Wood and paper properties of short rotation poplar clones

KWEI N. LAW, SYLVIE RIOUX, AND JACQUES L. VALADE

ABSTRACT

The authors evaluated five hybrid poplars aged 15 years grown in southern Quebec for their wood and papermaking properties. Among the clones studied, clone 3226 had the best growth performance, clone 131 had the least, and the other clones (3225, 3230 and 3308) fell between. Due to their high proportions of cells less than 0.2 mm and the high rigidity of their fibers, clones 3225 and 3226 produced chemithermomechanical pulps with inferior physical properties compared with other clones. All clones had similar optical properties.

Application:

Certain clones of hybrid poplars are an excellent source of raw material for mechanical pulping.

FIBER SUPPLY IS A KEY ISSUE FACING the pulp and paper industry in North America. The survival of this industry depends not only on technological advances but also on the source of inexpensive fiber. For more than a century, the pulp and paper industry has enjoyed a vast forest resource. The dwindling fiber supply in some areas, increasing demands, and augmenting extraction costs raise serious concerns over the competitiveness of this industry in the global market. This is particularly true with the rapid development of the pulp and paper industry in South America and Asian countries where trees grow much faster than in northern countries.

Natural forests previously constituted the main fiber supply for the pulp and paper industry in North America and Europe. This situation may not last forever for economical reasons and the competition from developing countries *(1)*. The forest products industry will need to develop strategies to ensure a reliable sustainable fiber supply *(2)*. Forest plantations of short rotation are therefore gaining increasing attention from the forest industry as a strategy *(3–7)*.

Recognizing the potential of short rotation culture of fast-growing species, the provincial government of Quebec launched a research and development program on Populus in 1968. Early work tried to improve the indigenous species and clones from Europe and Ontario. Since 1972, the Tree Improvement Service of the Ministry of Natural Resources of Quebec has been conducting research on the development of intensive culture of Populus to establish poplar plantations having high productivity—4 or 5 times faster than the Populus in a natural forest *(8–10)*. An objective was to develop clones and different varieties of poplar adaptable in various regions of Quebec with yields ranging from 8–15 m^3/year/ha with a rotation of about 15 years.

Wood quality of trees grown in these plantations is a primary concern of tree scientists. In 1995, a project was conducted to characterize the wood quality of some hybrid poplars developed in southern Quebec. The Pulp and Paper Research Center of the University of Quebec in Three Rivers participated in part of the evaluation. This paper provides information on the wood properties and papermaking characteristics of five poplar hybrids that had shown excellent growth performance and resistance to diseases and pests compared with other clones studied by Vallee *(9)*.

EXPERIMENTAL

Materials

Table I shows that five trees of each clone were selected. Each tree belonged to a group that showed the best height and diameter growth. The experimental site was established in 1981 on 1.6 hectare (ha) of abandoned agricultural land of fertile clayey soil with good drainage. The location is in the Richelieu Valley about 60 km northeast of Montreal. Density of planting was 2,257 cuttings per ha. The first thinning occurred four years later giving a density of 1,400 stems per ha. Selective thinning minimizes competition among the trees and canker attacks. The final density was 566 trees per ha.

The sample trees of each clone were harvested in May 1996. The bottom 1.22 m of each tree was reserved for veneering study by a plywood mill in Lac Megantic, Quebec. A disk about 5 cm thick was taken at 1.3 m above ground for wood quality evaluation, and a 1 m long trunk was removed above this height for saw-milling study at the laboratory of a Canadian company. At 2.5 m above ground, two logs of 1.22 m each were cut for pulping trials. These logs were debarked manually and chipped using a 48 in. commercially available chipper. The chips were screened on a laboratory classifier to remove the over-thicks and fines. The accepted chips had a nominal thickness of 2–6 mm. Chips from five trees were mixed in the proportions determined by the respective

Clone	Origin	Type of hybrid
131	Quebec	P. deltoides x P. nigra
3225	Belgium	P. trichocarpa x P. deltoides (cultivar Unal)
3226	Belgium	P. trichocarpa x P. deltoides (cultivar Beaupre)
3230	Belgium	P. trichocarpa x P. deltoides (cultivar Boelare)
3308	France	P. deltoides x P nigra (cultivar Regenerrata)

I. Poplar clones studied

Hybrid	131	3225	3226	3230	3308	Aspen
Lignin, %	22.70 (0.704)	23.00 (0.759)	22.91 (0.642)	23.04 (0.668)	22.55 (0.789)	18.12 (0.606)
Pentosans, %	16.81 (0.673)	16.04 (0.734)	16.28 (0.779)	16.16 (0.676)	15.92 (0.776)	17.20 (0.688)
Hot water solubility, %	3.33 (0.093)	2.52 (0.066)	2.77 (0.072)	2.65 (0.074)	0.85 (0.064)	2.75 (0.082)
1% NaOH solubility, %	21.06 (0.842)	19.06 (0.648)	9.40 (0.404)	22.49 (0.809)	18.05 (0.614)	19.30 (0.637)
DCM extraction, %	0.79 (0.032)	0.69 (0.022)	0.74 (0.021)	0.61 (0.016)	1.31 (0.046)	1.50 (0.048)
Ash, %	0.81 (0.019)	0.87 (0.022)	0.83 (0.022)	0.87 (0.021)	0.91 (0.023)	0.40 (0.011)

II. Chemical composition of poplar hybrid wood with standard deviations in brackets

Clone	Fiber length, mm	Fiber diameter, µm	Cell wall thickness, µm	Coarseness, mg/m	Rigidity index, $(T/D)^3$, 10^{-4}	Cells < 0.2 mm, arithmetic mean
131	0.83	17	1.88	0.103	13.53	16.45
3225	0.81	17	2.25	0.140	23.20	25.52
3226	0.85	16	1.98	0.139	18.93	21.53
3230	0.85	19	2.25	0.130	16.60	16.75
3308	0.92	19	1.88	0.138	9.69	14.50
Aspen	1.20	18	2.20	0.121	15.32	15.32

III. Fiber morphology data

weights contributed by each tree. This gave a composite chip furnish for an estimation of the between-clone variation in pulping properties.

Fiber characterization

A thin band of growth ring was selected from four different positions from pith to cambium across the sample disks to make a composite sample for maceration in a solution containing equal portions of acetic acid and hydrogen peroxide at 70°C for 3–4 h. The macerated fibers were characterized using a fiber quality analyzer for fiber length, length distribution, and fiber coarseness. The fiber quality analyzer provides three mean values:

- Arithmetic mean
- Length weighted mean, $L_w = (\sum n_i L_i^2)/(\sum n_i L_i)$, where i = 1, 2, 3, . . ., n = fiber count, L = contour length
- Weight weighted mean, $L_{ww} = (\sum n_i L_i^3)/(\sum n_i L_i^2)$.

The presence of fines or very short cells significantly influences the arithmetic mean, and the presence of long fibers influences the weight weighted mean. The value of length weighted average is useful to compare differences between samples. The value of length weighted average was used to compare differences between samples. This value is comparable to that obtained with the Kajaani fiber analyzer. Fiber diameter and cell wall thickness were measured on 20 µm thick cross sections of 1 x 1 cm blocks taken from two locations—fifth year ring and fourteenth year ring—across the tree diameter. Measurements used a standard research microscope.

Chemical analysis

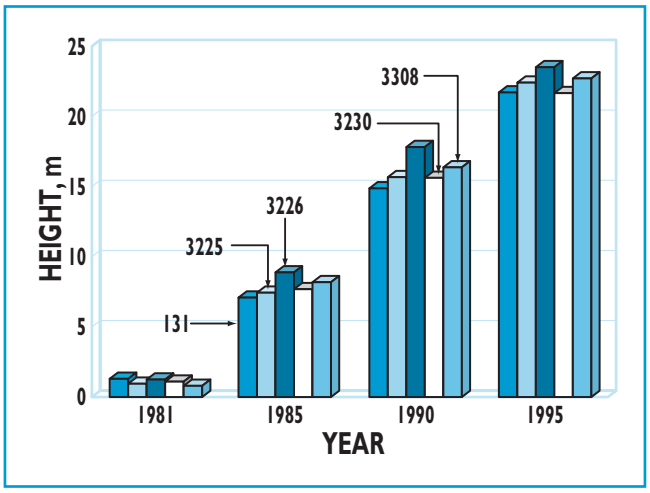
Chemical analyses of the wood sample disks taken at 1.3 m above ground followed TAPPI test methods. The analyses included lignin (method T 222), pentosans (method T 223), hot water solubility (method T 207), 1% NaOH solubility (method T 212), Dichloromethane extractives (method T 204 OM-88), and ash (method T 211).

Chemithermomechanical pulping

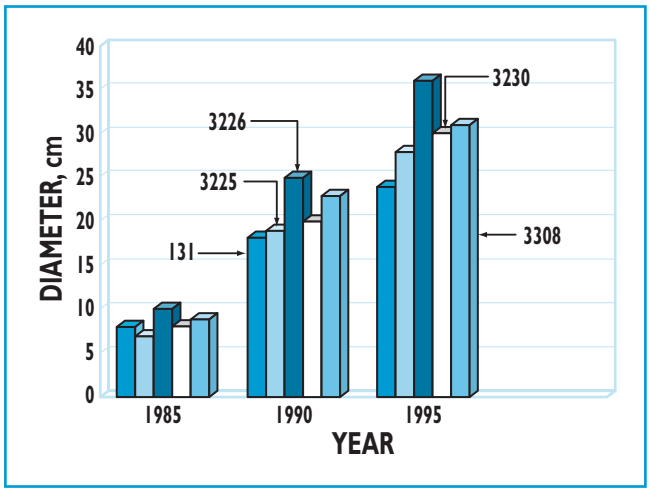
Chemithermomechanical pulping (CTMP) used a commercially available refiner equipped with a stator plate and a rotor plate. Pulps were produced in two stages. In the first stage, the chips were steamed under atmospheric conditions in the feed hopper for 10 min. They were then screw fed using a compression ratio of 2:1 into an impregnator located inside the digester containing a chemical solution of sodium sulfite and sodium hydroxide. Two vertical screws discharged the impregnated chips to the bottom of the digester where they were cooked at 170 kPa for 10 min before being refined under that pressure. The discharge consistency was about 18%. The sodium sulfite charge was 4% and that of the caustic was 3% on o.d. weight basis. After an interstage wash, the first stage pulps were refined using the same refiner under atmospheric conditions to yield at least three levels of CSF between 100–400 mL. Pulp consistency at discharge was about 15%.

Pulp characterization

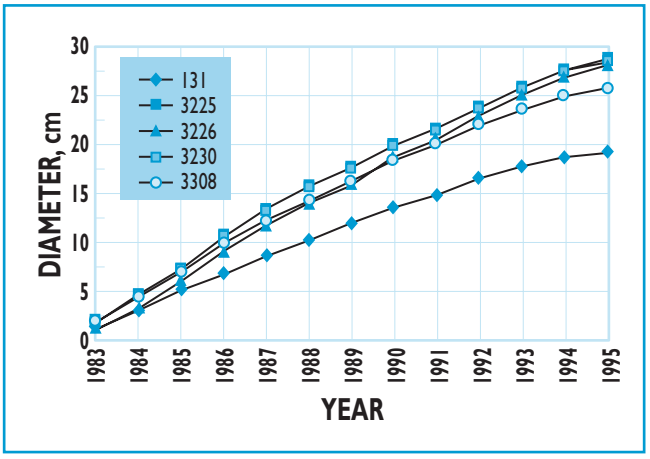
All pulps were disintegrated in hot water to remove latency. Freeness measurements, handsheet formation, and optical and mechanical



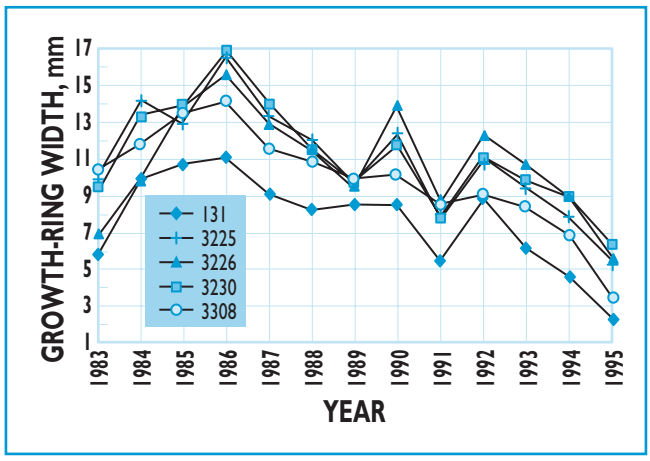
1. Growth in height of hybrid poplars on plantation



2. Growth in diameter of hybrid poplars on plantation



3. Growth in diameter of sample hybrid poplars



4. Growth-ring width of sample hybrid poplars

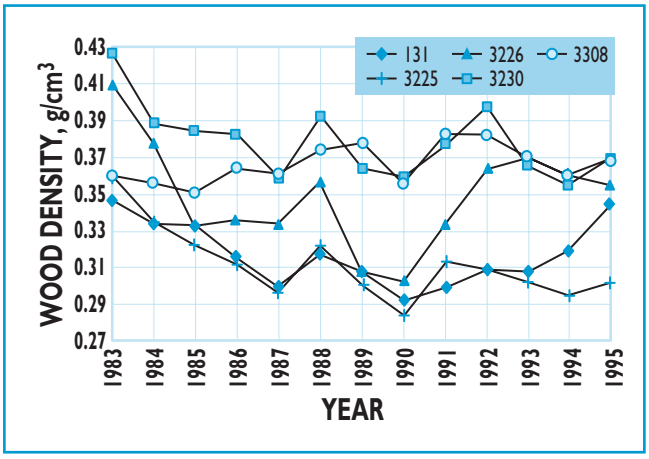
property determinations used TAPPI test methods. Macerated fibers from sample disks taken at 1.3 m above ground were used for fiber property evaluation.

RESULTS AND DISCUSSION

Tree growth

Figure 1 shows the average growth in height measured at five year intervals of trees on the planting site. The figure indicates that clone 3226 appeared to have the best performance among the five clones studied. At age 15, no significant difference in height was evident between the clones. Measurements of the total diametrical growth for 1995 indicated that clone 3226 was statistically better than the other clones. Clones 3225, 3230, and 3308 were comparable. Clone 131 showed the smallest growth as **Fig. 2** indicates. Among the experimental trees, clone 131 had the smallest diametrical growth as **Fig. 3** shows. Other clones were similar.

Figure 4 shows the variation in growth-ring width of the sample trees. The figure generally reflects the observation discussed above. Clone 131 again showed the smallest annual ring growth. The growth-ring width decreased gradually with age to produce narrower rings. Note the existence of three pronounced peaks in

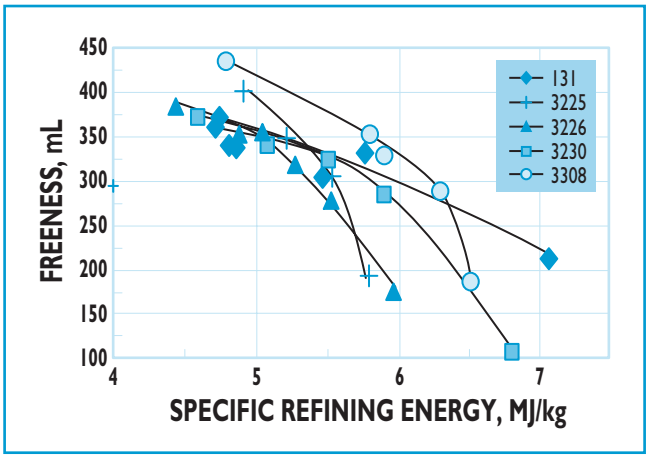


5. Variation in wood density of sample trees

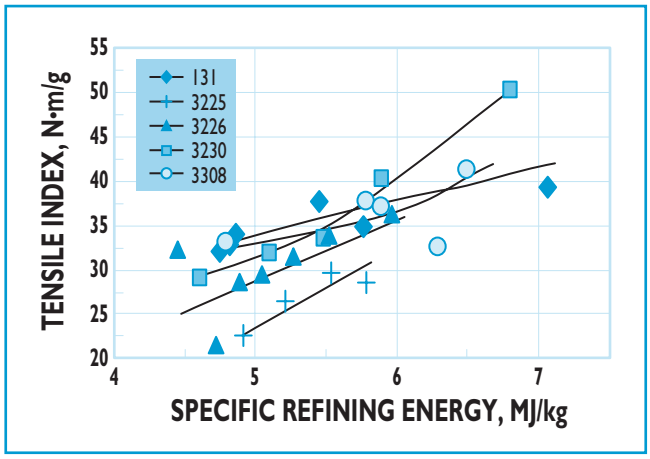
growth-ring width that were due to the selective thinning operations.

Wood properties

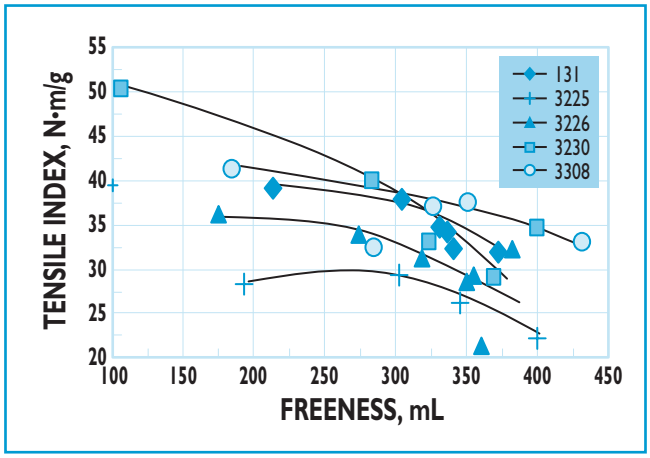
Chemical composition. The clones had similar lignin content between 22.55%–23.04%. This was 4–5 percentage points higher than that for aspen as **Table II** shows. The high lignin content could have significant impact on



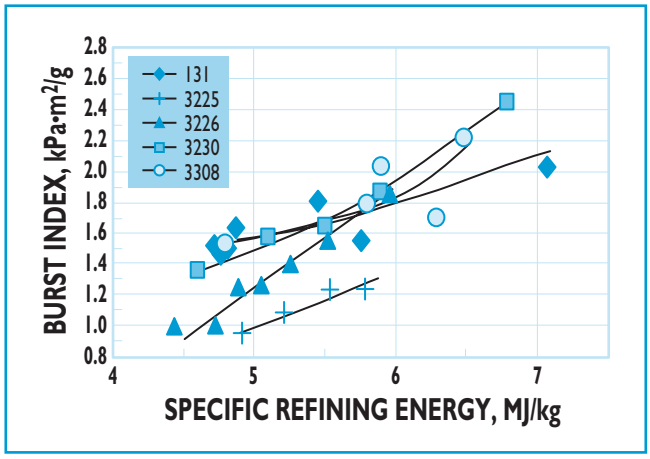
6. Pulp freeness as a function of refining energy



7. Tensile index vs. refining energy



8. Tensile index vs. freeness



9. Burst index vs. refining energy

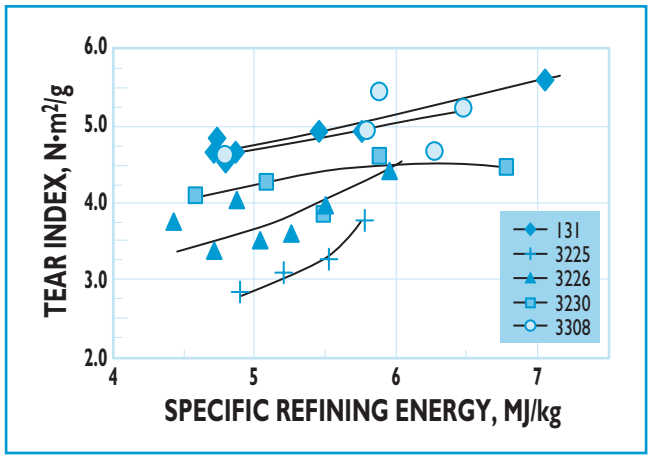
refining and paper properties of the clones. Compared with aspen, the hybrid poplars showed low dichloromethane (DCM) extractives at 0.61%–0.79% except clone 3308 that had 1.31%. They were comparable in other constituents.

Density. Wood density values in **Fig. 5** measured by X-ray densitometry decreased with increasing age. This observation agrees with the findings of recent reports *(11,12)*. The total density varied from about 0.29 to 0.40 g/cm^3. This is in the range reported in the literature *(12–16)*. Note that clones 3225 and 131 had the lowest density, clones 3230 and 3308 had the highest density, and clone 3226 fell between.

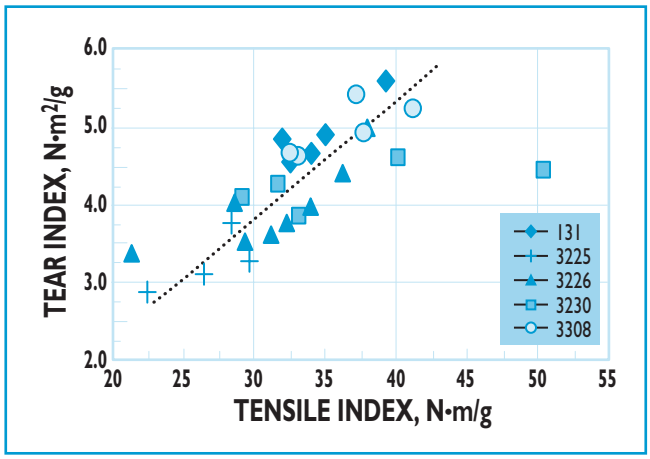
Fiber morphology. The length weighted fiber length varied from 0.81 to 0.92 mm as **Table III** shows. Most clones were comparable in fiber length at 0.81–0.85 mm except clone 3308 that had 0.92 mm. This is about 10% shorter than that for aspen. Koubaa *et al. (17)* reported that clones, heights, and the position of annual rings from pith had significant effects on the average fiber length.

Fibers of clones 131, 3226, and 3308 had comparable wall thickness with a value of 1.88–1.98 µm. This is thinner than the values of clones 3225 and 3230 at 2.25 µm. The latter value was comparable to those of aspen. The fiber coarseness ranged from 0.103 for clone 131 to 0.140 mg/m for clone 3225. Cell wall thickness and coarseness are valuable indicators of fiber quality. They are inadequate for completely characterizing fiber quality since fibers having similar wall thickness can have very different coarseness or vice versa. Conformability or collapsibility of fiber is an important factor determining fiber bonding potential. The collapsibility depends on wall thickness and diameter. Collapse pressure of a thin-wall cylinder is proportional to $(T/D)^3$ (18) where T is the wall thickness of the cylinder and D is the external diameter. We used this term here to express the rigidity of fibers arbitrarily. As Table III shows, clone 3225 had the greatest rigidity index. Clone 3308 had the lowest value. The differences in rigidity index might indicate the interfiber bonding potential of fiber.

Note that clones 3225 and 3226 showed an especially high proportion at 21.53%–25.52% of very short cells that were primarily parenchyma



10. Tear index vs. refining energy



11. Tear index vs. tensile index

cells. Clones 131 and 3230 had only 14.50%–16.75%. This is comparable to that for aspen. The presence of large amounts of very short cells could adversely influence the paper strength due to their low bonding capacity and propensity to cause linting. In a study on poplar species, Lehto *(13)* reported very low fines content of 0.2%–1.5% determined by a Kajaani analyzer.

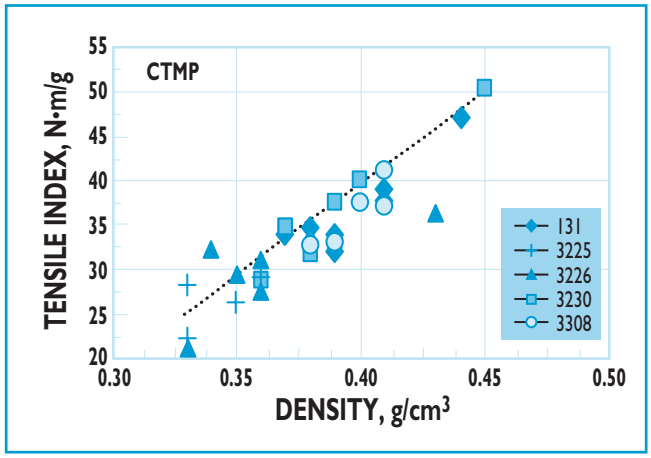
Pulp properties

Freeness. As **Fig. 6** shows, the clones had noticeable differences in the rates of freeness reduction as a function of refining energy. Clones 3225 and 3226 showed the most rapid drop in freeness, clones 131 and 3308 had the most gradual drop, and clone 3230 fell between. The rates in freeness reduction were probably associated with the rigidity index of fibers as Table III indicates. Fibers having higher rigidity exhibited a faster drop in freeness during refining. In all cases, the energy consumption for a freeness of 250 mL was low at less than 7 MJ/kg compared with that reported by Petit-Nonil *et al. (14)*. Richardson and Jones *(15)* obtained high aklaline peroxide mechanical pulping (APMP) refining energy of 7.2 MJ/kg at 400 mL freeness. The chemical charge used and the type of material used can significantly influence the energy requirement *(13–15)*.

Tensile strength. Clones 3225 and 3226 that had the highest fines and the greatest rigidity index as Table III showed gave the poorest tensile performance evident in **Fig. 7**. The other clones that had lower rigidity index values performed better at 40–50 N•m/g particularly with an energy consumption of 6–7 MJ/kg. Other workers have reported poor tensile strength from polar clones *(13,14)* ranging from about 14–35 N•m/g. The plot of tensile index as a function of freeness in **Fig. 8** confirms the inferior tensile strength of pulps produced from clones 3225 and 3226.

Burst index. As observed in the tensile index-energy relationships, practically all clones exhibited similar burst index. Clones 3225 and 3226 did give lower burst index for a given specific energy consumption as **Fig. 9** shows.

Tear index. Clones 3225 and 3226 showed particularly poor tear in **Fig. 10**. Clones 131 and 3308 had the best tear index. This also indicates the inferiority of the former clones.



12. Tensile index vs. handsheet density

Tear and tensile relationship. As indicated in **Fig. 11**, tear and tensile index values of the pulps were linearly correlated. The clones that produced pulps with low tensile index such as 3225 and 3226 also gave poor tear index.

Tear and density relationship. Sheet density is a valuable indicator of bonding potential for a fiber. Bulky sheets with low density yield low fiber bonding resulting in decreased tensile strength as **Fig. 12** shows. Clones 3225 and 3226 produced sheets with low density and inferior tensile strength. This is probably due to the morphological characteristics of these clones that had high fines and rigidity index.

Brightness. The clones studied produced pulps with similar unbleached brightness at 50%–52% ISO. They also showed comparable response to hydrogen peroxide treatment by attaining a brightness of 66% with 3% peroxide charge.

CONCLUSION

For growth, clone 3226 had the best performance, clone 131 had the least performance, and the other clones fell between. Clones 3225 and 3226 had higher percentages

of fines (cells < 0.2 mm), and their fibers showed a greater rigidity index. As a result, these two clones yielded inferior strength properties. The other clones gave good physical properties. All clones exhibited similar optical properties and peroxide bleaching response.

Considering their fast growth, these hybrid poplars and especially clones 131, 3220, and 3308 are an excellent source of raw material for mechanical pulping. Due to their young age, these trees have high proportions of juvenile wood that contains short fibers. Optimum blending of these fibers with some long fiber species would be necessary to produce paper with enhanced quality. **TJ**

Law is senior research associate, Rioux is graduate student, and Valade is adjunct professor at Pulp and Paper Research Center, University of Quebec in Trois-Rivieres, P. O. Box 500, Trois-Rivieres, Quebec, Canada G9A 5H7. Valade is adjunct professor in Department of Chemical Engineering at the same school.

Received for review March 2, 1998.
Accepted Oct. 22, 1998.

Acknowledgment: The authors thank Dr. Gilles Valle of the Ministry of Natural Resources of Quebec for providing the sample trees and information relating to the experimental plantation and Dr. Tony Zhang of Forintek Canada Corp. for sharing some basic wood quality data. Thanks are also due to Robert Lanouette and Alain Marchand for their skillful work on refining and pulp characterization.

LITERATURE CITED

1. McLaren, J. A, *Pulp Paper Intl.* 38(4):41(1996).
2. McNutt, J. A. and Rennel, J., *Pulp Paper Intl.* 39(1):34(1997).
3. Arnold, R. B., *Pulp & Paper* 69(4):135(1995).
4. Christiansen, L., *Timber Harv.* 40(2):22(1992).
5. Menetrier, J. and Gobheil, J., *Preprint of the Annual Meeting of the Poplar Council of Canada*, Poplar Council of Canada, Toronto, 1995, p. 107.
6. van Oosten, C., *Preprint of the Annual Meeting of the Poplar Council of Canada*, Poplar Council of Canada, Toronto, 1995, p. 123.
7. Koncel, J., *PIMA's North American Papermaker* 80(1):51(1998).
8. Valle, G., Roche, H., and La Barre, C., *Recherche et Dveloppement sur le Peuplier dans la Region de l'Est-du-Quebec. V-Rentabilite de 13 options d'Amenagement de Plantations*, Ministere des Ressources naturelles du Quebec, Montreal, 1975, pp. 1–115.
9. Valle, G., *Liste des Clones recommandes selon les Regions ecologiques forestieres du Quebec et Exemples de Production ligneuses obtenues avec ces Clones. Notice d'Information*, Ministere des Ressources naturelles du Quebec, Direction de la Recherche forestiere, Montreal, 1995, pp. Inclusive pages cited ??.
10. Valle, G., *Preprint of the Annual Meeting of the Poplar Council of Canada*, Poplar Council of Canada, Toronto, 1995, p. 89.
11. Goyal, G., Fisher, J., Krohn, M., *et al.*, *TAPPI 1997 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 857.
12. Cisneros, H. A., Belanger, L., Watson, P. A., *et al., TAPPI 1996 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 675.
13. Lehto, J. and Oy, K., *International Mechanical Pulping Conference Proceedings*, CPPA, Montreal, 1995, p. 9.
14. Petit-Conil, M., Chantre, G., and de Choudens, C., *International Mechanical Pulping Conference Proceedings*, CPPA, Montreal, 1995, p. 1.
15. Richardson, J. D. and Jones, T. G., *APPITA* 50(1):34(1997).
16. Koubaa, A., Hernandez, R., Beaudoin, M., *et al., Wood Fiber Science* 30(1):40(1998).
17. Vidosic, J. P., *Mark's Standard Handbook for Mechanical Engineers*, McGraw-Hill, New York, 1978, pp. 5–16.