PRESENCE OF HARDWOOD CHIPS AND ITS IMPACT ON PULP STRENGTH PROPERTIES IN THE PRODUCTION OF BLEACHED SOFTWOOD KRAFT PULP

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The effect of hardwood admixture (15-25% birch or aspen) in kraft cooking on the strength properties of the fully bleached pulp was investigated. Results obtained from both lab- and mill-processed ECF bleached pulps showed that adding 15-25% birch or aspen to the production of fully bleached softwood kraft pulp had a minor effect on the strength properties. No significant effect was observed for the hardwood admixture on the apparent density over a wide range of breaking length. Under the conditions studied, the results showed that pulping of mixed softwood/hardwood chips (chip blending) resulted in overall better strength properties than the pulp blending at a given freeness. It was hypothesized that the softwood fibers would be cooked to a higher kappa number in the cooking of mixed softwood/hardwood chips for the same target kappa number, thus having higher fiber strength due to higher pulp viscosity and preservation of the hemicellulose. This was supported by the results from zero-span tensile strength of the long fiber fraction of the samples from chip blending and pulp blending. The implication is that some softwood kraft pulp mills can add up to 25% of hardwood chips to the kraft cooking of softwood chips without significantly affecting the overall pulp strength properties.

Keywords: Kraft pulping; Mixed softwood and hardwood chips; ECF bleaching; Strength properties; Co-refining

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INTRODUCTION

With the present wood chip supply situation, some softwood kraft pulp mills in North America may have to use some hardwood in their raw materials due to shortages of softwood resources. In Canada, hardwoods comprise about 20% of the total wood volume (Hatton 1982), and most of the hardwood stands are mixed with the softwood stands, so it is of practical interest to harvest and subsequently cook softwoods and hardwoods as mixtures. In the literature, there are a number of studies showing that kraft pulping of mixed softwood/hardwood chips is not only technically feasible but also advantageous if the minor wood component does not exceed 20% of the total wood raw material (Hunt and Hatton 1976). For example, Hunt and Hatton (1976) stated that the advantages of kraft cooking of mixed softwood/hardwood may include higher pulp yield, shorter cooking time (or lower kappa number), and improved beatability (shorter refining time to 300 ml CSF). In addition, pulping of mixed softwood and hardwood chips means that the resulting pulp containing both softwood and hardwood fibers would have to be co-refined. Both separate- and co-refining systems for softwood and hardwood pulps are widely practiced in the industry (Ghosh et al. 2003; Mansfield and Kibblewhite 2000; Mohlin et al. 2006; Sampson and Wilde 2001). In some cases, the separate refining process produces better strength at lower energy consumption than the mixed refining process; in other cases, the mixed refining process is a better alternative. For lab PFI refining, the tear - tensile strength relationships were generally the same for separate- or co-refined softwood and hardwood kraft pulp blends (Mansfield and Kibblewhite 2000).

The main disadvantage of pulping mixed softwood/hardwood chips would be that the hardwood may be overcooked due to the use of the more severe softwood cooking conditions; therefore, it may be expected to have negative impact on the strength properties. In the literature, it was found that no strength loss of the brown stock was observed at 10% hardwood addition, and only small loss in strength at 20% hardwood addition, in comparison with that of 100% softwood (Hunt and Hatton 1976).

Due to the differences in the physical characteristics and chemical compositions, pulping mixed softwood and hardwood at the same time may lead to non-uniformity in pulping and subsequent bleaching. The unbleached pulp contains fibers of different lignin content, with the softwood fibers of higher kappa and the hardwood fibers of lower kappa. However, non-uniform cooking takes place even with only one wood species as the raw material in industrial-scale kraft pulping due to the size distribution of commercial chips (Agarwal and Arasakesari 1994; Croy 2000; Dai et al. 2004; Drost et al. 2004; Gullichsen et al. 1992, 1995; Liu et al. 1999). For example, it was reported that the kappa number of chips can differ by a factor of 4 between 2 mm and 10 mm chips (Agarwal and Arasakesari 1994). Also, wood chips from the same tree may differ in chemical composition and wood density between early wood and late wood, compression wood and normal wood, sap wood and heart wood. Single-fiber kappa measurement and modeling has revealed a broad kappa distribution of fibers from the same cook (Liu et al. 1999).

The available results in the literature have shown that it is technically and economically feasible to produce fully bleached softwood kraft pulp with about 20% hardwood chips as the admixture in the softwood chips. However, limited results have been reported on the strength properties of ECF bleached kraft pulps from cooking of mixed softwood and hardwood chips. In this study, we investigated the effect of hardwood admixture (15-25%) in kraft cooking and ECF bleaching of softwood on the strength properties of the fully bleached pulp. Both lab- and mill- processed ECF bleached pulps were used in the study.

EXPERIMENTAL

Kraft Cooking

Three wood chip samples, namely, softwood (mainly spruce), birch, and aspen were obtained from a Canadian mill. The three woodchip samples were screened separately with a laboratory pulpwood chips classifier. The under-sized pin chips and over-sized chips were rejected. Mixed chip samples were prepared by mixing 15 to 25% of the screened birch or aspen chips with 85 to 75% of screened softwood chips. Kraft cooking was carried out in a rotating digester with eight 1-liter bombs, as detailed before (Drost et al. 2003). The cooking liquor was prepared by dissolving sodium hydroxide and sodium sulfide (reagent grades from Scientific Fisher) with deionized water. About 90 g (bone dry) of wood chips were loaded into each of the 8 cooking bombs, followed by the addition of the prepared cooking liquor. The cooking conditions are shown in Table 1. After the completion of cooking, the cooked wood chips were washed with de-ionized water on a Buchner funnel, then disintegrated into pulp, and then washed thoroughly with deionized water on a Buchner funnel with a 150 mesh screen. The pulp samples were analyzed for kappa number, screened pulp yield, and screening rejects as per PAPTAC methods. The kappa numbers were 27.6 to 30.9 for the softwood and mixed softwood and hardwood chips, 22.7 for the 100% birch chips, and 21.2 for the 100% aspen chips. The pulping conditions and results are summarized in Table 1**.**

ECF Bleaching

The following conditions were used to bleach the kraft pulps to about 90-91% ISO brightness in a 5-stage ECF sequence as detailed earlier (Jahan et al. 2010a,b). The conditions and results are shown in Table 2 and below.

D_0: 1.29-2.02% ClO_2 (as is), depending on the initial kappa number of the unbleached pulp, with a kappa factor of 0.172 for the softwood and for the mixed softwood and hardwood pulps, and 0.160 for the hardwood pulps (Table 2); 3.5% pulp consistency; 45 min, 57°C; 2.8 end pH.

E_O: 2.0% NaOH (as is); 8.5% pulp consistency; 60 min, 85°C; oxygen pressure at 40 psi for the first 8 min; 10.9 end pH

D_1: 0.9% ClO_2 (as is); 0.27% NaOH (as is); 8.5% pulp consistency; 45 min, 65.5°C, 3.5 end pH.

E_2: 0.6% NaOH (as is); 8.5% pulp consistency; 45 min, 74°C, 10.8 end pH.

D_2: 0.42% ClO_2 (as is); 0.12% NaOH (as is); 8.5% pulp consistency; 90 min, 82°C, 4.9 end pH.

Table 1. Kraft Cooking of the Chips Samples

Chip composition	Effective alkali (Na_2O, %)	Temp. (°C)	Time (min)	Kappa number
100% Softwood	15.8	174	45	28.2
100% Birch	15.7	168	40	22.7
100% Aspen	15.3	168	40	21.2
85% Softwood + 15% Birch	15.8	174	45	28.3
80% Softwood + 20% Birch	15.7	174	45	29.2
75% Softwood + 25% Birch	15.3	174	45	28.2
85% Softwood + 15% Aspen	15.1	174	45	29.8
80% Softwood + 20% Aspen	15.0	174	45	27.6
75% Softwood + 25% Aspen	14.6	174	45	30.9

Other conditions: sulfidity: 30.0%; liquid to wood ratio: 4.5:1; time to temperature: 70 min.

Pulp Beating and Evaluation of Laoboratory-Made Handsheets

Bleached kraft pulps (never-dried) obtained from 100% softwood, 100% birch, admixture of softwood:birch and softwood:aspen bleached in the ratios of 85:15, 80:20, and 75:25, and bleached kraft pulps of softwood and birch and softwood and aspen, were refined in a PFI mill (PAPTAC, C.7) separately at different PFI revolutions, i.e. 0, 2000, 5000, and 9000 revolutions, and the pulp freeness (PAPTAC ,C. 1) was determined. The laboratory handsheets of 60 g/m^2 (PAPTAC, C. 4) were prepared with the pulps and conditioned at a temperature of 23 ± 1 ^oC, and relative humidity of 50 ±2% (TAPPI, T402), and then evaluated for various properties including breaking length (PAPTAC , D. 6), burst index (PAPTAC , D. 8), apparent density (PAPTAC , D. 4), and zero span tensile strength (TAPPI, T220, and T231). The confidence limit of the results was within 5% at a 95% confidence level. The results were regarded as similar, slightly different, or significantly different if their differences were less than 5%, 5 to 10%, or above 10%.

Table 2. Chlorine Dioxide Charge in the D_0 Stage and the Final Brightness of the ECF Bleached Pulps

Pulp ID	ClO_2 dosage of D_0 (%)	Final pulp brightness (% ISO)
100% Softwood	1.85	90.5
100% Birch	1.38	90.6
100% Aspen	1.29	92.5
85% Softwood + 15% Birch	1.86	89.9
80% Softwood + 20% Birch	1.91	90.0
75% Softwood + 25% Birch	1.85	90.3
85% Softwood + 15% Aspen	1.95	91.1
80% Softwood + 20% Aspen	1.81	91.0
75% Softwood + 25% Aspen	2.02	90.2

RESULTS AND DISCUSSION

ECF Bleaching

As shown in Table 1, the kappa number of the unbleached kraft pulps from the mixed softwood and hardwood was in the range of 28.2 to 30.9, which is compared to 28.2 for the unbleached pulp from 100% softwood. After five stages of ECF bleaching, the brightness of these mixed softwood/hardwood pulps was in the range of 89.9 to 91.1% ISO, which is compared with 90.5% ISO for the pulp from 100% softwood (Table 2), indicating that adding 15 to 25% birch or aspen in kraft cooking of softwood had insignificant effect on the bleachability of the resultant pulp. Other pulp properties such as cleanliness were also unaffected.

Strength Development during PFI Refining

Figure 1 reveals the effect of mixing the softwood and birch (chips blending) in different proportions, i.e. 100:0, 0:100, 85:15, 80:20, and 75:25 and beating at different PFI revolutions on breaking length and burst index. In all the five cases, breaking length improved up to 2000 PFI revolutions, and beyond that the increase in breaking length was insignificant. The curve plotted between breaking length and PFI revolutions of pulps having softwood and birch in the ratio of 80:20 coincides with the curve obtained from 100% softwood pulp. On the other hand, the breaking lengths of unbeaten softwood and birch pulps mixed in the ratios of 85:15, and 75:25 were below the breaking length of 100% birch wood pulp, but as the beating proceded these curves approached the vicinity of the 100% softwood curve. The differences of the breaking length results were due to the fact that after cooking, the disintegration was done in a blender, and the initial pulp strength properties would be very much affected by the disintegration process in the blender. Shown in Figure 1 (bottom) is also the development of the burst index, and it can be found that most of the burst index had already been gained at a PFI refining level of 2000 revolutions.

It can be further found from Fig. 1 that the breaking lengths of the mixed softwood/birch pulps were similar (less than 5% in difference) to those of the 100% softwood pulp, indicating that 15-25% birch chips as admixture in the softwood chips had negligible effect on the tensile strength of the bleached kraft pulp. However, the burst index was slightly lower for the mixed softwood/birch pulps than for the 100% softwood pulp.

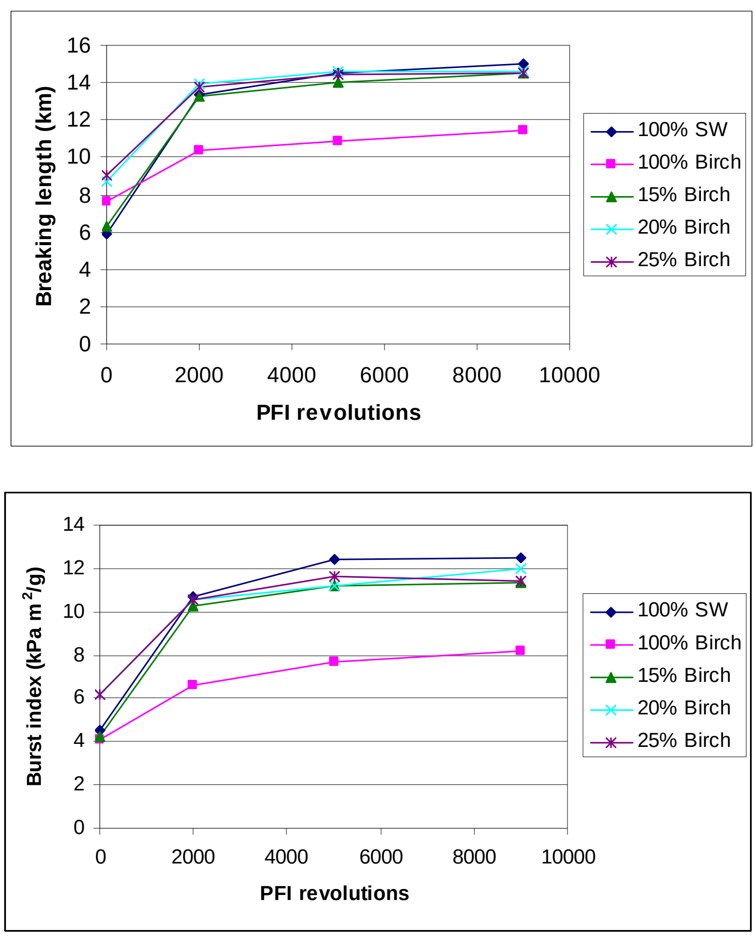
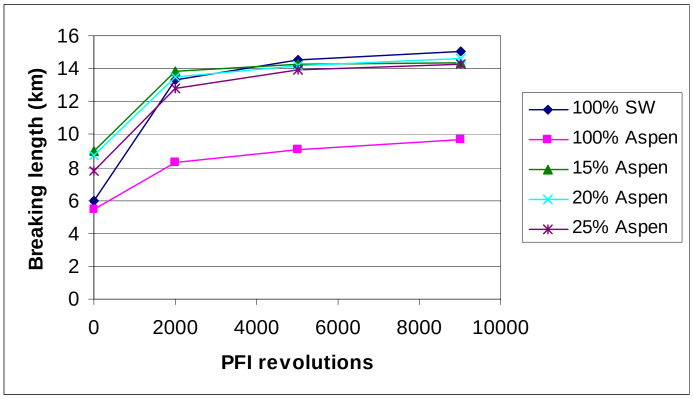


Fig. 1. Effect of birch chip admixture on the breaking length (top) and burst index (bottom)



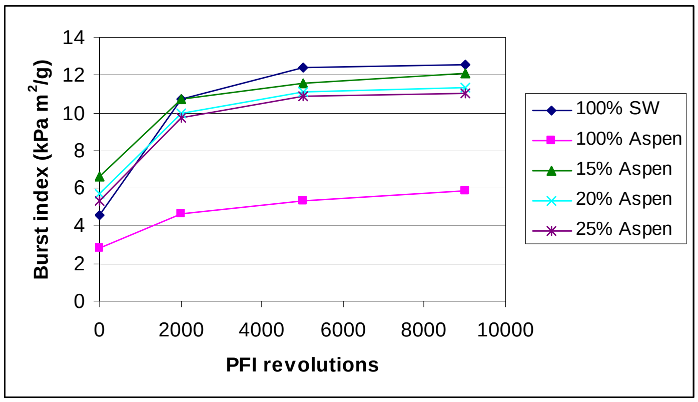


Fig. 2. Effect of aspen chip admixture on the breaking length (top) and burst index (bottom)

As shown in Fig. 2, the effect of aspen chip admixture on the breaking length and burst index development was similar to that of the birch chip admixture. Again, the variation in the strength properties of the unbeaten pulp was due to the differences in the disintegration processes after cooking, as noted before. With 15 to 25% aspen chips and 75 to 85% softwood chips, the breaking length development in PFI refining was similar to that of the 100% softwood pulp. However, a slight decrease in burst index was observed with the addition of 15 to 25% aspen chips.

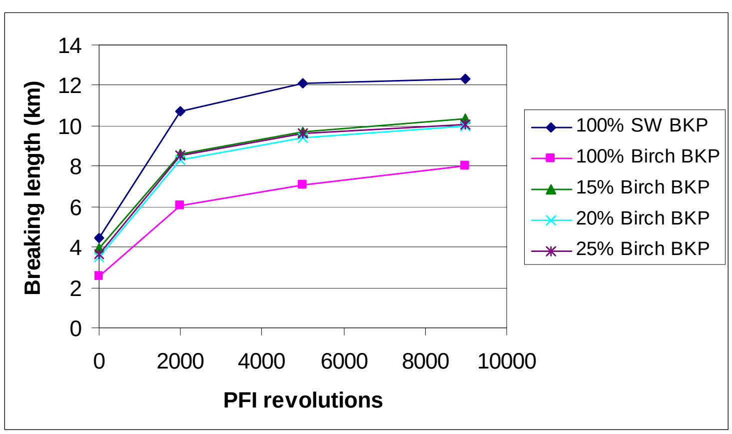


Fig. 3. Development of breaking length in co-refining of market bleached softwood and hardwood kraft pulps

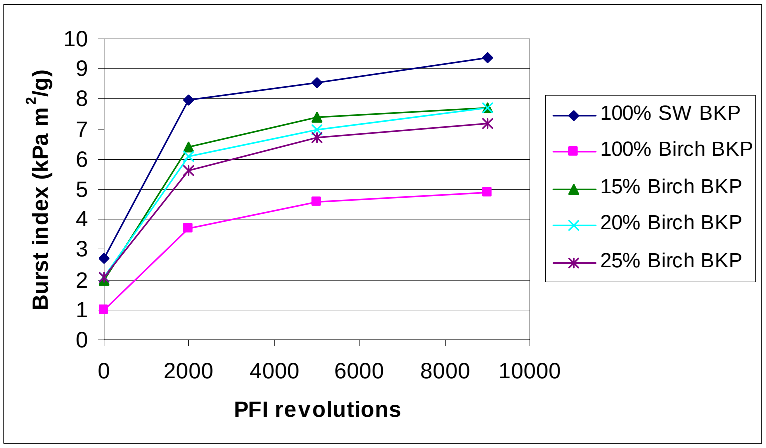


Fig. 4. Burst index development in co-refining of market bleached softwood and hardwood kraft pulps

Hardwood kraft pulps generally have lower strength than their softwood counterparts. As shown in Figs. 1 and 2, both the 100% birch and 100% aspen pulps had significantly lower breaking length and burst index than the softwood pulp at the same PFI revolutions. On this basis it might be expected that the presence of 15 to 25% hardwood fibers would result in some decrease in strength. However, the results in Figs. 1 and 2 show that the breaking length and burst index of the mixed softwood/hardwood pulps were very similar to those of the 100% softwood pulp.

We also studied the co-refining of a commercial softwood kraft pulp and a commercial hardwood kraft pulp (birch) in a PFI mill, and the results are shown in Figs. 3 and 4. One can see that the mixed softwood and hardwood pulps by pulp blending had significantly lower strength properties (breaking length and burst index) than the softwood pulp.

When mixed softwood and hardwood chips were pulped in the conventional kraft pulping process, for the same kappa number, the softwood fibers from a mixed cooking may have higher kappa while the hardwood fibers have lower kappa than those when they are cooked separately. It has been reported that kraft cooking to a higher kappa number can increase the pulp strength due to higher retention of hemicellulose and higher pulp viscosity (Poukka et al. 1999). As a result, the softwood fibers can have higher strength properties, which can compensate for the negative effect of hardwood fibers on the strength properties of the mixed pulp.

Strength-Freeness Relationship

The breaking length-freeness and burst-freeness relationships of the pulps from mixed chip cooking are shown in Fig. 5 for birch and Fig. 6 for aspen. At the same freeness, the softwood pulp had significantly higher breaking length and burst index than the hardwood pulps. However, the mixed softwood/hardwood pulps (from chip blending) had breaking length similar to the 100% softwood pulp. This was particularly true in the cases of birch chips. The burst index of the mixed softwood pulps was only slightly lower than that of the 100% softwood pulp at the same freeness. In contrast, when a commercial birch kraft pulp was mixed with a commercial softwood pulp at the same hardwood to softwood ratios (15-25%) and then subjected to beating in a PFI, the breaking length and burst index of the resultant pulps were significantly lower than those of the softwood pulp at the same freeness (Fig. 7).

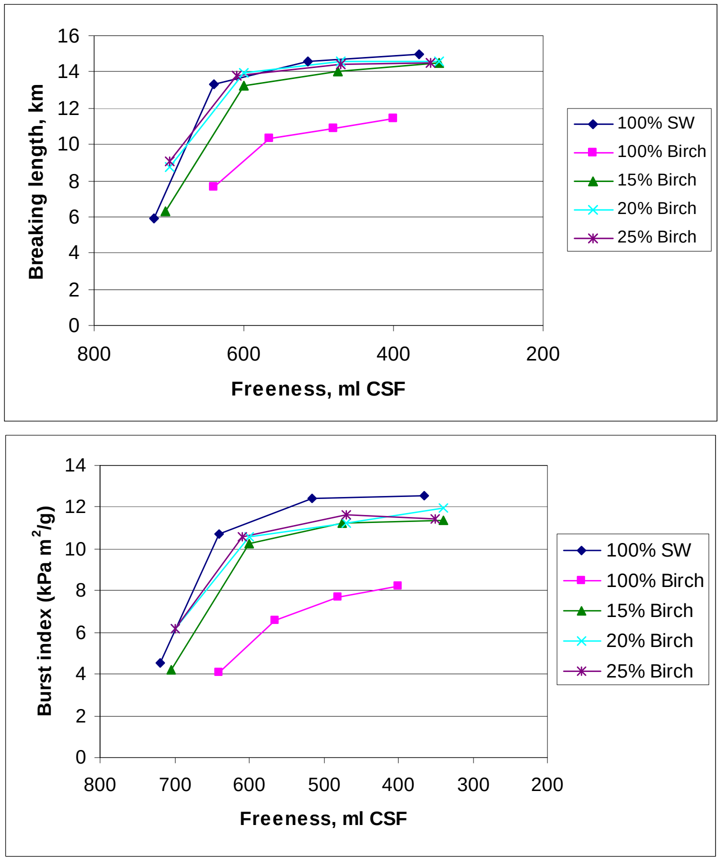


Figure 5. Effect of birch chip admixture on the relationship of breaking length vs. freeness (top) and burst index vs. freeness (bottom)

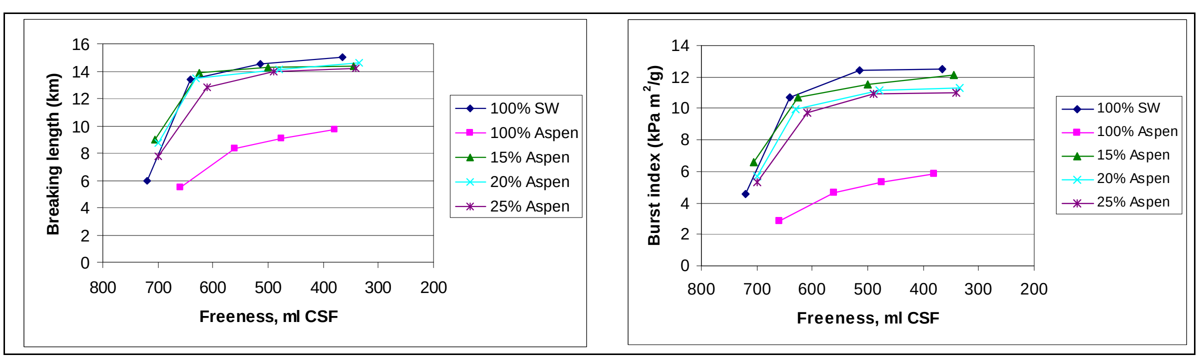


Figure 6. Effect of aspen chip admixture on the relationships of breaking length vs freeness (left) and burst index vs. freeness (right)

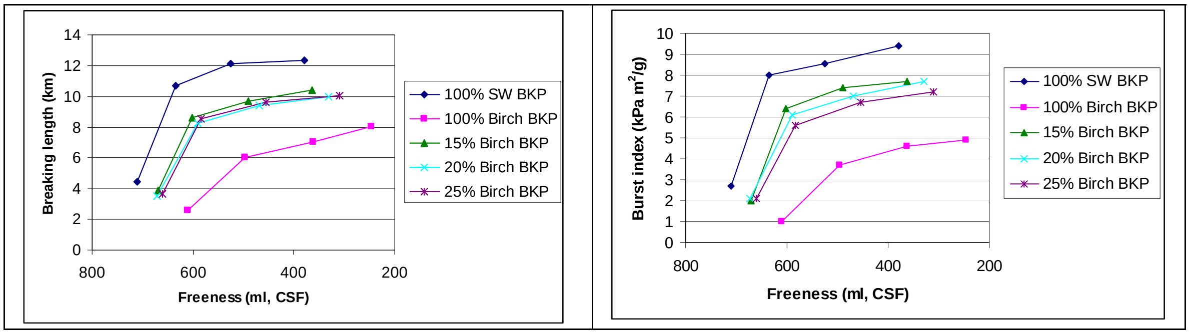


Figure 7. Relationships of breaking length vs. freeness (left) and burst index vs. freeness (right) in co-refining of market bleached softwood and a hardwood kraft pulps

Tear-Tensile Relationship

The tear-tensile relationships of the pulps from mixed softwood and birch (or aspen) chips are shown in Fig. 8. It can be seen that the tear index was somewhat lower with the addition of 15 to 25% of birch or aspen chips to the cooking process. This is understandable because hardwood fibers have shorter average fiber length than the softwood fibers.

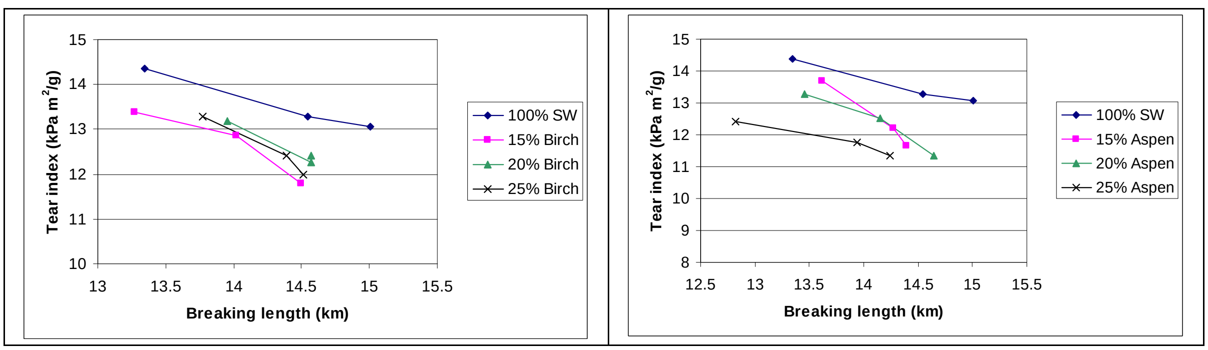


Figure 8. Effect of birch chip admixture (left) and aspen chip admixture (right) on the relationship of tear index and breaking length

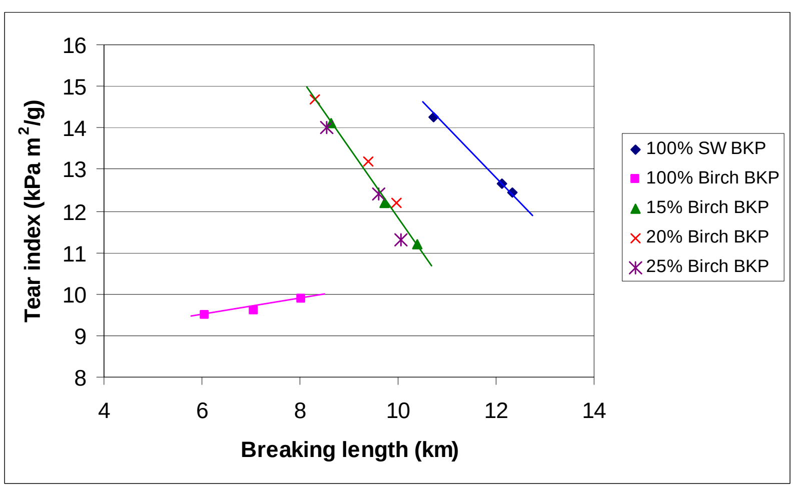


Figure 9. The relationship of tear index and breaking strength in co-refining of market bleached softwood and a hardwood kraft pulps

The decrease in tear index was more pronounced when a commercial softwood kraft pulp was co-refined with a hardwood (birch) kraft pulp. As shown in Fig. 9, the presence of 15 to 25% birch pulp caused about 20% decrease in the tear index at the same breaking length, which was compared to about 8% when 15 to 25% birch chips were pulped together with softwood chips. The difference between the mixed chip pulping and the co-refining of mixed pulps in tear index was again due to the stronger softwood fibers from the mixed kraft cooking.

Apparent density-Tensile Breaking Length Relationship

Apparent density is another important pulp property. The results in Fig. 10 show that a 15 to 25% hardwood chip admixture had negligible effect on the apparent density-tensile breaking length relationship. This was true for both birch and aspen. However, as shown in Fig. 11, when 15 to 25% of a hardwood pulp was co-refined with 85 to 75% of a softwood pulp, the apparent density-tensile breaking length relationship was between those of the hardwood pulp and the softwood pulp.

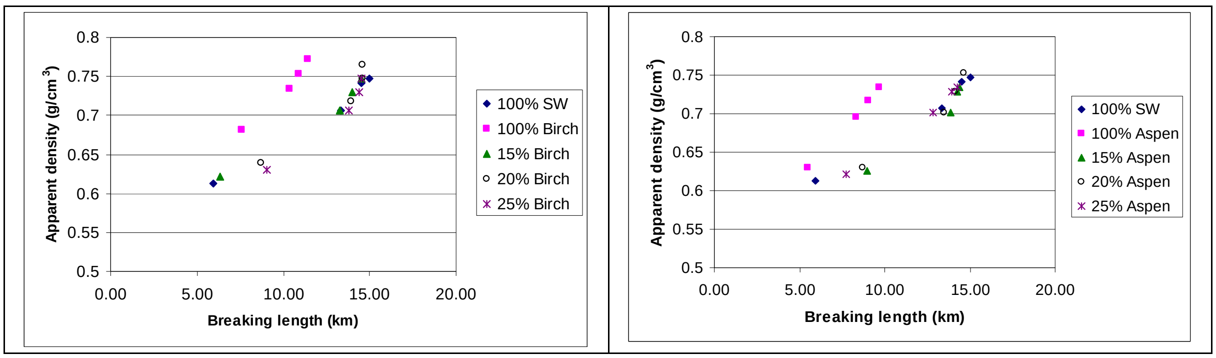


Fig. 10. Effect of birch (left) and aspen (right) chip admixture on the relationship of apparent density and tensile breaking length

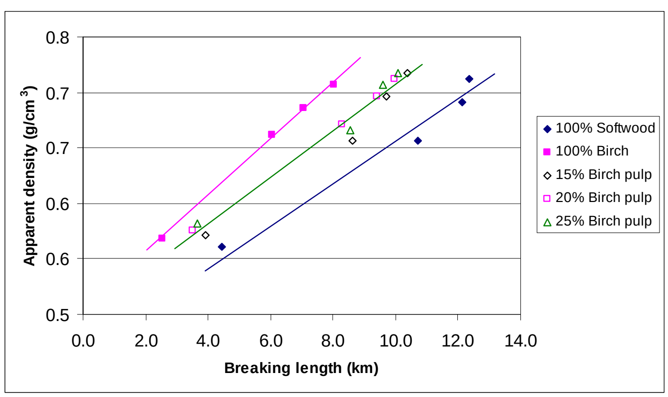


Fig. 11. The relationship of apparent density and tensile breaking length in co-refining of market bleached softwood and hardwood kraft pulps

The shorter and smaller hardwood fibers can decrease the apparent density of the mixed softwood/hardwood pulps by filling in the void volume amid the longer and larger softwood fibers, as indicated in Fig. 11. However, when mixed softwood/hardwood chips were cooked together, the effect of hardwood fiber on apparent density may be offset by the stronger and less flexible/collapsible softwood fibers from a mixed kraft cook. The observed apparent density-tensile properties of the pulps from kraft cooking of mixed softwood and hardwood chips may be the net result of the two opposite effects.

Chip Blending versus Pulp Blending

The results presented in the previous sections supported the conclusion that 15 to 25% hardwood chip admixture has minor effect on the strength properties of softwood pulp. Furthermore, these softwood pulps from mixed kraft cooking with a small percentage of hardwood admixtures can have better strength properties than mixed pulps by pulp blending at the same hardwood to softwood ratios.

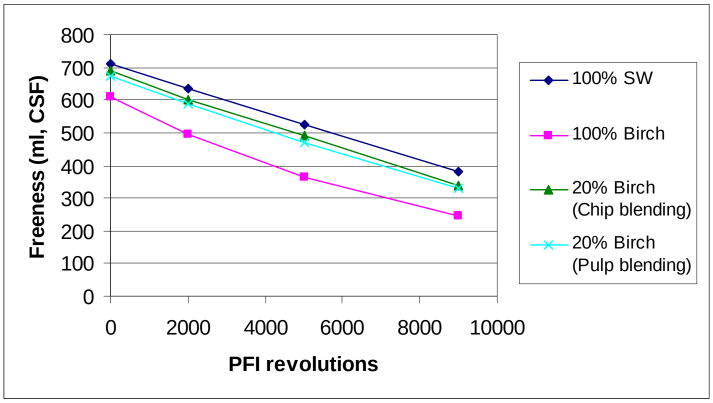


Fig. 12. Comparison of the relationship of freeness and PFI refining revolutions of the mixed softwood/hardwood pulps obtained by either chip blending or pulp blending

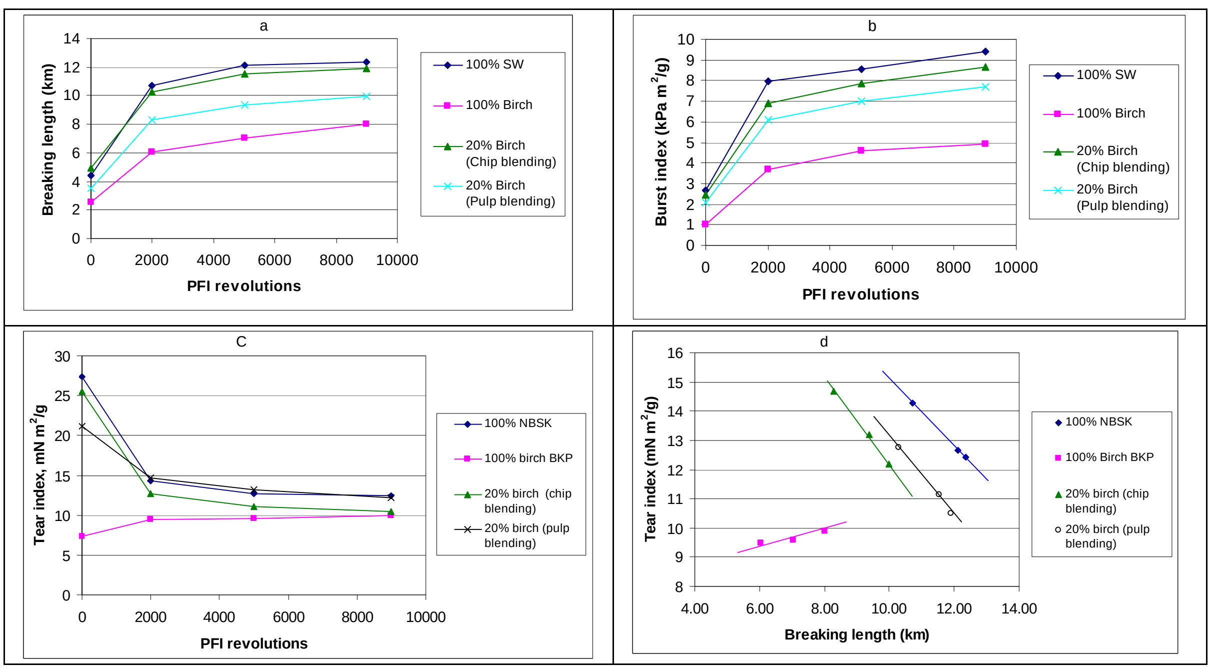


Fig. 13. Comparison of the tensile (a), burst (b), and tear (c) developments, and the tear index-breaking length relationship (d) in the PFI refining of the mixed softwood/hardwood pulps obtained by either chip blending or pulp blending

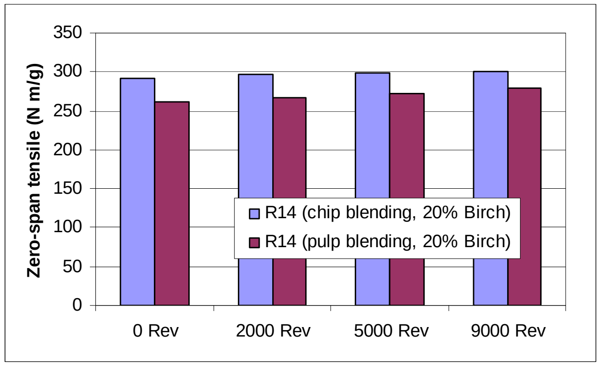


Fig. 14. Zero-span tensile of the softwood fibers separated from the pulps by Bauer-McNett (softwood/birch)

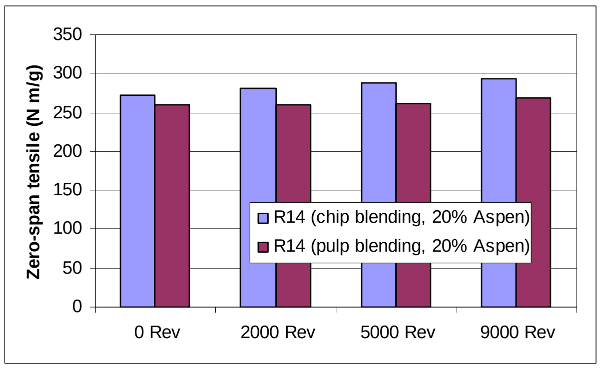


Fig. 15. Zero-span tensile of the softwood fibers separated from the pulps by Bauer-McNett (softwood/aspen)

To further support the above conclusions, three dried lap pulps obtained from the same mill were used: softwood bleached kraft pulp, birch bleached kraft pulp, and mixed softwood/birch bleached kraft pulp from mixed cooking with 20% birch chip admixture. The cooking and bleaching conditions, as well as the unbleached kappa number and the brightness of these mill pulps, were similar to those used for the lab pulps. It is known that the strength properties of laboratory-prepared pulps tend to be different from those of mill pulps, due to the fact that under the laboratory conditions, the mechanical damage to the fibers will be much less compared to fibers exposed to mill conditions, as was documented in a systematic study (Li 2000). The fourth pulp was prepared by mixing 20% of the birch kraft pulp with 80% of the softwood kraft pulp. Figure 12 shows the freeness change during PFI refining of the four pulps. Similarity in freeness is evident between the two pulps containing 20% birch fibers. However, significant differences can be observed between the two pulps in strength development during PFI refining, as shown in Fig. 8. The tensile strength of the mixed softwood/hardwood pulp from mixed chips was similar to that of the softwood pulp at the same PFI revolutions. In contrast, the tensile strength of the mixed softwood/hardwood pulp prepared by pulp blending was substantially lower than that of the softwood pulp. Figure 13 shows that the mixed pulp from chip blending also had higher burst index than the mixed pulp from pulp blending. Results in Fig. 13 (c) show that the tear index of all the three softwood pulps with or without 20% hardwood fibers decreased dramatically after 2000 revolutions of PFI refining. The results also indicate that the chip blending resulted in a faster decrease in the tear index than the pulp blending. This is associated with the faster development of the inter-fiber bonding strength in the case of the chip blending. As shown in Fig. 13 (d), the beating curve (tear index vs. breaking length) for the chip blending was above that for the pulp blending, indicating that at a given breaking length, the chip blending gives the higher tear index than the pulp blending.

Based on the results presented above, one can draw a conclusion that under the conditions studied chip blending can lead to overall better strength properties than pulp blending at a given freeness. It is proposed that the better strength properties are due to the stronger softwood fibers from mixed kraft pulping. As discussed before, higher unbleached kappa number can yield stronger bleached pulp fibers (Poukka et al. 1999).

To further support the above hypothesis, co-refined bleached kraft pulp samples, which were obtained by either chip blending or pulp blending, were subjected to fiber classification in a Bauer-McNett fiber classifier. The long fiber fraction (R14) consisted mostly of softwood fibers (length >2 mm) (Gooding and Olson 2001) were tested for zero-span tensile strength (Seth 2001, 2006; Seth and Chan 1999). As shown in Figs. 14 and 15, the long fibers separated from the chip blending samples had consistently higher zero-span tensile strength than those separated from the pulp blending samples, indicating that the bleached softwood fibers from the chip blending samples were stronger than those from the respective pulp blending samples. This was true for both softwood/birch and softwood/aspen mixtures.

CONCLUSIONS

The effect of adding 15 to 25% birch or aspen chips on the strength properties of softwood kraft pulp was studied. A 15 to 25% hardwood chip admixture had only a minor effect on the strength properties. No significant effect was observed for the hardwood admixture on apparent density over a wide range of tensile breaking length. Pulping of mixed softwood/hardwood chips (chip blending) resulted in overall better strength properties than pulp blending at a given freeness. The possible explanation for the above results may be that the softwood fibers are cooked to relatively higher kappa number in the cooking of mixed softwood/hardwood chips for the same target kappa number, and thus have higher fiber strength due to higher pulp viscosity and preservation of the hemicellulose. This was supported by the results on zero-span tensile strength of the long fiber fraction of the sample from chip blending and pulp blending. The implication is that some softwood kraft pulp mills can add up to 25% of hardwood chips to the kraft cooking of softwood chips without significantly affecting the overall pulp strength properties.

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