

Influence of oxidation and cationization on the properties of thermomechanical pulp fibers

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ABSTRACT: Thermomechanical pulp (TMP) fibers were separately oxidized using 4-acetamido-2,2,6,6-tetramethylpiperidyl-1-oxyl (4-acetamido TEMPO) and cationized by 2,3-epoxy-propyl-tri-methyl ammonium chloride. The goal was to evaluate the influences of the interaction of oxidized, cationized, and untreated fiber components on paper properties. TEMPO-mediated oxidation can enhance interfiber bonding potential of mechanical long fibers. Cationization can improve the interfiber bonding only when the cationic charge density is lower than 400 mmol/kg; the bonding capacity drops off with increasing cationic charge density. However, as these modified long fibers were mixed with untreated long fibers and short fibers, the interaction between these fibers affected the paper sheet strength. The addition of oxidized fibers improved the sheet density remarkably, but it only had apparent effort on tensile strength when the carboxyl group content was less than 500 mmol/kg; higher carboxyl content did not enhance the sheet properties. The addition of cationized fibers had no positive effort on sheet density, and when they were mixed with other fiber fractions the interaction between positively charged and negatively charged fibers resulted in poor paper structure with rough surface and decreased tensile strength. Both oxidation and cationization had adverse influence on intrinsic fiber strength and tear index; either high carboxyl content or high cationic charge density could lead to remarkable decrease in these two properties. The side reactions, such as β -elimination and alkoxy fragmentation during TEMPO-mediated oxidation and alkaline degradation during cationization, which degraded the cellulose, were responsible for the drastic decrease in zero span tensile strength and tear strength.

Application: Papermakers can improve the physical properties of paper made from TMP fibers by fiber oxidation and replace the conventional polymeric retention aid with cationized wood fibers.

The fines in mechanical pulps play an important role in determining the physical and optical sheet properties [1,2] and the quality of white water [3,4]. Because of their small sizes, significant portions of fines could be lost through the paper machine wire due to high stock turbulence, thus influencing the paper characteristics and white water quality. When mills run with a closed white water circuit, any material that is not retained in the first pass will be circulated back to the paper forming process and most of it will be retained in the sheet. However, the white water could be gradually enriched with fines and cause problems with deposits in a closed system.

The fibrous elements, fillers, and most additives used in papermaking are negatively charged; hence, cationic polymers are usually used to retain these materials in the sheet. However, such soluble polymers have some disadvantages. For example, the viscosity contribution of soluble polymers, in most cases, depends on pH and salt concentration in the aqueous medium. Polymeric aids are also very sensitive to dosage and should be applied in stoichiometric concentrations. Overdosage leads to a change from a negative to a positive net charge for all species present, resulting in another repelling interaction [5]. To address such problems, the concept of using cationic pulp fibers was recently introduced [5-7]. The cationic fibers are reported to be more active and do

not show any sign of saturation and overdosage when used in papermaking. In addition, they drain more readily and exhibit slightly higher beating resistance [5]. Improved clay retention and distribution on fiber surfaces was obtained when cationic kraft pulp was used, as reported by Sang [8] and Zheng [9]. Cationic thermomechanical pulp (TMP) could improve clay retention up to 20% in the headbox and had little effect when the clay charge was 30% or higher [5]. However, cationization has destroyed some of the carboxyl and hydroxyl groups on fibers that are beneficial for fiber bonding [10,11]. This characteristic is especially undesirable when the fibers carry very high cationic charge density, reducing the interfiber bonding capacity. This shortcoming could be addressed by 2,2,6,6-tetramethylpiperidyl-1-oxyl (TEMPO)-mediated oxidation, which converts the primary alcohol groups on cellulose into carboxylic acid groups [12-14]. It is known that the long fibers (LF) of TMP have poor interfiber bonding capacity [15], and their bonding potential could be significantly enhanced by oxidation. We investigated the possibility of cationizing a portion of the LF as a retention agent and oxidizing another portion as a reinforcement component. The main objective was to eliminate or minimize the use of foreign agents in papermaking involving the use of mechanical pulp.

Our recent study [16] confirms the hypothesis mentioned above. Only one level of oxidation and cationization was per-

formed. It is of interest, therefore, to widen the degree of oxidation and cationization to better understand the effects of these modifications on fiber surface functionality and on the characteristics of white water and fibers. The effects on white water had recently been reported [16,17], while those affecting the fiber properties are discussed in this paper.

EXPERIMENTAL

Materials

A low-freeness (~55 mL) TMP of a mixture of softwoods (mainly spruce and balsam fir) was obtained from a local mill in Trois-Rivières, PQ, Canada. It was fractionated into LF and short fiber (SF) fractions by means of a special technique. More precisely, the sample pulp (25 g per batch, o.d. basis) was first disintegrated in a standard pulp disintegrator using hot water (~95°C) for 5 min (~1.3% consistency). About 10 g (o.d. basis) of the sample pulp was washed by dipping and shaking repeatedly in a bucket of water (~20 L) using a 20-cm-wide stainless steel kitchen strainer of ~22-mesh size. The washing, performed in batches, was continued until little fibers got through the strainer. Such a process permitted us to recover all fines with less effort than carrying out the process with a Bauer McNett classifier. The LF fraction retained on the strainer represented ~66%, while the SF fractions passed through the strainer represented ~34%.

Oxidation

Table I gives the experimental conditions, and the detailed procedures are similar to those described elsewhere [16]. Briefly, the experiment was conducted in a 2-L glass reactor at 21°C. First, 30 g (o.d. basis) of LF were diluted to 1.5% consistency in deionized water to which predetermined amounts of 4-acetamido TEMPO, sodium bromide (NaBr), and sodium hypochlorite (NaClO) were then added gradually. The pH of the system was maintained at 10.5 using sodium hydroxide (NaOH) or hydrochloric acid (HCl) solution depending on the situation. If the pH was less than the desired pH of 10.5, NaOH was used to increase it to 10.5; if it was higher than 10.5, then HCl was employed to reduced it to 10.5. The pulp suspension was continuously agitated by means of an electric

stirrer. At the end of predetermined reaction time (50 min), the fibers were drained, washed, and filtered and then the pH of the fiber suspension was adjusted to 5.0. The pulp was again drained, washed, and filtered at least four more times before the carboxylic acid content was measured in accordance with the technique described in [18].

Cationization

The cationization of LF using 2,3-epoxy-propyl-tri-methyl ammonium chloride (EPTMAC) was conducted in polyethylene bags. Each bag contained 30 g (o.d. basis) of LF at 11% consistency. A predetermined amount of NaOH (20% o.d. weight of pulp) was used to activate the cellulose and hemicellulose of fiber to induce them to react with the epoxy groups of EPTMAC to form ether. The alkali-treated fiber mixture was kneaded manually and left to stand for 20 min, after which a required quantity of EPTMAC solution was introduced into the bag, which was then sealed. The mixture was well mixed before being submerged in a water bath at 45°C for 90 min. Intermittent kneading of the mixture was performed throughout the reaction time. The reaction was stopped by adding acetic acid (4% by weight of pulp) and then kneading the mixture well. The acidified pulp was then filtered and thoroughly washed with deionized water. Cationic charge density on the cationized fibers was determined by the back titration method using Mutek PCD-03 [7].

Pulp blending

In the blending trials, we looked at four different scenarios: (1) short fraction (SF) + cationized long fibers (CLF); (2) SF + oxidized long fibers (OLF); (3) SF + equal proportions of untreated long fibers (ULF), OLF, and CLF; and (4) SF + equal proportions of CLF and OLF. The long fiber fractions (ULF, CLF, and OLF) were recombined with the SF following the proportions indicated in **Table II**. The LF/SF ratio was the same as that of the initial whole pulp. Note that the OLF and CLF were, respectively, oxidized and cationized to various levels of carboxylic acid content and cationic charge density, as Table I shows.

TEMPO-Mediated Oxidation			Cationization		
Long fiber (LF): 30 g TEMPO: 0.05g NaBr: 6 mmol/g Fiber pH: 10.5 Time: 50 min Temperature: 21°C	NaClO (mmol/g fiber)	Carboxyl Content (mmol/kg)	Long fiber (LF): 30 g NaOH: 6 g Temperature: 45°C Time: 90 min	EPTMAC (g)	Cationic Charge (Density mmol/kg)
	0.88	146		15	229
	1.88	262		30	363
	3.88	515		50	453
	5.88	744		75	656
	7.88	911		90	734

I. Oxidation and cationization conditions of thermomechanical pulp long fibers.

Trials	ULF	CLF	OLF	SF
A	0%	66%	0%	34%
B	0%	0%	66%	34%
C	22%	22%	22%	34%
D	0%	33%	33%	34%

II. Fiber composition of pulp blending.

RESULTS AND DISCUSSION

Characteristics of oxidized long fibers

TEMPO-mediated oxidation is effective in generating carboxylic acid groups on mechanical fibers; it also has remarkable effects on fiber properties (**Table III**). For example, pulp freeness dropped from 310 mL to 175 mL (about a 44% decrease) when the TMP LF were oxidized to yield 911 mmol/kg of carboxylic acid. The oxidation increased fiber flexibility, improving the sheet density by nearly 50%. The increases in carboxyl content and fiber flexibility led to significant improvement in interfiber bonding, as a result of improved fiber conformability. Consequently, the tensile index of handsheets was considerably enhanced. The burst index was also improved.

However, the oxidative treatment also brought about some undesirable effects. Particularly, it degraded the intrinsic fiber strength, as shown by the noticeable decreases in zero-span tensile breaking length of dry handsheets. The side reactions during the TEMPO-mediated oxidation, such as β -elimination [19,20] and alkoxy fragmentation [21] reactions, can degrade the cellulose and decrease the intrinsic fiber strength. Further, it was reported [22] that some pores in the fiber wall might have been partly blocked during oxidation, which might have prevented the fiber from shrinkage during drying and could

have reduced the zero-span tensile strength. In addition, tearing resistance of paper suffered severe losses, which were almost 70% when the fibers were oxidized to high carboxyl content, (i.e., 911 mmol/kg). When the sheet density and interfiber bonding are greatly increased, the tearing strength will depend on the intrinsic fiber strength, which was reduced in this case. For optical properties, there were decreases in opacity, light-scattering coefficient, and light absorption coefficient. The decreases are believed to be related to both physical and chemical changes brought about by the oxidative reactions. The increase in sheet density due to the introduction of carboxylic acid groups would usually reduce the opacity and light-scattering power. However, the brightness of the oxidized fibers increased with the increasing carboxyl content. This could be attributed to the high dosage of NaClO, which is a strong oxidant (a bleaching agent) that destroys the chromophoric groups on fibers. When the reaction was carried out without NaClO the brightness dropped from 52% to 37.5% and the light absorption coefficient increased from 4.2 to 7.1 m²/kg (Table III). In fact, the alkaline pH alone (i.e., 10.5 in this study) could change chemical, physical, and optical properties of fibers such as cell wall swelling, darkening, and dissolution of low-molecular wood components.

Characteristics of cationized fibers

Cationization also had significant impact on fiber characteristics (**Table IV**), but the effects were different and more complex than those caused by oxidation. The complexity was manifested particularly by sheet density, tensile, and burst indices. Table IV shows that, in general, the properties increased with increasing cationic charge density, which agrees with the finding of Zheng et al. [9]. However, these increases were dependent on the cationic charge density; they fell off noticeably when cationic charge density was higher than 450

Carboxyl Content (mmol/kg)	85 [#]	89 [*]	146	262	515	744	911
Freeness, mL	300	310	265	255	215	190	175
Sheet density, g/cm ³	0.33	0.33	0.32	0.32	0.36	0.42	0.49
Zero-span tensile, km	12.6	12.5	12.3	11.5	10.3	9.8	9.1
Tensile index, N*m/g	36.8	37.4	37.9	41.8	45.1	50.3	54
Burst index, kPa*m ² /g	2.21	2.24	2.28	2.39	2.58	2.55	2.61
Tear index, mN*m ² /g	8.5	8.8	9.4	8.4	6.4	4.4	2.7
Brightness, % ISO	52	37.5	39.8	44.5	50.0	48.9	46.8
Opacity, %	94.8	97.5	97.3	94.3	89.7	87.3	83.6
Light scattering coefficient, m ² /kg	47.1	46.9	45.0	43.0	38.1	33.3	28.7
Light absorbing coefficient, m ² /kg	4.2	7.1	7.1	4.3	2.5	2.3	2.2

[#]Untreated fiber.

^{*}Control (treatment condition: 0.05 g TEMPO; 6 mmol/g fiber NaBr; pH 10.5; 50 min; 21°C, without NaClO).

III. Properties of oxidized long fibers (OLF).

Cationic Charge Density (mmol/kg)	#	*	229	363	453	656	734
Freeness, mL	300	315	255	220	215	210	220
Sheet density, g/cm ³	0.33	0.36	0.38	0.38	0.39	0.31	0.28
Zero-span tensile, km	12.6	12.2	12	11.1	11	10.2	10
Tensile index, N*m/g	36.8	41.6	46.7	48.4	44.7	32.7	30.9
Burst index, kPa*m ² /g	2.21	2.64	2.93	3.24	3.21	2.48	2.34
Tear index, mN*m ² /g	8.5	8.5	8.3	6.9	6.6	6.3	5.9
Brightness, % ISO	52.3	34.6	33.9	31.2	30.1	30.0	29.9
Opacity, %	94.8	95.2	95.5	93.2	92.2	92.4	90.7
Light scattering coefficient, m ² /kg	47.1	43.8	39.4	33.7	30.4	31.4	30.4
Light absorbing coefficient, m ² /kg	4.2	5.4	5.1	4.6	4.1	3.9	3.8

Untreated fiber.

*Control (treatment condition: 6g NaOH; 45°C; 90 min; without EPTMAC).

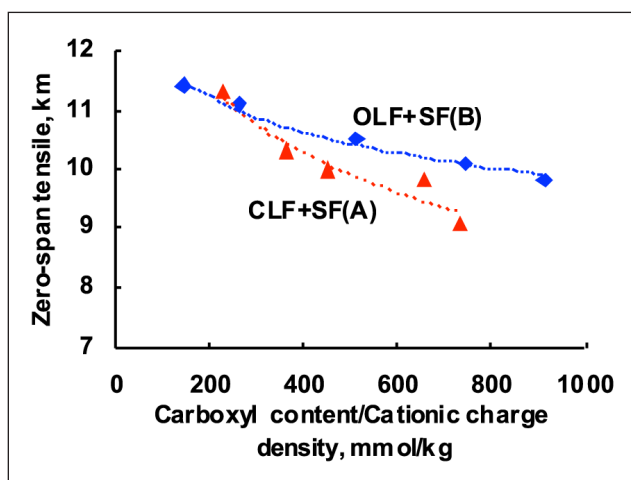
IV. Properties of cationized long fibers (CLF).

mmol/kg. The increased repulsive force between the highly cationized fibers might be the cause [23]. The drop in zero-span tensile strength as a result of increasing cationic charge density was probably due the high NaOH dosage (20% o.d. basis on pulp), relatively high temperature (45°C), and long reaction time (90 min) used, which could severely damage the fiber structure. In addition, the repulsive force between the cationic groups might somewhat influence the zero-span tensile [23]. With the decreases in interfiber bonding and intrinsic fiber strength, it is understandable that the tear strength of the cationic fibers decreased remarkably as the cationic charge augmented.

In general, other fiber properties, such as freeness and optical characteristics, suffered gradual losses with increasing cationic charge. These decreases were relatively less extensive than those caused by oxidation. Evidently, this phenomenon is associated with the differences in the nature of chemical treatments. However, the tensile and burst strengths of the control fibers increased remarkably while the brightness decreased sharply when compared with the untreated fibers. Understandably, the high dosage of NaOH dissolved out some low-molecular-weight lignin and enhanced fiber flexibility, thus increasing fiber conformability and fiber bonding in sheet consolidation. On the other hand, the brightness of fiber fell due to the alkaline darkening effect.

Zero-span tensile strength

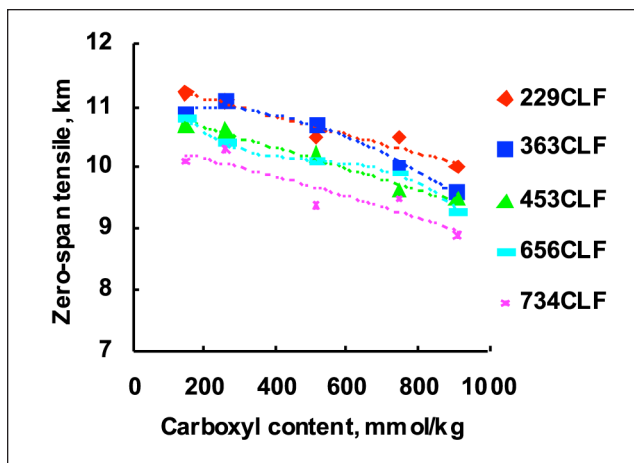
When the CLF or OLF were blended with the SF, the zero-span tensile strength of handsheets dropped relatively sharply as a function of cationic charge or carboxylic acid content (**Fig. 1**). The decrease rate of the CLF/SF blend was greater than that of the OLF/SF mixture. As seen earlier, the loss in fiber strength was greater for OLF (Table III) than for CLF (Table IV). This observation suggests that factors other than



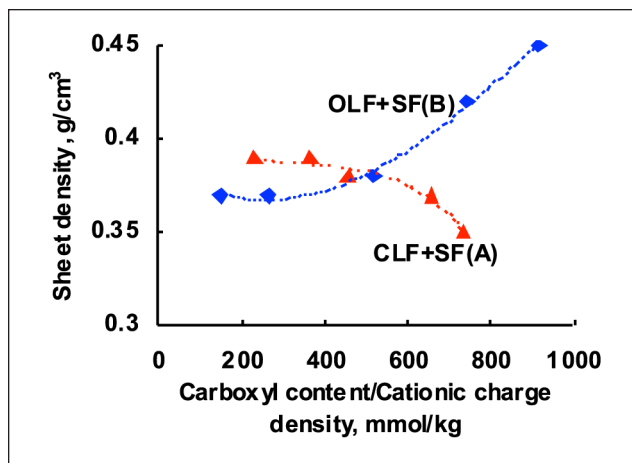
1. Zero-span tensile strength of handsheets prepared from cationized long fibers (CLF)/oxidized long fibers (OLF) mixed with untreated short fibers (USF)

the intrinsic fiber strength also play a role in determining the zero-span tensile strength of dry handsheets. Poor sheet formation due to the attraction between the cationic and anionic fines could possibly affect this sheet property [23].

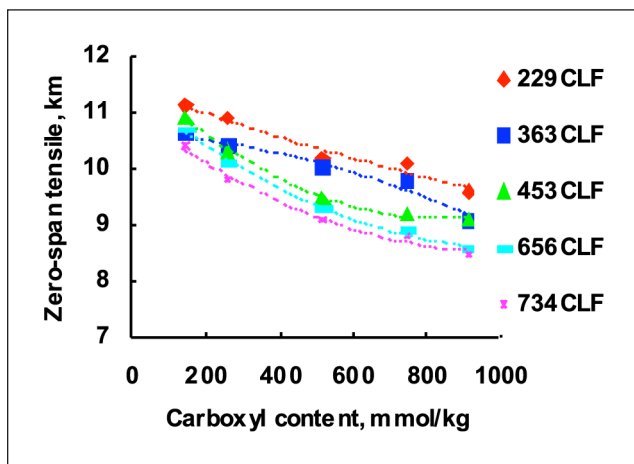
When the proportions of LF were equally shared by the three types of LF (i.e., 22%ULF+22%CLF+22%OLF) and mixed with SF (34%), the zero-span tensile strength of handsheet also showed relatively sharp decreases (**Fig. 2**). The zero-span tensile strength decreased with increases in both carboxyl content and cationic charge density. In fact, this strength property was relatively poor when the highly charged CLF (i.e., 734 mmol/kg) was mixed with highly charged OLF (i.e., 911 mmol/kg). It is believed that the low intrinsic strength of CLF and OLF, and the interaction between these two types of fibers, had a negative impact on zero-span tensile strength.



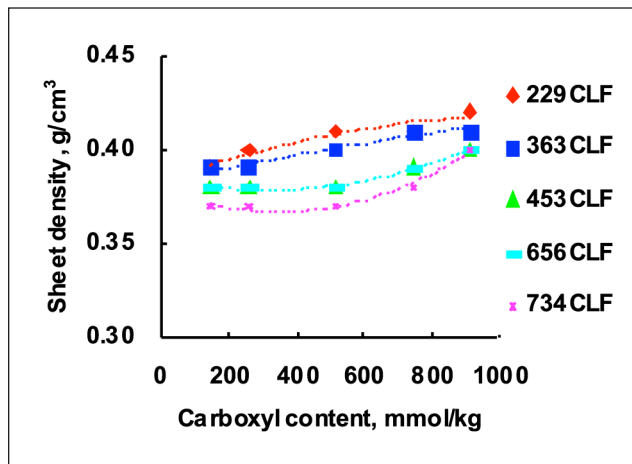
2. Zero-span tensile strength of handsheets prepared from a mixture of 22%ULF+22%CLF+22%OLF+34%SF.



4. Density of handsheets prepared from CLF/OLF mixed with USF.



3. Zero-span tensile strength of handsheets prepared from a mixture of 33%CLF+33%OLF+34%SF.



5. Density of handsheets prepared from a mixture of 22%ULF+22%CLF+22%OLF+34%SF.

Similar trends in zero-span tensile strength reductions were also observed in mixed furnish without ULF (**Fig. 3**). However, a higher portion of CLF and OLF led to greater reduction in zero-span tensile strength in comparison with that shown in Fig. 2.

Handsheet density

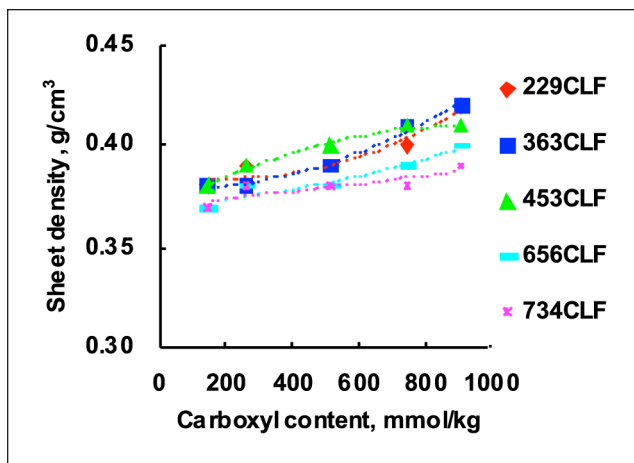
Oxidation of fibers increased handsheet density (Table III). As a result, when the OLF was blended with the SF, the sheet density augmented with increasing carboxylic acid content (**Fig. 4**). In contrast, the mixing of CLF with SF had negative impact on sheet density, particularly when the CLF carried high cationic charge. The repelling force between cationic charge and the branch chains on the cationic fibers (e.g., trimethyl ammonium chloride group) might have negatively affected the sheet formation.

Figure 5 shows that when the blend contained equal amounts ULF, OLF, and CLF, the sheet density increased somewhat with increasing carboxylic acid content but dropped slightly as the cationic charge of CLF augmented.

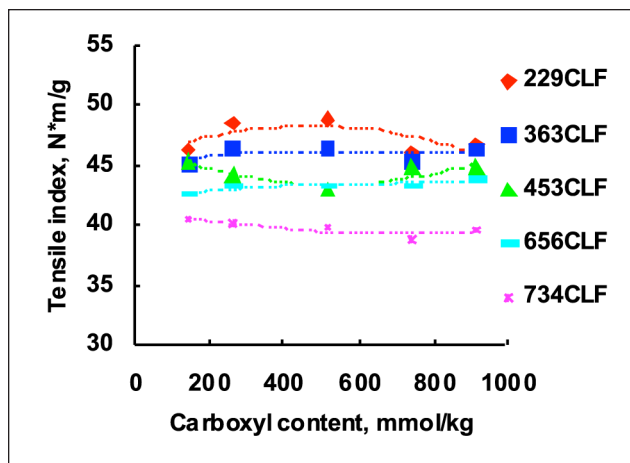
The attraction and, consequently, the deposition of anionic trash and fines onto the CLF might have interfered with sheet consolidation and affected the cohesion between the long fibers. A similar phenomenon was observed with the sheets prepared from a mixture of 33%CLF+33%OLF+34%SF (**Fig. 6**), but the influence of various levels of cationic charge on paper density was not very clear cut.

Tensile index

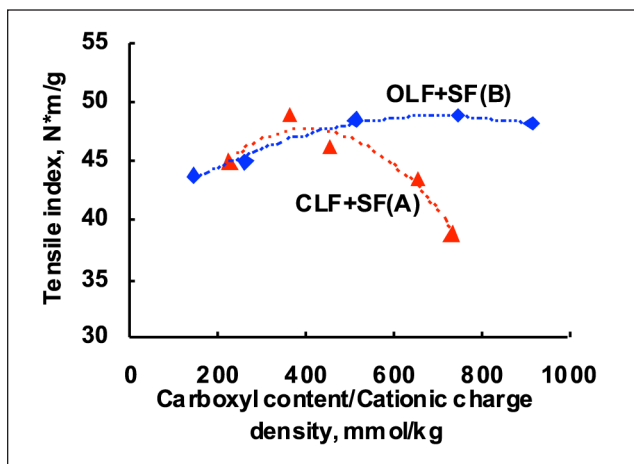
Similar to the trends observed for sheet density (**Fig. 4**), the tensile index of handsheets increased as the carboxyl content augmented (**Fig. 7**). However, the increases dropped off after peaking at about 500 mmol/kg of carboxyl content. It is known that the tensile strength of paper sheets depends not only on the interfiber bonding, but also the intrinsic fiber strength [24]. In this study, the intrinsic fiber strength decreased remarkably with the increasing carboxyl content (**Fig. 1**), especially when the carboxyl content was greater than 500 mmol/kg. This explains why the tensile index of blend B (OLF+SF) did not vary much (**Fig. 7**) while the sheet



6. Density of handsheets prepared from a mixture of 33%CLF+33%OLF+34%SF.



8. Tensile index of handsheets prepared from a mixture of 22%ULF+22%CLF+22%OLF+34%SF.



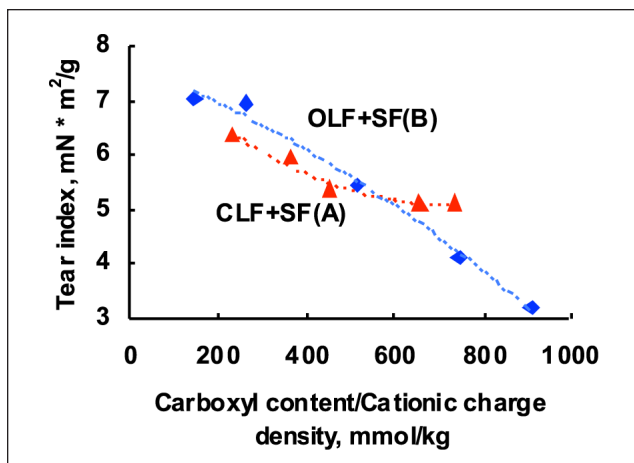
7. Tensile index of handsheets prepared from CLF/OLF mixed with USF.

minimal [23]. Therefore, as shown in Fig. 7, the tensile strength of blend A increased initially as the cationic charge density augmented. A peak value in tensile index was noted with a cationic charge density around 400 mmol/kg, where the cationic fibers can develop a tail-and-loop configuration and adsorb onto an anionic surface adequately to induce sufficient association with the anionic groups. However, the tensile strength dropped off sharply when the cationic charge density was greater than 400 mmol/kg. This characteristic might be attributable to the flattened configuration formed, the repulsive force between fibers, and the decreased fiber intrinsic strength.

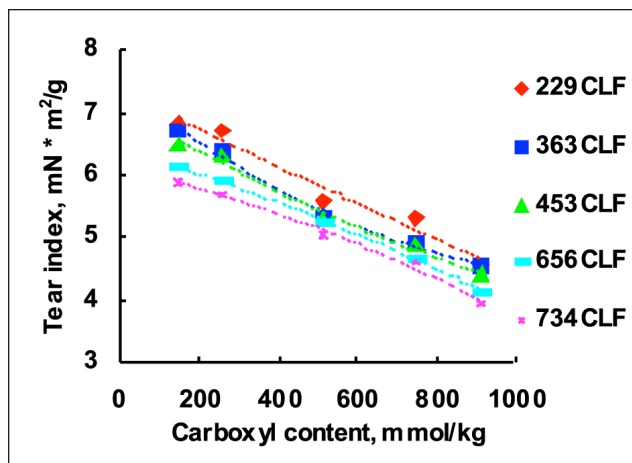
For the sheets containing equal amounts of ULF, CLF, and OLF (Fig. 8), there was, in general, little effect of carboxyl content on tensile index, except when the cationic charge density was low (i.e., 229 mmol/kg). In this case, the initial increase in tensile index fell off at about 400 mmol/kg of carboxyl content (Fig. 8). Similar to the trend of blend A and blend B (Fig. 7), the paper strengths decreased when the carboxyl content and cationic charge density were too high. Flattened configuration on the fiber surface tended to occur when equal amounts of CLF and OLF were used, resulting in poor fiber bonding. On the other hand, the attraction between the positive charge of CLF and the strong negative charge of OLF led to nonuniform sheet structure. For example, when the highly positive-charged CLF (i.e., 743 mmol/kg) mixed with the strongly negative-charged OLF (e.g. 911 mmol/kg), the roughness of this blend was 7.64 μm , compared with 6.42 μm for the control sample. This indicates that most of the oxidized fibers might be attracted to the cationic fibers, forming large aggregates and resulting in poor paper structure with increased surface roughness. When the ULF component was excluded from the blending (Fig. 9), there was a gentle reduction in tensile strength as a function of carboxyl content; an exception was noted for the sheet made with CLF having a low degree of cationization (i.e., 229 mmol/kg). Again, tensile index generally decreased with increasing cationic charge density.

density of blend B increased remarkably (Fig. 4) at high carboxyl content.

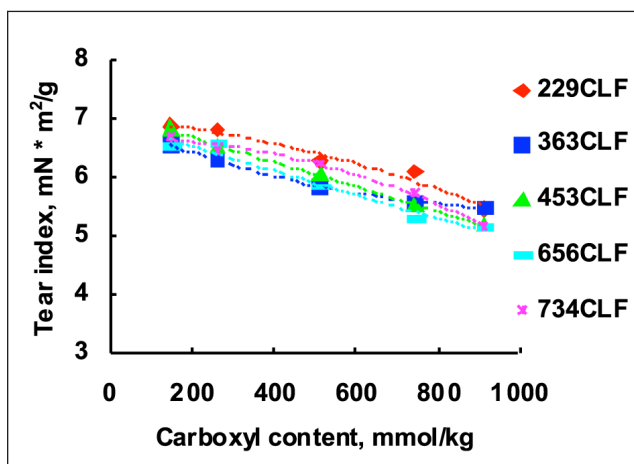
The influence of cationic polymers on papermaking is associated with many factors such as the molecular weight and the other anionic groups on fiber surfaces [23]. Similarly, the use of cationized fibers would be affected by their configuration relative to the surface of other fibers, as well as the effective interaction between the cationic fibers. The molecular weight of the cationic fibers we used was constant and it should not have any particular influence on fiber bonding. However, as reported previously by others [25,26], the configuration of a polymer segment on the fiber surface depends on its charge density. Polymers with low charge densities tend to develop tail-and-loop configurations on the fiber surface, whereas highly charged polymers result mainly in a flattened configuration that is undesirable for fiber-bonding enhancement. In addition, if the charge density of a polymer segment adsorbed on a fiber surface is inadequate to induce sufficient association with the anionic groups on the surface of neighboring fibers, the improvements in strength will be



10. Tear index of handsheets prepared from CLF/OLF mixed with USF.



12. Tensile index of handsheets prepared from a mixture of 33%CLF+33%OLF+34%SF.



11. Tensile index of handsheets prepared from a mixture of 22%OLF+22%CLF+22%OLF+34%SF.

Tear index

In contrast to the tensile index, the tear index is directly related to the intrinsic fiber strength at a given fiber length. The energy of tear failure is primary derived from the energy released when fibers fail rather than when they are pulled out or when the bonds are broken [27]. The tear strength at a given tensile strength is proportional to the intrinsic fiber strength with a ratio of 2.5/3.0, which means that a 10% loss in fiber strength can lead to a 25%–30% loss in tear strength [28]. As in the case of zero-span tensile strength (Fig. 1), the tear index decreased sharply as the carboxyl content or cationic charge density augmented (Fig. 10) by 54% and 20%, respectively. Figures 11 and 12 exhibit similar trends as those illustrated in Fig. 10, but smaller adverse influence on tear index was observed due to the lower OLF content used. The carboxyl content of OLF and the proportions of OLF mixed with other fibers were responsible for the considerable decrease in tear index. On the other hand, the cationic fibers had less impact on the tear index as compared with the OLF due to their relatively

higher intrinsic fiber strength (Table IV). Cationic fibers with low cationic charge yielded better tear index.

CONCLUSIONS

TEMPO-mediated oxidation can enhance interfiber bonding potential of TMP long fibers. In contrast to oxidation, cationization can improve the interfiber bonding only when the cationic charge density is lower than 400 mmol/kg; it then drops off with increasing cationic charge density. However, as these modified TMP LF were mixed with untreated LF and SF, not only the interfiber bonding capacity but also the interaction between these fibers affected the paper sheet strength. The addition of OLF improved the density of a paper sheet remarkably, but had an apparent effect on tensile strength only when the carboxyl group content was less than 500 mmol/g. Higher carboxyl content had little enhancing effect on paper. The addition of CLF had no positive effect on sheet density. However, when they were mixed with OLF, ULF, and SF, the interaction between positive charge and negative charge resulted in poor paper structure and rough surface, decreasing tensile strength.

Both oxidation and cationization adversely influenced intrinsic strength of fiber and tear index. Either very high carboxyl content or cationic charge density could remarkably decrease the intrinsic fiber strength and tear strength. The side reactions, such as β -elimination and alkoxy fragmentation during TEMPO-mediated oxidation and alkaline degradation during cationization, caused cellulose degradation, significantly decreasing the zero-span tensile strength and tear strength.

In summary, the side reactions were inevitable during the modification processes, especially for fibers with very high carboxyl content or cationic charge density. But fibers with relatively low intrinsic fiber strength could yield very high interfiber bonding capacity suitable for enhancing the paper. Our study showed that the optimum carboxyl content for the oxidized fibers would be ~500 mmol/kg and the optimum cationic charge density for the cationic fibers would be 230

mmol/kg for obtaining the best paper properties. Interestingly, these conditions were also found to be the best choice for maintaining excellent paper properties and white-water quality [16]. **TJ**

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We sought to improve the quality of mechanical pulp fibers by introducing carboxyl groups on the fibers. We also sought to transform a portion of mechanical pulp fiber into a cationic state to employ them as a retention agent in papermaking. This study continued our previous efforts to improve the quality of white water and paper properties made from mechanical pulp. In previous research, only one level of oxidation and cationization was conducted. By performing several degrees of oxidation and cationization, we were able to optimize these two chemical treatments.

The bonding capacity of fibers could be greatly enhanced by oxidation. Also, we found that the cationized fibers could be effectively used as a retention aid for fines and clay, significantly improving the quality of white water. Cationized fibers have a potential use in papermaking because they are renewable and biodegradable, as opposed to the conventional soluble polymers. While the technical aspects of this research were not particularly difficult, it would be a challenge



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to scale up the process to an industrial level. Future work would involve pilot trials and studies focused on process optimization and environmental and economic analyses.

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