

# *Cationization of oat $\beta$ -D glucan as a dry-strength additive for paper*

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**ABSTRACT:** Oat  $\beta$ -D glucan was treated with 3-chloro-2-hydroxypropyl-trimethyl ammonium chloride (10%, 20%, 30%, or 50% of beta glucan) to obtain a range of cationic  $\beta$ -D glucan samples. The derivatization was confirmed by the results of Fourier transform infrared (FTIR) tests and elemental analysis. Addition of 1% cationic  $\beta$ -D glucan based on the mass of unbleached pine kraft fiber increased burst, tensile, and folding endurance properties of the resulting paper. Similar effects were observed at pH 5 and pH 8.5, showing that the system can be considered robust relative to typical acidic and alkaline papermaking conditions. The strength benefits were also observed in recycled sheets made by reslurrying paper prepared with cationic  $\beta$ -D glucan, even when the initial drying conditions had been severe. The beneficial results of cationization, which can be explained by a more hydrophilic nature and better retention, hold promise as a means of improving the strength properties of virgin paper. The treatment of the initial paper also can enhance the dry-strength performance when the fibers are recovered and used again.

**Application:** Treating a hemicellulosic byproduct of oat processing to give it a positive charge can improve its effectiveness as a dry-strength agent for wet-end addition.

Recently we reported that a byproduct of oat processing known as  $\beta$ -D glucan can be rendered much more effective as a dry-strength agent for papermaking by treating it to increase the amount of negatively charged carboxyl groups [1,2]. One of the approaches employed to increase the negative charge of the  $\beta$ -D glucan involved oxidation of hydroxyl groups, primarily in the C6 position, by means of 2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) with sodium hypochlorite [1]. The other approach used sodium chloroacetate to carboxymethylate hydroxyl groups of the  $\beta$ -D glucan [2]. In both cases, there were substantial increases in tensile strength, burst strength, and folding endurance when suspensions of unbleached softwood kraft fibers were treated with solutions of the modified, as opposed to the as-received,  $\beta$ -D glucan material. Results could be further enhanced with an optimum addition level of aluminum sulfate ( $\text{Al}_2[\text{SO}_4]_3$ ), which was thought to provide positively charged sites for the more effective adsorption of the negatively charged  $\beta$ -D glucan and its modified versions. In each case, there were substantial losses in bonding ability after drying, reslurrying, and forming the material into a new generation of hand-sheets. Those systems that had been treated in the first cycle with the modified  $\beta$ -D glucan yielded higher strength properties in the recycled paper.

The reason for selecting oat beta-glucan as a starting material for the current work is based on its availability as an underused byproduct of another industry. Due to the enzymatic treatment conditions used by the manufacturer, the beta-glucan can be expected to have a higher molecular mass than is typical for such compounds. Though a detailed analysis of costs and availability are not included in the present work, we

also wanted to find out whether an impure commercial byproduct of this type could serve as the basis for preparing an effective dry-strength agent for papermaking.

To account for the increased dry-strength contribution of the  $\beta$ -D glucan following its anionic modification, it had been proposed that the higher level of carboxylate groups made the material more soluble in water [1]. Indeed, the raw material was described as containing 32%–35% of dietary fiber, whereas after modification the solutions were clear. It was thought that more complete solubility in water would allow the material to mix more efficiently in a papermaking suspension. Also, it is known that dry-strength performance tends to be highest in highly hydrophilic polymer materials [3-5]. A higher charge density of a polyelectrolyte in solution will result in a more expanded macromolecular conformation. This effect has been correlated with higher dry-strength performance in the case of polyampholytes, where a higher net ionic substitution level was found to generally yield higher dry strength [5-7].

Cationic polyelectrolytes, especially cationic starch products, have been widely used as wet-end additives to increase the dry strength of paper. The mechanisms of action and factors leading to effectiveness of such dry-strength systems have been discussed [5,8-10]. In particular, cationic modification has been shown to be highly beneficial in terms of efficiently retaining the additive on fiber surfaces [11]. There has been some precedent for the cationic treatment of polysaccharides, such as hemicellulose components, that are inherently anionic [12-17], as in the case of the  $\beta$ -D glucan considered earlier by the authors. Even when such treatments are carried out to an extent that renders the net charge positive, there still will

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be negatively charged groups to the extent that a polyampholyte or amphoteric polymer is created. Polyampholytes sometimes have been shown to outperform dry-strength additives having only one sign of ionically charged groups [6-7,18-20].

In view of the reported positive effects of (a) derivatization to increase the amount of ionizable groups, (b) cationic modification of polysaccharide-based dry-strength agents, and (c) the superior performance of dry-strength polymers bearing both ionizable groups of both signs of charge, the goal of the present work was to evaluate the effects of cationization of the same  $\beta$ -D glucan that was considered in our earlier work [1-2]. Cationization was realized with 3-chloro-2-hydroxypropyl-trimethyl ammonium chloride under alkaline conditions, which made hydroxyl groups covalently connect with quaternary ammonium salt groups. Variables considered included the dosage of cationic reagent employed, the pH at which the paper sheets were formed, and the effects of three severity levels of drying when evaluating the strength attributes of recycled paper sheets made from the same fibers without further refining or further chemical addition. Changes to the  $\beta$ -D glucan were investigated by infrared spectroscopy and elemental analysis. Effects of the as-received and modified  $\beta$ -D glucan were compared by forming paper handsheets.

## EXPERIMENTAL

### Materials

Oat  $\beta$ -D glucan was obtained in powder form from Biovelop International AB, Kimstad, Sweden. The molecular weight of the glucan was given as 1,300,000 Da. The compositional data were provided as follows: 32%-35% of dietary fiber (soluble  $\beta$ -D glucan), 34%-37% of total dietary fiber, 54%-56% of carbohydrate (maltodextrin), 2.5%-3.5% of protein, 3%-4% of ash, and 0.5%-1% of fat.

Kraft pulp of loblolly pine was prepared under the following laboratory conditions: liquor ratio 1:4.5, alkali dosage 19%, sulfidity 25%, and H-factor 1800. Pulp was prepared from wood chips to allow the subsequent tests to be carried out with never-dried fibers. Also, by preparing the pulp in the laboratory, the conditions of preparation can be specified. The yield of the pulp was 50%. After refining to 400 mL (CSF), the fibers large enough to be collected on a 48-mesh screen were used.

## METHODS

### Cationization

A selected amount of water and 0.06 g of sodium hydroxide (NaOH) were put into a 100-mL beaker with an impeller stirring apparatus. The mixture was stirred at room temperature until the NaOH was dissolved. Then, 6g of oat  $\beta$ -D glucan (dry basis) and 3-chloro-2-hydroxypropyl-trimethyl ammonium chloride (10%, 20%, 30%, or 50% of beta glucan on a mass basis) were put into the beaker. Each mixture included 25% water, together with selected amounts of beta glucan, 3-chloro-2-hydroxypropyl-trimethyl ammonium chloride, and NaOH. The pH was approximately 10 before and after the re-

action. The mixture was stirred for 10 min, and the beaker flask was put into the 70°C oven for 4 h. The bottle was placed into tap water to cool it to room temperature, and then 60 mL of 80% ethanol (V/V) were combined in the beaker. The solids were collected on filter paper, washed four times with 50 mL of 100% ethanol, and dried in air. In this manner, four samples of cationic  $\beta$ -D glucan were obtained.

### Papermaking and physical properties of handsheets

Standard handsheets were prepared (1.2 g o.d.) and tested in accordance with TAPPI Standard Test Method T 205 sp-95, "Forming handsheets for physical tests of pulp." Other papermaking conditions were as follows: use of 1% cationic  $\beta$ -D glucan based on the dry mass of fibers, and pH adjusted as specified.

A portion of the handsheets were dried under different conditions: gentle dryness (dried at room temperature), ordinary dryness (dried in an oven at 105°C for 30 min), and severe dryness (dried in an oven at 150°C for 60 min). The handsheets were immersed in water at room temperature for 24 h, then disintegrated. Without further addition of chemicals, the pulp samples were formed again into recycled handsheets, following TAPPI Standard Test Method T 205 sp-95. Paper sheets were equilibrated overnight at 50% RH before evaluation of paper properties.

### Analytical tests

The cationic  $\beta$ -D glucan and a certain amount of potassium bromide were oven dried, then ground into powder to obtain a sample suitable for fourier transform infrared (FTIR) analysis. The absorbance between 4000 and 400  $\text{cm}^{-1}$  was studied, using a Spectrum-100 infrared spectrometer from PerkinElmer (Grayson, GA, USA).

An S-3000N scanning electron microscope (SEM) (Hitachi Ltd.; Tokyo, Japan) was used for observation of handsheet surfaces and fractured edges at location of breakage. Gold sputtering was used to avoid changing effects.

Elemental analysis was carried out using a Flash EA1112 unit (Thermo Electron SPA America; West Palm Beach, FL, USA). The carbon (C), hydrogen (H), and nitrogen (N) contents were tested. Oxygen (O) content was obtained from the total elements, excluding C, H, and N.

Dosage of Cationic Reagent (%)	N (%)	C (%)	H (%)	O (%)
Unmodified $\beta$ -D Glucan	0.83	43.12	6.53	49.52
20% Reagent	1.09	42.98	6.50	49.43
30% Reagent	1.05	42.98	6.50	49.47
50% Reagent	1.05	42.89	6.56	49.50

### I. Elemental analysis of cationic oat $\beta$ glucan.

**RESULTS AND DISCUSSION**

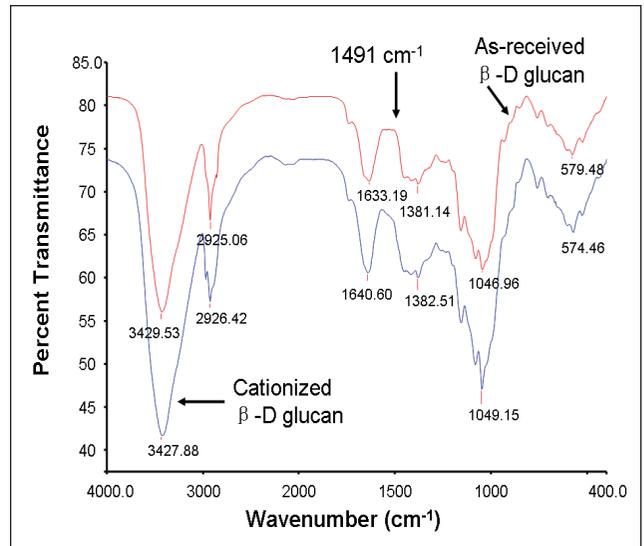
*Elemental analysis of cationic oat β-D glucan*

Elemental analysis results for the β-D glucan and its cationic derivatives are presented in **Table I**. As shown, the unmodified glucan was found to contain N, C, H, and O. Nitrogen is derived from protein, which is 2.5%-3.5% of the unmodified β-D glucan. Nitrogen content increased after cationization due to the incorporation of quaternary ammonium salt groups that had been connected to the glucan. With increasing N percentage, the proportional amounts of O, C, and H generally decreased, as shown.

The main finding was that, except for an increase in N and a decrease in C when comparing treated versus unmodified beta-D glucan, there were no other notable trends. In other words, the lowest treatment dosage was sufficient to achieve measurable cationization, and higher concentrations did not measurably increase the level of derivatization. The fact that the N content did not show further significant increases at dosage levels higher than 20% of the cationic reagent is attributed to two factors. First, the most accessible or reactive of the hydroxyl groups are expected to become derivatized first, followed by much slower reaction with the remaining OH-groups. Further work will be needed to confirm the validity of this assumption. Second, the reaction conditions were relatively mild, consistent with the aim of minimizing breakdown of the glucan molecular chains. It is likely that a higher degree of substitution could be achieved by use of a higher concentration of NaOH.

*FTIR analysis*

FTIR spectrograms of cationic and unmodified β-D glucan are presented in **Fig. 1**. The 3429 cm<sup>-1</sup> peak corresponds to hydroxyl groups; the 2925 cm<sup>-1</sup> peak is for methylene groups; the 1633 cm<sup>-1</sup> peak is for carbonyl (C=O) groups; and the 1727 cm<sup>-1</sup> peak represents carboxylic ester groups, which can be at least partly attributed to the presence of ester groups on the glucan or in the fatty acid component. Notably, the 1727 cm<sup>-1</sup> peak still was observable in cationic β-D glucan; this



**1. Fourier transform infrared spectra of the as-received β-D glucan (upper) and cationically derivatized β-D glucan (lower).**

indicated that an ester group in the original material was not lost during the course of cationization. According to the literature, the C-N stretching in a quaternary system with methyl groups should give rise to a small peak at 1491 cm<sup>-1</sup> [21-22]. As shown by the arrow positioned at 1491 cm<sup>-1</sup>, the shape of the curve was changed in this location, consistent with the presence of a quaternary ammonium group.

*Effects of dosage of cationic reagent on handsheet properties*

As shown in **Table II**, the tensile index, burst index, and folding endurance of handsheets prepared with cationic β-D glucan increased greatly compared with the control sample (no glucan added) and also in comparison to treatment with the unmodified β-D glucan. The values were increased by 52.9%, 67.8%, and 230.5%, respectively, relative to the control, when the dosage of cationic reagent used to prepare the glucan was 50% on the glucan (dry basis). The tear index showed a diver-

	Density (g/m <sup>3</sup> )	Tensile Index (Nm/g)	Burst Index (kPam <sup>2</sup> /g)	Folding Endurance (double folds)	Tear Index (mNm <sup>2</sup> /g)
Control	0.518	52.79	4.25	456	5.73
β-D glucan, unmodified	0.553	68.17	5.91	899	3.81
TEMPO oxidized (30 min)	0.540	71.81	6.52	1,028	3.63
Carboxymethylated (45 min)	0.586	79.92	6.83	1,300	4.72
Cationic reagent 50%	0.594	80.70	7.13	1,507	4.43

**II. Dosage of cationic reagent versus handsheet properties. The dosage of cationic reagent is on the oat β-D glucan (dry basis). The control sample was prepared with no chemical additives; the other samples were prepared with 1% cationic β-D glucan on a dry fiber basis. The pH was adjusted to 5.**

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pH	Density (g/cm <sup>3</sup> )	Tensile Index (Nm/g)	Burst Index (kPam <sup>2</sup> /g)	Folding Endurance (double folds)	Tear Index (mNm <sup>2</sup> /g)
5	0.594	80.70	7.13	1507	4.43
6.5	0.594	78.02	6.99	1454	4.54
7.5	0.594	76.97	6.90	1217	4.82
8.5	0.589	77.88	6.96	1448	4.39

### III. Effects of pH on handsheet properties. The dosage of cationic reagent is 50% on the oat $\beta$ -D glucan (dry basis).

	Dosage of Cationic Reagent (%)	Density (g/cm <sup>3</sup> )	Tensile Index (Nm/g)	Burst Index (kPam <sup>2</sup> /g)	Folding Endurance (double folds)	Tear Index (mNm <sup>2</sup> /g)
Gentle dryness	Control	0.473	45.21	3.73	59	5.87
	Unmodified	0.528	53.46	4.08	407	4.82
	10% Reagent	0.559	60.29	5.19	893	5.48
	20% Reagent	0.559	62.83	5.37	904	5.41
	30% Reagent	0.558	61.86	5.32	831	5.48
	50% Reagent	0.552	61.08	5.25	770	5.64
Ordinary dryness	Control	0.506	37.54	3.35	56	5.35
	Unmodified	0.465	44.58	3.48	97	5.82
	10% Reagent	0.542	56.39	4.96	676	7.92
	20% Reagent	0.544	56.90	4.97	771	7.83
	30% Reagent	0.543	55.00	4.95	573	7.85
	50% Reagent	0.543	54.87	4.91	531	7.85
Severe dryness	Control	0.444	26.41	3.15	6	4.18
	Unmodified	0.401	26.84	3.29	12	4.91
	10% Reagent	0.499	35.49	4.40	58	6.97
	20% Reagent	0.512	40.74	4.34	96	6.69
	30% Reagent	0.510	37.99	4.33	64	6.72
	50% Reagent	0.508	38.22	4.31	60	6.80

### IV. Dosage of cationic reagent versus properties of recycled paper. The control sample was prepared with no chemical additives; the other samples were prepared with 1% cationic beta glucan. The pH was adjusted to 5.

gent trend with the increasing of the dosage of cationic reagent, which is consistent with the earlier studies involving anionic forms of the glucan [1-2]. Thus, one of the consequences of the enhanced interfiber bonding, due to the  $\beta$ -D glucan addition, was a more brittle character of the resulting paper, according to its evaluation by the tear test.

The results shown for handsheet strength properties suggest that the cationized beta-glucan might be considered as a

competitor to cationic starch products, which are the most widely used type of wet-end additive used to increase paper's dry-strength attributes. For instance, several authors [5,8-11] have reported significant increases in tensile or burst strength following the addition of cationic starch to the furnish. An overall impression of how cationic starch compares, in terms of its dry-strength performance, with many other possible treatments can be gained from the tabulated results in a recent

	Dosage of Cationic Reagent (%)	Density (g/m <sup>3</sup> )	Tensile Index (Nm/g)	Burst Index (kPam <sup>2</sup> /g)	Folding Endurance (double folds)	Tear Index (mNm <sup>2</sup> /g)
Freshly prepared handsheets	10%	0.580	73.49	6.49	1,033	4.56
	20%	0.587	77.83	6.57	1,144	4.54
	30%	0.589	77.82	6.73	1,164	4.54
	50%	0.589	77.88	6.96	1,448	4.39
Gentle dryness	10%	0.561	57.46	5.29	570	5.60
	20%	0.568	61.25	5.42	713	5.42
	30%	0.561	58.41	5.15	604	6.03
	50%	0.559	58.08	5.13	600	6.05
Ordinary dryness	10%	0.546	56.95	4.78	541	6.86
	20%	0.549	54.53	4.75	538	7.82
	30%	0.543	53.33	4.65	525	7.76
	50%	0.543	55.38	4.72	548	6.67
Severe dryness	10%	0.514	39.75	4.48	104	6.62
	20%	0.505	39.48	4.58	103	6.69
	30%	0.506	37.97	4.29	102	6.64
	50%	0.518	42.42	4.35	113	6.59

**V. Properties of handsheets prepared at pH 8.5, subject to different drying histories.**

review article by one of the authors [23]. It was shown that a broad range of water-soluble polymers can be used to enhance paper strength, but the detailed results are also quite sensitive to the characteristics of the fibers. It is recommended that comparative tests versus cationic starch be included in a future study of cationic beta-glucan as a dry-strength additive.

The effects of pH value on paper physical properties are presented in **Table III**. As shown, the relative changes of tensile index, burst index, and folding endurance were quite small with changes of pH values. It had been expected that at pH 5 the added cationic glucan could more quickly neutralize and reverse any excess anionic charge in the pulp. In cases where the amounts of dissolved and colloidal substances are relatively high [24], such an effect might improve the strength of handsheets. When the pH is higher, one can expect there to be a somewhat higher affinity of the cationic additive to the negatively charged fiber surfaces; this situation can lead to higher adsorption of the modified glucan onto the fibers, leading to higher dry strength. However, as shown, none of the strength results varied by more than 4% relative to the mean value when comparing the lowest and highest pH.

The effects of cationic β-D glucan on physical properties of recycled paper are presented in **Table IV**. In these experiments, the cationic glucan was optionally applied only

when forming the original sheets, not when making the recycled paper. Compared to the respective recycled paper without glucan (control samples), the tensile index, burst index and folding endurance of recycled paper made with the glucan increased greatly, even in the case of severe drying and recycling after the chemical treatment. Even the unmodified β-D glucan had a positive effect. The tensile index, burst index, and folding endurance, respectively, increased by 39%, 44%, and 1432% relative to the control in recycled sheets after gentle drying, reslurrying, and preparation of the recycled sheets when 1% cationic β-D glucan (dosage of cationic reagent 20% on dry basis of β-D glucan) was used. The tensile index, burst index, and folding endurance, respectively, increased by 51%, 48.4%, and 1277% after ordinary drying, when compared to the corresponding samples without β-D glucan products but dried in the same way. However, they were increased by 54.3%, 37.8%, and 1500% relative to the control after severe drying. Thus, it is clear that the cationic β-D glucan added during the initial cycle of papermaking also can be highly beneficial for the production of recycled paper even after severe drying. Though severe drying is not a usual treatment for paper, it is proposed that it be considered as an indication of changes that might occur over several cycles of paper usage, storage, and recycling.

## *pH versus properties of recycled paper*

In view of the widespread use of alkaline papermaking conditions, further handsheet tests were carried out at pH 8.5. The effects of different drying histories on the strength of handsheets, each time prepared at pH 8.5, are shown in **Table V**. These results can be compared with those in Tables II and IV, which correspond to a forming pH of 5. At pH 8.5, in comparison to the recycled paper without  $\beta$ -D glucan, the tensile index, burst index, and folding endurance of recycled paper also increased greatly, when comparing the handsheets prepared from fibers in the presence of modified glucan with those formed from fibers in the absence of glucan and then subjected to the same drying conditions. This relationship held true even in the case of fibers that had been subjected to severe drying conditions after the chemical treatment. Such findings are in general agreement with past work [25]. The bonding ability of kraft fibers is known to suffer as a result of drying, with the effects becoming more severe with increasing drying temperature [25-26]. It was found that the tensile index, burst index, and folding endurance, respectively, increased by 35.5%, 45.3%, and 1108% relative to the control after the gentle drying when 1% cationic  $\beta$ -D glucan was used. The tensile index, burst index and folding endurance, respectively, increased by 45.3%, 41.8%, and 861% after ordinary drying. However, they were increased by 49.5%, 45.4%, and 1617% relative to the control after severe drying. The tensile index, burst index, and folding endurance of treated sheets were lower than the control for pH 5 (see Tables II and IV) after gentle dryness and ordinary drying. However, the results for severe drying were in parallel with the strength results at other pH values. The alkaline condition was somewhat more favorable for the modified  $\beta$ -D glucan in the case of severe drying. When comparing the results for the two different pH conditions, the results were quite similar. In other words, the  $\beta$ -D glucan system was robust relative to pH and could be used effectively under both acidic and weakly alkaline papermaking conditions.

## *Electron microscopy*

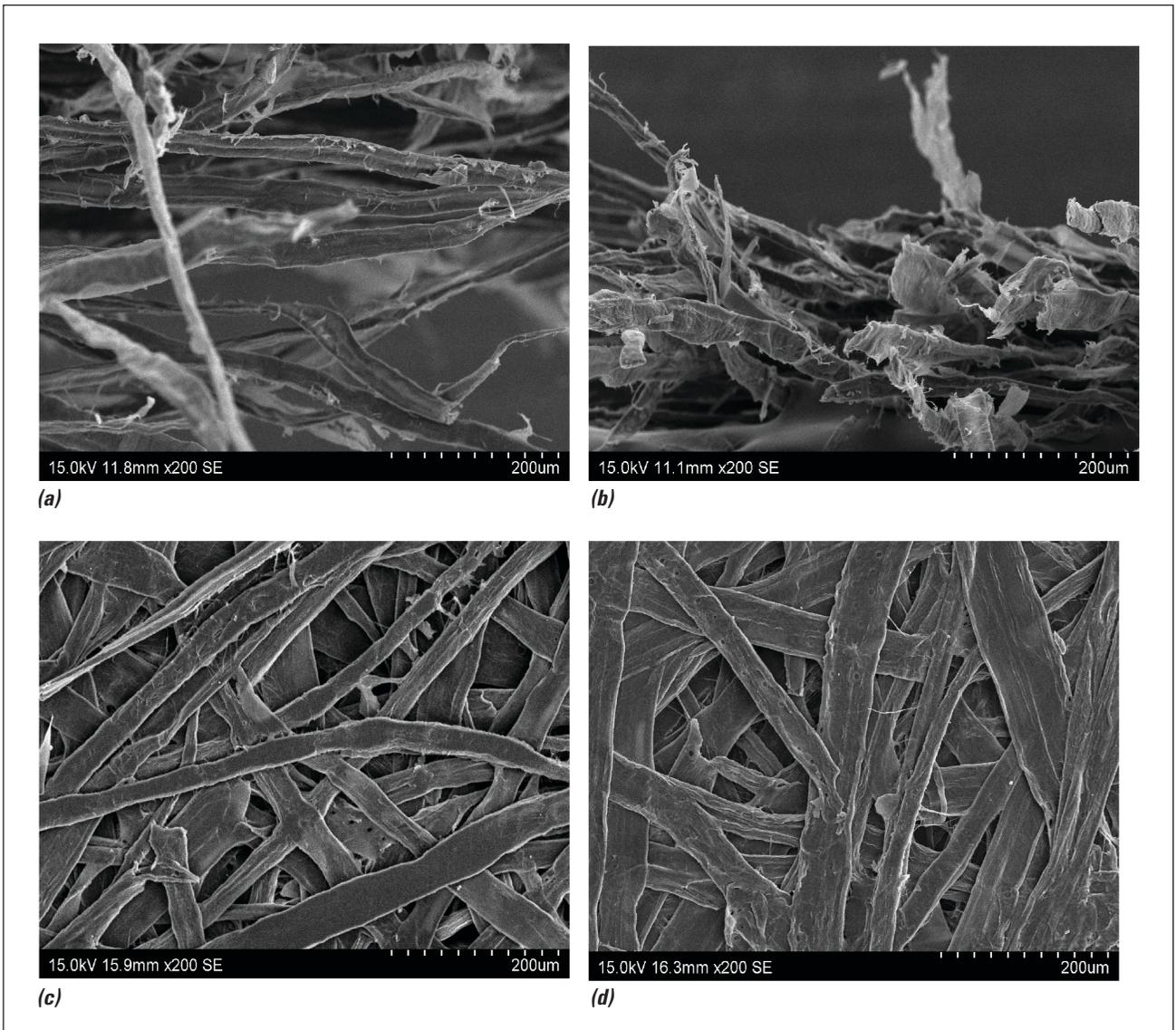
SEM fracture images of handsheet samples without and with cationic  $\beta$ -D glucan are presented in **Fig. 2**. As shown in Fig. 2a, after the control handsheet was disrupted by tensile force, the majority of fibers along the broken edge were intact; however, most of fibers in Fig. 2b (with cationic  $\beta$ -D glucan treatment) were fractured at the point of breakage of the handsheet. The images shown here were typical, and they were selected from many similar photographs in each case. The fact that a high proportion of fibers were broken in sheets that had been prepared with the cationic  $\beta$ -D glucan provides evidence that is consistent with the results from the strength tests. Because the fibers themselves had not been changed by the treatment, the greater breakage of the fibers must be explained based on increased interfiber bonding.

SEM surface images of a paper sample without and with cationic  $\beta$ -D glucan are presented in Figs. 2c and 2d. As shown, there appeared to be a somewhat bulkier structure in Fig. 2c. The sheets containing the cationic  $\beta$ -D glucan appeared to be denser and more tightly integrated. All of these results can be attributed to the role of cationic  $\beta$ -D glucan in increasing bonding force and densification among fibers.

**Table VI** compares certain of the present results with those obtained in the earlier studies involving negatively charged derivatives of the same  $\beta$ -D glucan, together with the same fibers [1-2]. The level of treatment was 1% in each case. As shown, all of the treatments involving  $\beta$ -D glucan yielded increases in burst index, tensile index, and folding endurance relative to the control. The cationic glucan yielded the highest values for the same group of bonding-dependent strength tests, though the results were not materially different from what was obtained for carboxymethylation in the burst and tensile tests. These results support the hypothesis given earlier that cationic modification of the glucan could be expected to yield important increases in its effectiveness as a dry-strength agent due to a more hydrophilic nature and better retention on the fibers. Unlike the other results shown in

Cationic Reagent (%)	Density (g/cm <sup>3</sup> )	Tensile Index (Nm/g)	Burst Index (kPam <sup>2</sup> /g)	Folding Endurance (double folds)	Tear Index (mNm <sup>2</sup> /g)
Control	0.518	52.79	4.25	456	5.73
Unmodified	0.553	68.17	5.91	899	3.81
10% Reagent	0.577	72.06	6.58	1079	5.17
20% Reagent	0.587	77.12	6.68	1431	4.91
30% Reagent	0.590	77.52	6.71	1434	4.88
50% Reagent	0.594	80.70	7.13	1507	4.43

**VI. Effects of three different modified  $\beta$ -D glucans and unmodified  $\beta$ -D glucan versus the paper properties.**



2. Scanning electron microscopy fracture images and surface images of a paper sample: (a) control, (b) with cationic  $\beta$ -D glucan, (c) control, and (d) with cationic  $\beta$ -D glucan.

Table VI for various glucan products, the results for the cationic glucan were obtained without the addition of  $Al_2(SO_4)_3$ .

**CONCLUSIONS**

As we proposed, it was found that cationic treatment of the glucan greatly increased its effectiveness as a dry-strength agent. In the first generation of handsheets, the tensile index, burst index, and folding endurance were increased by 53%, 68%, and 230%, respectively, when the dosage of cationic reagent was 50% on the dry basis of  $\beta$ -D glucan during preparation of the cationically modified version.

The system performed well over a wide range of pH (from 5 to 8.5), and pH had little influence on the results. In addition, cationic glucan provided increased strength when the fibers were repulped and formed into recycled sheets, despite there being no further addition of dry-strength additive.

When comparing severely dried paper samples, the tensile index, burst index, and folding endurance, respectively, increased by 54%, 38%, and 1600% relative to the control after severe drying when 1% cationic  $\beta$ -D glucan (cationic reagent was 20% on the dry basis of  $\beta$ -D glucan) was used in preparing the original sheets at pH 5.

SEM micrographs showed that fibers were integrated more closely together as a benefit of the presence of cationic glucan. Strength results achieved with the cationized glucan compared favorably to those obtained earlier with carboxylated forms of the same type of glucan in the presence of alum. **TJ**

**ACKNOWLEDGMENTS**

Xianliang Song acknowledges the support of Beijing Forestry University and China Scholarship Council. The authors also

thank North Carolina State University for providing laboratory facilities for much of the described research.

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## ABOUT THE AUTHORS

We chose to do this research because there is a lot of interest in bonding agents for paper. There are problems associated with paper recycling and the lowering of basis weights. We already had carried out some very interesting research with negatively charged derivatives of the same base material. We were curious to find out whether comparable results could be achieved with positively charged derivatives of the glucan.



Song

The biggest challenge we faced was that the material did not initially go into solution, and it was classified as dietary fiber. Derivatization of the material appeared to make it more soluble. Although we thought that the negatively charged versions of the glucan would be more effective for strength, we were surprised at how well the material actually performed.



Hubbe

This work can help various chemical companies as they consider various new dry-strength additives, which might be used in place of cationic starch. One can expect that the cationic glucan used in the present work would be less affected by slime bacteria in a typical papermaking system compared to starch products, but we have not yet evaluated that idea.

Our work is done for now, but the next logical step will be to try to cost optimize the chemical derivatization step. We used rather high dosages during the chemical derivatization since we just wanted to find out if the approach might work, not whether we could do it cost effectively.

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