other a strength increase. At very low contaminant levels (less than several ppm), the strength-loss mechanism dominates. As the level of contaminants increases, the strength-increase mechanism counteracts the strength-loss mechanism. The anionic levels used in our research were relatively high, so it is very likely that the second mechanism was dominant. The pH dependence of the anionic contaminant effect on burst may be related to the dissociation or association of hydrogen in these materials.

Different degrees of closure were simulated by adding "contaminants" at the dosages listed in **Table V**. The response of burst strength to increasing levels of simulated closure is illustrated in **Fig. 4**. The trend in the graph is clear: increasing contaminants raised the burst strength by more than 25%.

V. Contaminant levels at simulated degrees of closure

Degree of closure	Ca, ppm	Na, ppm	Lignin, ppm	Xylan, ppm
0	0	0	0	0
1	100	500	25	50
2	175	1325	62	187

3	250	2250	100	325
4	325	3125	138	463
5	400	5000	175	600



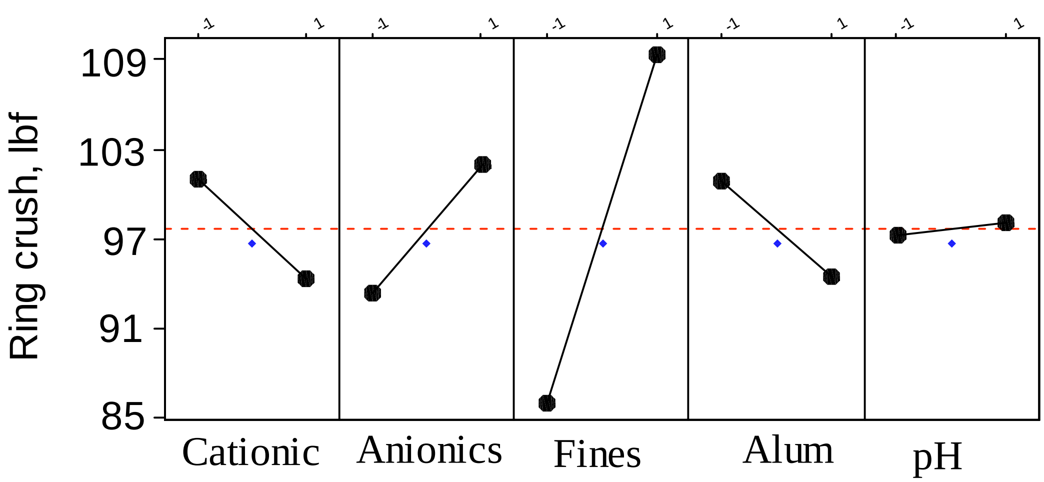
4. Main effects on burst strength

Ring crush

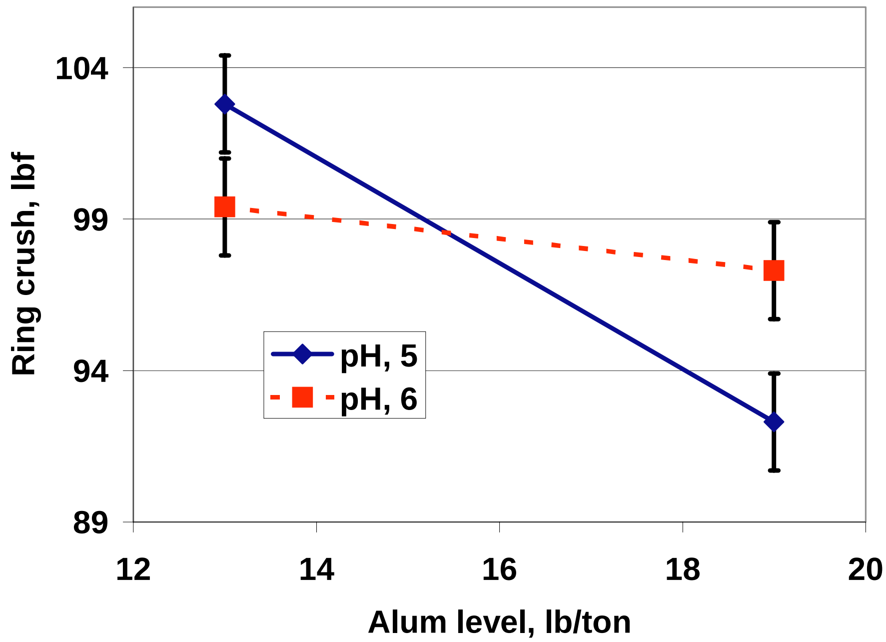
Table VI reveals that alum–pH was the only interaction significant at the 95% confidence level, although pH by itself did not affect the ring crush. **Figure 5** shows the main effects of different contaminants on ring crush. Similar to the effects of contaminants on burst strength, ring crush was negatively affected by adding alum and other metal ions, but it was positively affected by the addition of anionic trash. Fines content had the greatest impact, almost double that of the organic anionic substances. A certain level of fines can fill the cavities in the fiber network and improve sheet strength by increasing bonding areas. Increasing the alum decreased the ring crush. While changing the pH from 5 to 6 had no impact on the ring crush by itself, it did interact with alum, as shown in **Fig. 6**. Increasing the level of closure improved ring crush, as seen in **Fig. 7**, which shows that ring crush increased from 85 to around 115, an increase of more than 35%.

VI. *p*-values for ring crush

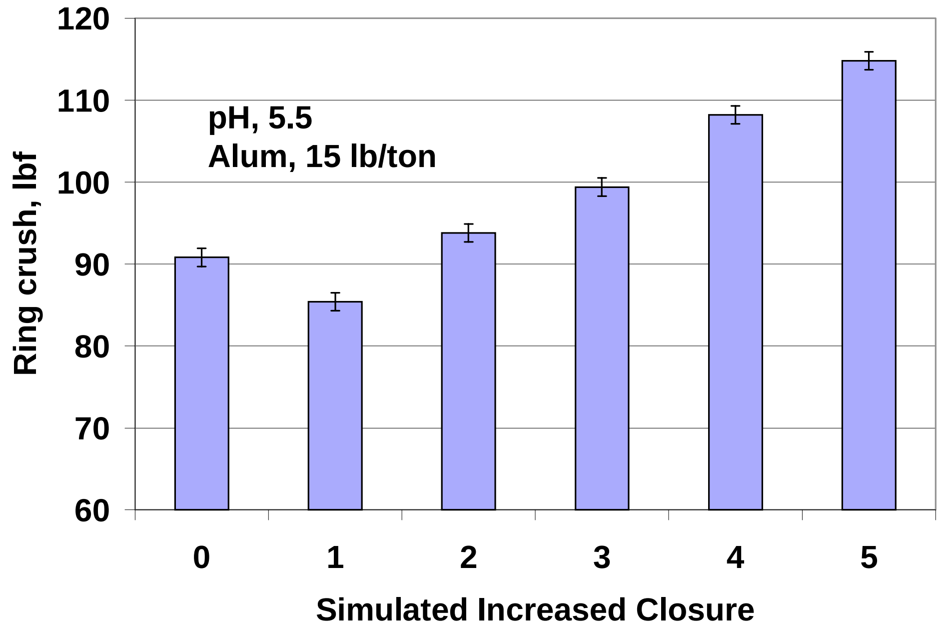
Factors	*p*-value
Main effects	
Metal ions	0.002
Organic anionic substances	<0.001
Fines	<0.001
Alum	0.003
pH	0.638
Two-way interactions	
Alum–pH 0.030	



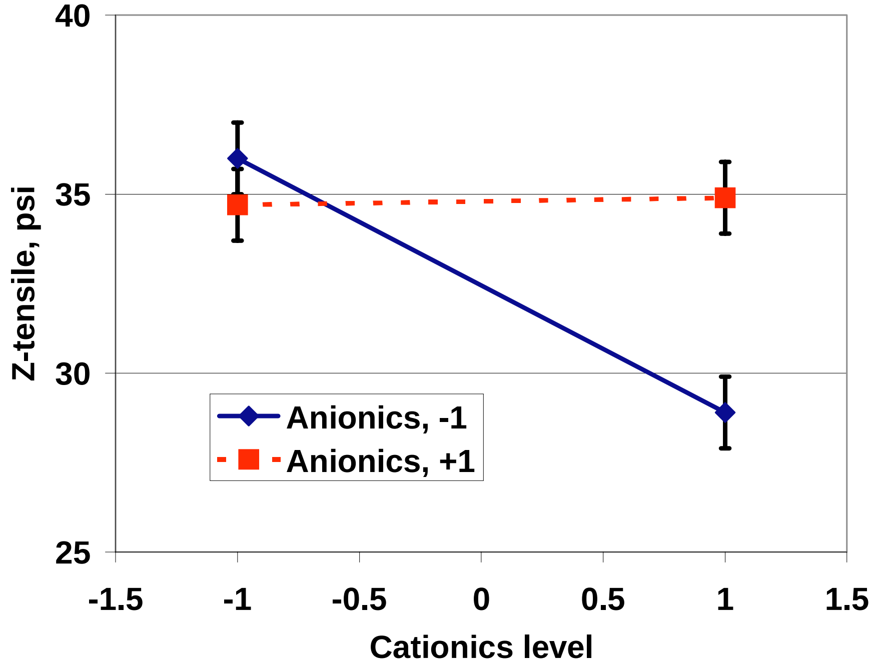
5. Effect of two-way interaction (pH–alum) on ring crush



6. Main effects on ring crush



7. Effect of stimulated closure on ring crush



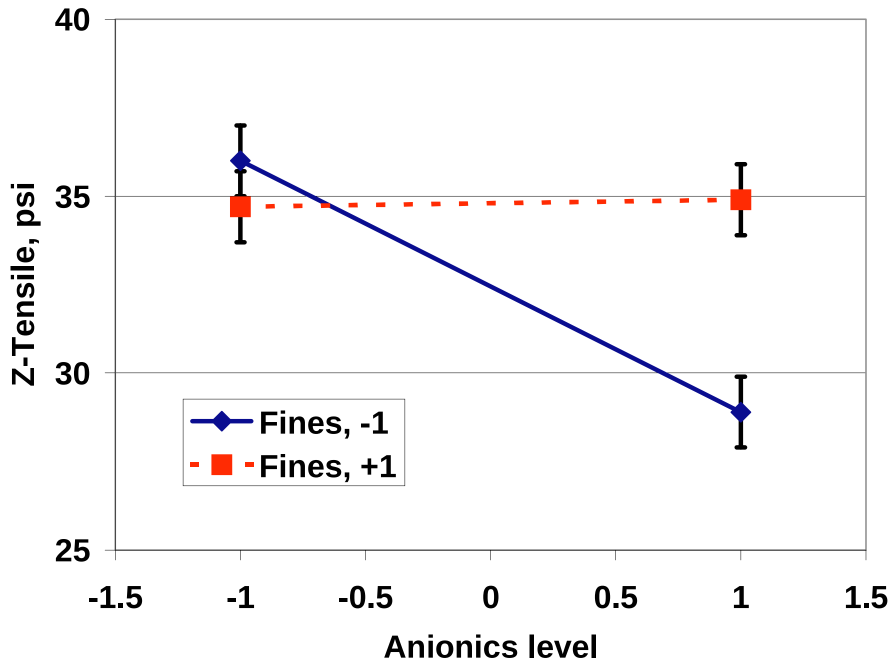
z-*direction tensile strength*

Table VII shows the *p*-values for the main effects and two-way interactions for *z*-tensile strength. The pH was not significant as a main effect or as a two-way interaction. However, the results showed a significant effect for three two-way interactions: organic anionics–metal ions, fines–organic anionics, and alum–fines, as seen in **Figs. 8–10**, respectively. Increasing the metal ions decreased the *z*-tensile only when the anionic level was low (Fig. 8). It is probable that at low levels, the anionic materials are more saturated with calcium and sodium, thus weakening their beneficial effect. In terms of white-water closure, this is not a problem because the organic anionic substances are at a high level when the metal ions are at a high level.

VII. *p*-values for *z*-tensile

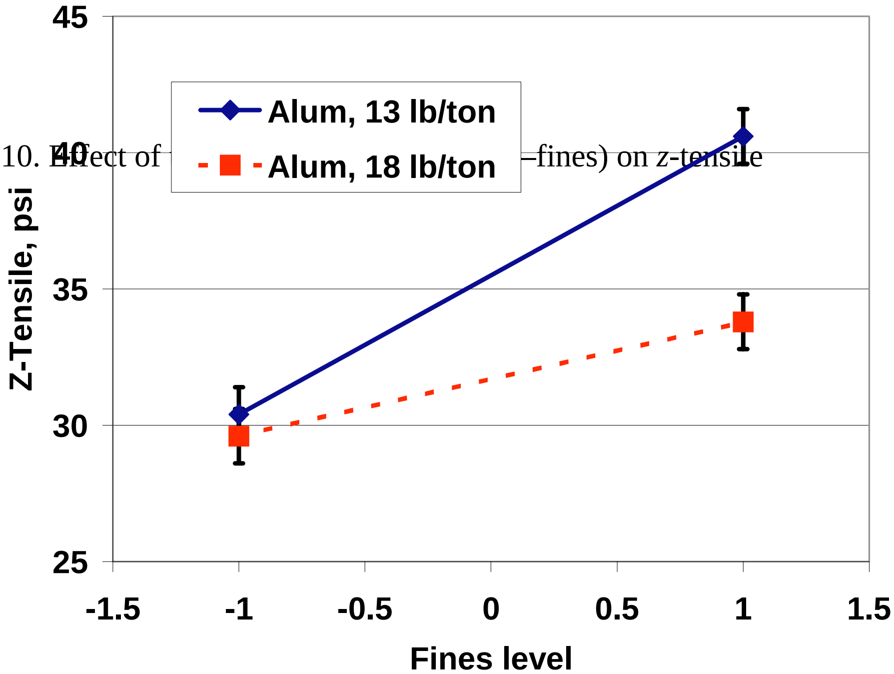
Factors	*p*-value
Main effects	
Metal ions	0.004
Organic anionic substances	0.028
Fines	<0.001
Alum	0.002
pH	0.482
Two-way interactions	
Metal ions–organic anionic substances	0.003
Organic anionic substances–fines	0.044
Fines–alum	0.008

8. Effect of two-way interactions (organic anionic substances–metal ions) on *z*-tensile



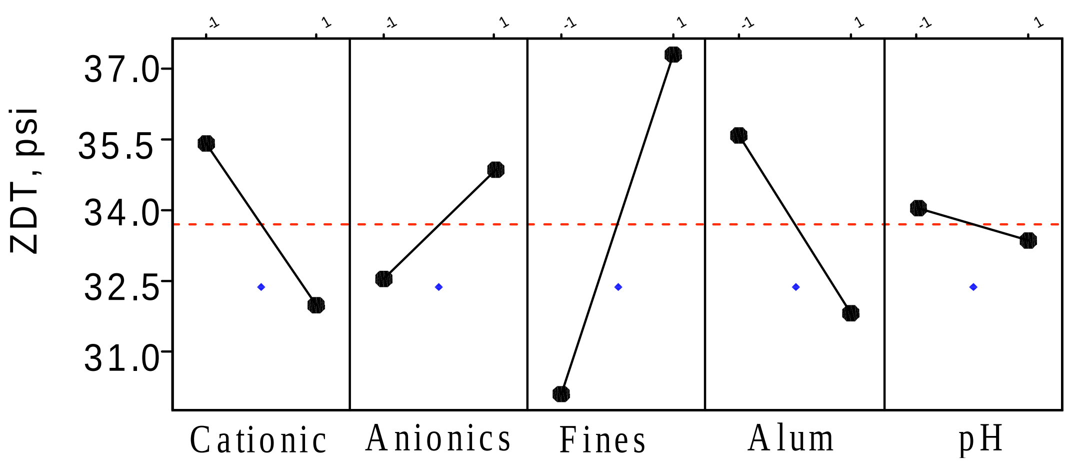
9. Effect of two-way interactions (fines–organic anionic substances) on *z*-tensile

10. Effect of [illegible]–fines) on *z*-tensile

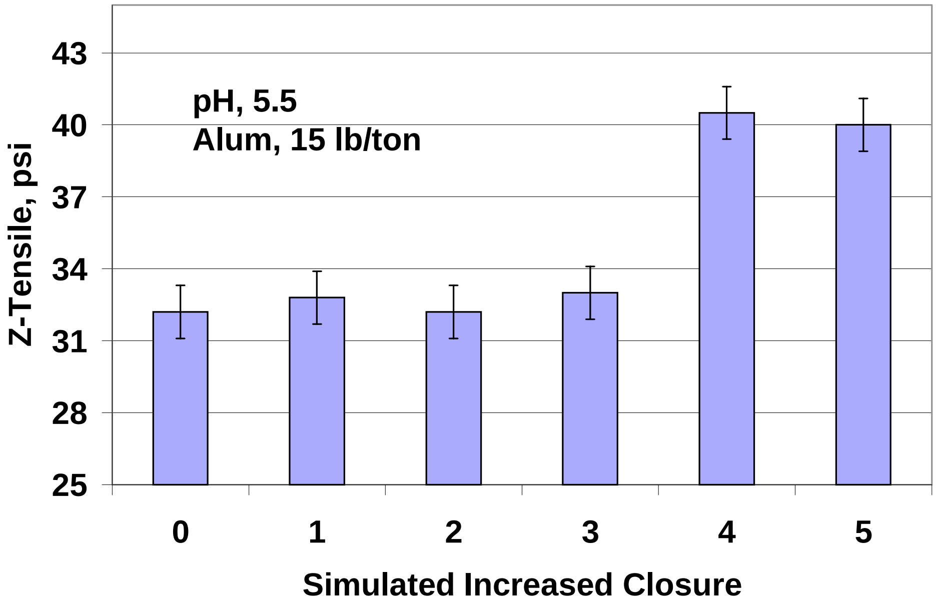


Increasing the organic anionic substances at a low fines level reduced the *z*-tensile strength, whereas there was no effect at a high fines content, as seen in Fig. 9. From a process point of view, this may not be too critical because the levels of organic anionic substances and fines should both increase with increasing water closure. The beneficial effect of fines was greater with lower alum dosages, as seen in Fig. 10. For example, *z*-tensile strength increased by 33% at 13 lb/ton of alum compared with a 10% increase at 18 lb/ton of alum.

Figure 11 shows the main effects of different contaminants on *z*-tensile strength. Again, metal ions decreased sheet strength, while the organic anionic substances and fines increased the strength. Increasing the level of closure improved *z*-tensile strength, as seen in **Fig. 12**, which shows that *z*-tensile strength increased by 25%.



11. Main effects on *z*-tensile11. Main effects on *z*-tensile



12. Effects of simulated closure on *z*-tensile

Conclusions

Closure of the white-water system increases the concentration of metal ions, organic substances, and wood fines. However, this does not necessarily imply that recirculation of white water will have a detrimental impact on the physical properties of linerboard. Indeed, the data suggest that closure could improve the physical properties of linerboard. Burst strength increased by 25–35%; ring crush increased by 35–45%; and *z*-tensile strength increased by 25–45%.

The experiments also revealed two-way interactions. Alkaline papermaking conditions diminished the potential improvements in burst strength and ring crush obtained in the presence of organic ionic substances. The combination of a high fines content and an elevated level of organic anionic substances produced an increase in *z*-direction tensile strength.

Despite these positive results, it should be noted that the impact of white-water closure on paper properties may be strongly dependent on the types and content of organics in the furnish and the grade of paper products. For linerboard products, the general conclusion is that water closure should have no significant effect on the strength.

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