THERMOMECHANICAL PULP PROPERTIES OF WHITE BIRCH

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ABSTRACT

Handsheet properties of an experimental white birch thermomechanical pulp (TMP) were evaluated in terms of fiber length and were compared with those of a standard spruce/fir newsprint furnish. These properties, including Canadian Standard Freeness (CSF), sheet density, tear resistance, tensile strength, scattering coefficient, opacity, and brightness, were found to increase with a decrease in fiber length as a result of refining. The increase in sheet strength can be attributed to the improvement in fiber bonding.

With respect to the species differences, the birch TMP yields significantly lower strength properties than does the spruce/fir furnish. These reductions are attributed to the morphological differences between softwoods and hardwoods. It is hoped that this analysis will contribute towards a more efficient utilization of low-grade hardwoods in high-yield products, including paper, paperboard, insulation board, and possibly for hardboard.

Keywords: Thermomechanical pulp (TMP), balsam-fur, spruce, white birch, fiber length, sheet density, paper strength, opacity, burst index, breaking length, tear index, Canadian Standard Freeness (CSF).

INTRODUCTION

The introduction of some of the low-grade hardwoods into high-yield pulping processes continues to remain a challenge even today. In fact, it seems simply impossible to make a good quality product, such as newsprint, out of a pulp furnish containing white birch TMP (Koran et al. 1985). Although a pretreatment of the chips with ozone (Soteland 1982) or with sodium percarbonate (Marton et al. 1986) produced some improvements in the qualities of CTMP, the strength properties remained on the low side of the papermaker's requirements (Eriksen and Oksum 1980). Even in the neutral sulfite chemimechanical process (NSCM), only 10% of the birch pulp could be incorporated into newsprint (Richardson 1962). Only a 50-minute interstage OPCO treatment produced superior results with a 10% sodium sulfite solution (Koran 1994).

In the light of the above results, it was necessary to study the fiber characteristics of white birch TMP in comparison with a standard softwood TMP produced under identical conditions. Since fiber length is known to have a significant effect on the properties of paper (Clark 1978), the comparisons were made at identical fiber lengths.

MATERIALS AND METHODS

Experimental TMP was produced from white birch (*Betula papyrifera*) chips in a two-stage Jylhavaara refiner at 138 kPa gage pressure in the first stage and at atmospheric pressure during the second stage. Pulp samples were collected from both refining stages and from the screened TMP to provide materials refined to different levels of CSF. The pulp characteristics and the handsheet properties were evaluated using the standard CPPA techniques; the Bauer-McNett fiber classification was done according to Tappi Standard T 233 cm-82.

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TABLE 1. *The determination of the weighted average fiber length for a sample of white birch TMP.*

Tyler series	(A) Sieve opening mm	(B) Fraction retained W, %	(C)[1] Fiber length L, mm	(D)[2] B × C
14	1.2	13	3.10	40.3
28	0.6	21	2.00	42
48	0.3	32	1.17	37.5
100	0.15	23	0.71	16.3
200	0.075	10	0.36	3.6
P200	<0.075	1	0.18	0.2
Total	—	100	—	139.9

[1] From Tasman's curve (Tasman 1972).
[2] Weighted average fiber length = D_{TOTAL}/B_{TOTAL} = 139,9/100 = 1.4 mm.

The average fiber length values of each sample were calculated from the Bauer-McNett data. A summary of this approach is presented in Table 1, including the sieve openings (column A), the oven-dry percentages of the fibers retained on each screen (column B), the average fiber length values (column C), and the calculation of the weighted average fiber length (column D). It should be noted that the average fiber length of each fraction (L) listed in column C was determined from Tasman's curve (1972), and the weighted average fiber length values (L) were determined using the following formula:

$$L = (W_{14}L_{14} + W_{28}L_{28} + W_{48}L_{48} + W_{100}L_{100} + W_{200}L_{200} + W_{p200}L_{p200}) \div (W_{14} + W_{28} + W_{48} + W_{100} + W_{200} + W_{p200})$$

where,

W = oven-dry weight, or percentage of fiber fraction retained on each screen
L = average fiber length of each fraction in mm shown in column C of Table 1

Alternatively fiber length measurements could be made by the semi-automated method of Sugden (1968), or by the fiber length distribution technique of McIntosh (1965) per gram of fibers, or by a number of other methods reviewed by the Forest Biology Subcommittee (1968). In addition, the Tappi Standard methods by projection (T 232 cm-85), by classification (T 233 cm-82), and by optical automated optical analyzer (T 271 pm-91) are also available for fiber length determination. The most recent technique involves the Kajaani instruments (FS-100 and 200) offering a fully automated method for the determination of fiber length (Gess 1985). This type of measure is mostly aimed to monitor refiner performance for a particular grade of paper (Dagan and Gould 1987).

RESULTS AND DISCUSSION

The drainage properties of the experimental white birch TMP are plotted in Fig. 1 as a function of fiber length along with a mixture of spruce (*Picea* species) and fir (*Abies balsamea*) TMP as a reference pulp. Similarly, the handsheet properties are listed in Table 2 and are illustrated in Fig. 2 for both type of pulps.

Canadian Standard Freeness (CSF)

As expected, an increase in refining produces a significant decrease in CSF in both pulps (Fig. 1). This decrease is most rapid during the initial stages of refining for the spruce/fir furnish in contrast to a rapid decrease in CSF occurring in the short fiber region for the white birch TMP. This implies that the spruce/fir TMP produces the most fines during the initial stages of refining in contrast to the birch TMP, in which drainage becomes increasingly slower as 100 ml CSF is approached.

It is surprising to note that the spruce/fir TMP is made up of significantly longer fibers than the birch TMP at all CSF levels (Fig. 1). This is especially evident at 300 ml CSF where the weighted average fiber length of the spruce/fir furnish (1.7 mm) is twice the value of that of the white birch TMP. This corresponds to a 2.3 times difference in the standing tree where the spruce/fir tracheid and the birch fiber measure 3.5 and 1.5 mm in length, respectively (Koran 1989). By the time the pulp is refined to 100 ml CSF, every birch fiber is divided into two segments, each measuring on the average 0.76 mm. In comparison, each spruce/fir tracheid is cut into 3 segments, each mea-

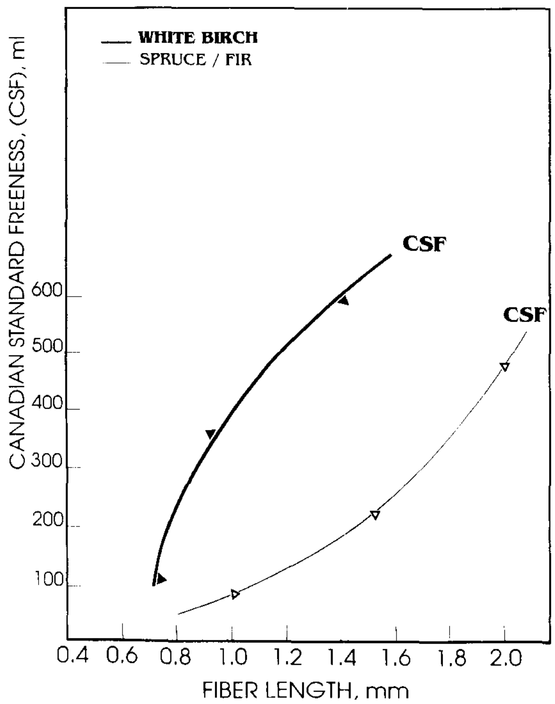

Fig. 1. The effect of fiber length on Canadian Standard Freeness (CSF) of white birch TMP and the standard spruce/fir TMP.

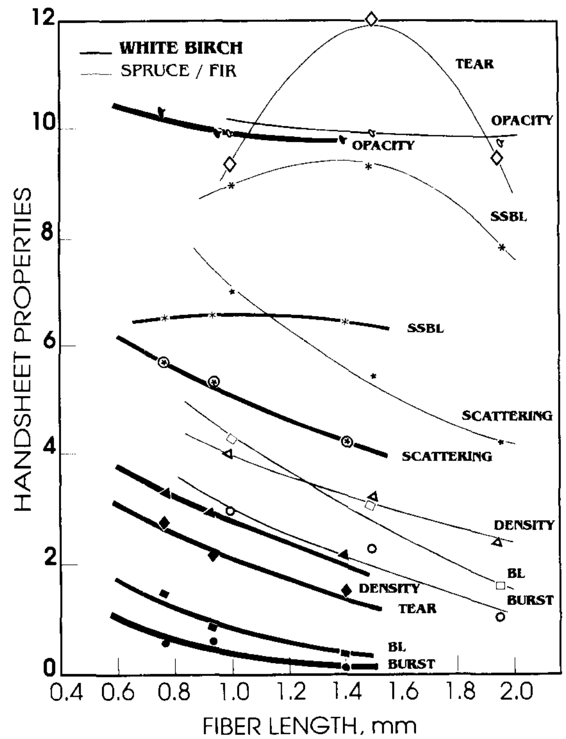

Fig. 2. The influence of fiber length on the handsheet properties of white birch TMP and the standard spruce/fir TMP furnish. The units of the sheet properties are listed in Table 2.

suring on the average 1 mm. This implies that birch fibers are significantly more resistant to refining than the corresponding spruce/fir tracheids (3.5 mm; 1.5 μm) because of their thicker walls (3.5 μm) and lower initial length (1.5 mm). Furthermore, the probability of a longer fiber being cut between the bars of the refiner plates is greater than that of a shorter fiber.

Figure 1 also shows that, for the same fiber length, the birch TMP has a significantly higher CSF than the spruce/fir furnish. At an average fiber length of 1.2 mm, for example, the birch TMP has a 4 times higher CSF than the spruce/fir furnish. Although this difference becomes increasingly smaller with a decrease in fiber length, nevertheless the birch TMP remains a much coarser pulp than the spruce/fir TMP. A coarse pulp is known to form a very loose fibrous network that drains faster than the tighter mat of spruce/fir fibers. Although this is a negative feature in the manufacture of newsprint, fast drainage is a desirable quality on the wire from the point of view of increasing the speed of the paperboard machine and as a consequence, the production rate of cartons.

Apparent sheet density

As expected, sheet density increases with a decrease in fiber length at the same rate in the two types of pulp (Fig. 2). A 1-mm decrease in fiber length, for example, produces a 200 kg/m^3 increase in the densities of the two types of handsheets. Thus, regardless of the pulp type, short fibers make a denser sheet than do long fibers.

With respect to species effect, the spruce/fir furnish produces a significantly denser sheet than the corresponding birch TMP at any fiber length. At 1-mm fiber length, for example, 280 kg/m^3 sheet density is obtained for white birch in comparison with 380 kg/m^3 for the spruce/

TABLE 2. *Fiber characteristics and handsheet properties of white birch TMP and the standard spruce/fir furnish.*

Parameters	Sample no.:	White Birch TMP 1	White Birch TMP 2	White Birch TMP 3	Spruce/Fir TMP 1	Spruce/Fir TMP 2	Spruce/Fir TMP 3
CSF, mL		596	360	100	472	218	77
Fiber length, mm		1.41	0.93	0.76	1.95	1.50	1.00
Bauer McNett Fiber fractions, %							
14	3.10	13	1	5	36	15	5
28	2.00	21	12	3	27	31	23
48	1.17	32	33	27	19	25	19
100	0.71	23	25	24	9	11	10
200	0.36	10	10	13	5	6	6
P200	0.18	1	19	28	4	12	38
Tear, $mN \cdot m^2/g$		1.4	2.1	2.7	9.1	11.5	9.0
Burst, $kPa \cdot m^2/g$		0	0.25	0.50	0.9	2.2	2.8
Breaking length, km		0.24	0.77	1.4	1.5	3.0	4.1
Stretch, %		0.2	0.9	0.9	1.4	2.0	2.0
Short span, BL, km		6.1	6.2	6.2	7.5	9.0	8.6
Apparent density, $kg/m^3 \times 10^2$		2.10	2.80	3.10	2.30	3.10	3.80
Brightness, %		46	49	50	49	52	54
Opacity, %		95	96	99	94	96	96
Scattering coefficient, $cm^2/g \times 10^2$		4.05	5.09	6.74	4.02	5.20	6.78

fir handsheet (Fig. 2). This is a 38% increase, which can be attributed to the partial collapse of the relatively thin-walled (1.5 μm) spruce fibers in comparison with the thick-walled (3.5 μm) and uncollapsed birch fibers. The latter are rigid elements that do not conform to one another in the handsheet. Consequently, such fibers form a loose fibrous network that possesses low sheet density and high bulk. Although high bulk is an unwanted property in most paper products, it is a desirable quality in paperboard. Since high bulk implies a thick sheet, this in turn translates into superior stiffness as indicated by the following formula:

$$R = \frac{bt^3}{12}.$$

It is evident that the rigidity of paperboard (R) is directly related to the third power of the sheet thickness (t) at unit sample width (b).

Insulation board is another product where the high bulk of white birch TMP is a desired quality. At 600 ml CSF, for example, 86% of the board volume is occupied by air at a sheet density of 210 kg/m^3. Even at 100 ml CSF, the sheet porosity is still 80%. Therefore, birch TMP fibers offer an excellent potential for the manufacture of insulation board.

Optical properties

Figure 2 further shows that a decrease in fiber length produces a corresponding increase in the scattering coefficient of the handsheet. This is a 414 m^2/kg-increase in scattering coefficient for a 1-mm reduction in the length of a birch fiber in comparison with a 291 m^2/kg-increase for the spruce/fir TMP. These figures show that the increase in scattering coefficient is 1.4 times greater for the birch TMP than for the spruce/fir furnish. This increase is due to a significant increase in the number of air-solid interfaces in the birch handsheet.

It can be further noted that the above increase in scattering coefficient produced significant increases in the opacities of the spruce/fir (2%) and birch (6%) handsheets (Fig. 2). The latter is an especially significant increase, which can be attributed to the significantly higher fines content in the birch TMP (38%) than in the spruce/fir (28%) furnish. However, the greater increase in the opacity of white birch corresponds to a lower brightness in the same sheet (50% at 100 ml CSF) than in the spruce/fir TMP (54% at 77 ml CSF). This difference can be attributed to the gum content of birch as reported previously (Koran and Yang 1972).

Tensile strength

Figure 2 shows that a decrease in fiber length corresponds to a significant increase in sheet density, which in turn produces a similar increase in the tensile strength of the handsheet. Thus, a 1-mm decrease in the fiber length of birch TMP produces a 0.8 times increase in burst and a 1.8 times increase in breaking length. In comparison, the spruce/fir TMP results in an even higher burst strength (2 times) and breaking length (2.7 times). This implies that the spruce/fir tracheids react more favorably to refining than do the birch fibers from the point of view of developing sheet strength. In contrast, the birch fibers are little modified during refining. On the whole, they tend to maintain their straight form (without fold), cylindrical shape (without collapse), and they show little disturbance (fibrillation, delamillation) on their surface. Only the vessel elements have the tendency to break up into wall fragments varying in shape and size. Even the short-span breaking length of white birch TMP is little affected by refining, showing a slight increase (2%) as a result of a 500-ml CSF drop.

In contrast, the short-span breaking length (SSBL) of spruce/fir TMP changes significantly in the form of a bell-shaped curve. This resembles the traditional bell-shaped curve of tear also shown in Fig. 2.

Tear strength

It is well known that the tear strength of chemical pulps decreases with a decrease in fiber length. In contrast, the tear strength of birch TMP increases with a decrease in fiber length. This increase can be attributed to the initial low degree of bonding between the coarse birch fibers. The same is true for the spruce/fir TMP at the high end of the fiber length scale. Here the TMP has undergone a low degree of refining as indicated by its high CSF (472 ml). This pulp is also made up of relatively rigid fibers that form a loose fibrous network with low sheet density and poor internal bonding. Thus, during the tear test, such fibers tend to pull out of the network rather than being broken in the zone of fracture. Consequently, this coarse pulp yields low tear strength as seen in Fig. 2 at 2-mm fiber length.

In contrast, at the other end of the scale (e.g., at 1-mm fiber length), the CSF has dropped to 77 ml as a result of additional refining. This is now a relatively fine pulp, which is made up of short (1-mm) and flexible fibers with a high degree of fibrillation. For these reasons, this pulp forms a dense sheet with superior fiber-to-fiber bonding. However, because of the excessive reduction in fiber length (1 mm), this pulp yields an equally low tear strength.

In comparison, the half-way point in between (1.5 mm) represents the optimal degree of refining from the point of view of developing tear strength. At this point, the flexibilities of the fibers have been sufficiently improved to produce a relatively dense sheet (310 kg/m^3) with improved fiber-to-fiber bonding at the cost of a small reduction in fiber length (1/2 mm). This pulp (200-ml CSF) is made up of relatively long and flexible fibers (1.5 mm) that become well-bonded in an intermediately dense sheet. Consequently, such fibers provide the necessary conditions for the development of maximal tear strength (Fig. 2).

Species differences

Figure 2 also shows that the short-span breaking length (SSBL) of the spruce/fir TMP is 1.5 times greater than that of the white birch furnish at the same fiber length of 1.5 mm. This corresponds to similar differences in density (1.7×) and scattering coefficient (1.4×). Species difference is especially important for tear strength where a 10-fold difference can be noted between the birch TMP and the reference pulp at the same fiber length of 1 mm. Although the tear strength is known to be controlled predominately by the fiber length, this is not the case here. The morphological differences between hardwoods and softwoods must be responsible for such a huge difference in tear strength.

The most important features include fiber coarseness, shape, length, diameter, wall thickness, rigidity, and cell type (e.g., parenchyma cells, vessels, and fibers). The presence of the large vessels (65 μm), for example, would be expected to contribute a great deal to the heterogeneity of the structure of the birch handsheet. The stiff, needlelike fibers would further promote the formation of a rather loose fibrous network in the birch handsheet. Even though the parenchyma cells tend to fill in some of the available space in between the fibers, the internal bond strength is improved only slightly in what appears to be a comparatively dense sheet. Further work is necessary to elaborate on each one of these morphological features from the point of view of developing sheet strength for most paper and paperboard products.

All of the above results show that the experimental white birch TMP is simply unsuitable for the manufacture of paper like newsprint. Even at 100 ml CSF, both the breaking length and tear strength are only one third of the value required for newsprint (Fig. 2). Consequently, white birch TMP should be used in the manufacture of paperboard where fiber rigidity is a required quality rather than a handicap as it is in newsprint.

High sheet bulk is another quality of white birch TMP which leads to the formation of thick sheets, which in turn produces a corresponding increase in the stiffness of paperboard. Even the machine speed can be increased as a result of the increased CSF of white birch TMP. This in turn leads to an increase in the production rate of paperboard.

Birch TMP is also suitable for the manufacture of insulation board where a high degree of porosity is a requirement. As shown previously, white birch TMP gives rise to a highly porous sheet (86%), especially at high freeness (600 ml CSF).

CONCLUSIONS

A decrease in fiber length was found to produce significant increases in sheet density, scattering coefficient, burst, and breaking length of both the birch and spruce/fir TMP. In contrast, the tear strength of spruce/fir TMP exhibited the typical bell-shaped curve when plotted against fiber length. With respect to the species effect, the spruce/fir TMP yielded significantly higher tear strength (10 ×), breaking length (12 ×), burst (9 ×), short-span breaking length (1.5 ×), scattering coefficient (1.3 ×), opacity (1 ×), brightness (1.1 ×), and sheet density (1.7 ×) than the experimental white birch TMP at the same fiber length of 1.5 mm. All of these figures suggest that white birch TMP is unsuitable for the manufacture of paper and therefore should be used in the manufacture of such products as paperboard, insulation board, and possibly hardboard.

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