

# PHYSICAL PROPERTIES OF KRAFT PULP FROM FOUR-YEAR-OLD ASPEN HYBRIDS AND CROSSES

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## ABSTRACT

Short-rotation forestry and species hybridization offer acceptable raw materials for pulp and paper production. Poplars (*Populus sp.*) are the most promising materials because of their fast growth rates and their suitability for pulp. The objectives of this study were to determine the kraft pulp properties of three new aspen hybrids and crosses and to compare these properties with those of other poplars. We used *Populus alba* × *Populus tremula*, *Populus alba* × *Populus alba* Bolleana, and *Populus alba* × *Populus grandidentata*. Results indicated that the *P. alba* × *P. tremula* hybrid was most suitable for pulp production. Handsheets made from the *P. alba* × *P. tremula* hybrid had greater burst and tear strengths and a comparable tensile index compared with those of the kraft pulps of other juvenile poplars. Results suggest that *P. alba* × *P. tremula* is a promising hybrid for pulp production.

**Keywords:** Aspen hybrids and crosses, kraft pulp, specific gravity, fiber length.

## INTRODUCTION

The demand for high quality pulpwood is

rising dramatically. A USDA Forest Service report (Haynes et al. 1995) has projected that consumption of pulpwood will increase about 0.7% annually over the next five decades. This increased demand for pulpwood is not likely to be met by acquiring new forest lands be-

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cause forestry is competing with other land uses due to global population growth. Pulpwood production can be increased without acquiring more land through tree improvement and intensive cultural practices. Intensive forestry practices, especially short-rotation intensive culture, are being considered as a means to provide dependable, high-quality pulpwood supplies in the future.

Poplars consist of two distinctive species groups, the cottonwoods and aspens. Cottonwoods are extremely fast growing and have low wood density. Aspens are slower growing and have denser wood than cottonwoods. The cottonwood hybrids, commonly referred to as hybrid poplars, have been widely planted throughout the world, whereas aspen hybrids have been rare.

Poplars were chosen for intensive management, biomass energy, and pulp production primarily because of their fast growth rates. In the past four decades, numerous studies have been conducted to investigate the wood and pulping characteristics of many aspen species and hybrids. Einspahr *et al.* (1968) compared wood properties of 5-year-old triploid aspen hybrids, triploid, and diploid plantation-grown aspen trees. They found that the triploid hybrids had faster growth rates, higher wood specific gravities, and longer fibers than the triploid and diploid trees. Zarges *et al.* (1980) also studied several short-rotation intensive culture cottonwood hybrids and found a wide variation in specific gravity and fiber length among them.

Juvenile poplars have shorter fibers and lower specific gravity than those of mature trees. Silvicultural management for young poplars also has been studied intensively. Holt and Murphey (1978) found that plant spacing did not affect properties of juvenile cottonwood hybrids. Snook *et al.* (1986) also studied some cottonwood hybrids grown under four management strategies on different sites and found little differences in biomass yield and pulp properties. They suggested that short-rotation intensive culture poplars should be grown to the highest biomass yield at the low-

est possible cost. Studies have shown that chemical pulps from short-rotation intensive culture poplars have acceptable burst and tensile strengths and only slightly lower tear strengths than do pulps from mature poplar trees (Einspahr *et al.* 1970; Hunt and Keays 1973; Sierra-Alvarez and Tjeerdsama 1995).

The opportunity for the present study arose when a number of experimental aspen hybrids and crosses became available from the tree improvement research programs at Iowa State University. The objective of this study was to determine the kraft pulp properties of these new materials, and to compare their properties with the properties of other poplar hybrids.

#### MATERIALS AND METHODS

##### *Plant material*

Three trees from each of three aspen hybrids or crosses were selected for this pulping study. These materials, grown near Moingona, Iowa, were the result of the following crosses: *Populus alba* × *Populus tremula* (1XAE91), *Populus alba* × *Populus alba* Bolleana (21XAA91), and *Populus alba* × *Populus grandidentata* (9XAG91). The origin and growth characteristics of the parents of these hybrids are given in Table 1. Trees were grown from seedlings and planted at 5-m by 5-m spacing, and most trees had two or three main stems. Trees were harvested in spring, 1996, at age 4 years. Stems up to 2.5-cm diameter tops were debarked manually and cut into 2.2-cm-thick disks with a bandsaw. After air-drying, disks were cut into chips about 2.2 cm long, 1.6 cm wide, and 0.3 cm thick. Knots that could not be chipped properly were discarded.

##### *Specific gravity and fiber length*

The wood specific gravity was determined from the oven-dry weight and green volume measurements. Twenty random wood chips from each sample were immersed in distilled water and treated with a vacuum (30 min at 30 in. Hg) and pressure (30 min at 90 psi) cycle, followed by measuring the green vol-

TABLE 1. *Origin and growth characteristics of 4-year-old hybrid aspens studied.*

Family designation	Parents	Average height (cm)	Average taper	Average volume (cm <sup>3</sup> )	Survival (%)
1XAE91	A-2-66 × E-120	439	0.0089	1863	95
21XAA91	A-502 × Bolleana	437	0.0088	1957	100
9XAG91	PCA-2 × Bt-016	298	0.0103	1159	76

Parents:

Female A-2-66: *Populus alba*, from I.P.C. Planting at the old PCA nursery. This clone originates in Czechoslovakia.

Male E-120: *Populus tremula*, no other information is available.

Female A-502: *Populus alba*, originally from Italy as I 58/57.

Male Bolleana: *Populus alba*, ornamental clone was selected for its upright (fastigate) branching

Female PCA-2: *Populus alba*, selection was made in the plantings of Packing Corporation of America near Traverse City, MI.

Male Bt-016: *Populus grandidentata*, this parent was used in MSU's 1982 plantings of aspen material. This clone located near Gainesville, MI (south-central lower Penn).

ume of each chip by the water displacement method. Chips then were oven-dried at  $103 \pm 2$  °C. There were three replications of this test. Fiber length measurements were made on un-beaten pulp fiber. Nine slides were prepared with 50 fibers per slide per tree.

#### *Kraft pulping*

Three 600-ml stainless steel canisters were used for pulping. Each of these canisters could pulp about 70 g of air-dried wood chips. Canisters were heated in an oil bath with constant rotation during pulping. Kraft pulping was done under the following conditions: 17.5% active alkali, 25% sulfidity, 4:1 liquor-to-wood ratio, 90 min to maximum temperature of 170°C from a preheated temperature of 120°C, and 90 min at the maximum temperature. After pulping, the canisters were withdrawn from the oil bath, and pulp was disintegrated in the standard disintegrator for 500 counts. Thoroughly washed pulp was made into thick mats with a handsheet machine, and these mats were cold-pressed between two stainless steel screens to about 35% consistency and stored in a refrigerator in a plastic bag. The Kappa number of pulp samples was determined in accordance with TAPPI Standard T236 cm-85.

#### *Handsheet properties*

Pulp beating was done with a PFI mill in accordance with TAPPI Standard T248 cm-85. The Canadian Standard freeness (CSF) of pulp samples was measured at intervals, and beating was terminated when the freeness reached about 400 ml. TAPPI Standards were used for forming handsheets (T 205 om-88) and physical testing of pulp handsheets (T220 om-88).

#### *Data analysis*

Data were analyzed by General Linear Methods (GLM) procedure of SAS Institute Cary, N C (1987). The Scheffe's test in the General Linear Methods was used to conduct the contrast test. Means different from one another with a  $P < 0.05$  were identified. Completely randomized design was applied for the experiments.

#### RESULTS AND DISCUSSION

##### *Wood specific gravity and fiber length*

Specific gravity varied among families and trees (Table 2). There were significant differences in the specific gravity in all three aspen families, with the 1XAE91 family having the greatest specific gravity (0.366) and the 9XAG91 the lowest (0.327). Specific gravity values of the three trees in the 1XAE91 family

TABLE 2. Selected wood properties, specific gravity and fiber length, and kraft pulping characteristics, pulp yield and kappa number, of hybrid aspen families IXAE91 (Populus alba × Populus tremula), 21XAA91 (Populus alba × Populus alba Boiteana) and 9XAG91 (Populus alba × Populus grandidentata).

Properties	Hybrid family											
	IXAE91			21XAA91			9XAG91			Mean		
	Tree1	Tree2	Tree3	Tree1	Tree2	Tree3	Tree1	Tree2	Tree3	Tree1	Tree2	Tree3
Specific gravity	0.368	0.373	0.358	<b>0.366</b> A <sup>1</sup>	0.325	0.418	0.318	<b>0.354</b> B	0.291	0.339	0.352	<b>0.327</b> C
Fiber length (mm)	0.912	0.897	0.927	<b>0.912</b> A	0.882	0.904	0.892	<b>0.893</b> B	0.892	0.878	0.888	<b>0.886</b> B
Pulp yield (%)	52.80	52.98	53.06	<b>52.90</b> B	54.54	54.77	54.50	<b>54.60</b> A	52.52	54.80	54.28	<b>53.90</b> AB
Kappa number	16.8	16.3	16.4	<b>16.5</b> A	15.1	13.0	16.1	<b>14.7</b> B	15.6	14.8	15.6	<b>15.3</b> B

<sup>1</sup> Means within a row with common letters are not different from one another at the 95% confidence level.

were relatively uniform and varied by only 4.02%, whereas those values in the 21XAG91 family varied by 23.92%. Tree 2 of the 21XAA91 family had the greatest (0.418) and tree 1 of the 9XAG91 family had the lowest specific gravity (0.291), a 30% variation. The cause of this large variation in specific gravity between these two trees was not investigated. However, the fact that tree 2 of the 21XAA91 family had an exceptionally low Kappa number 13.0 may suggest a correlation between the presence of tension wood and high specific gravity.

When compared to specific gravity values reported for other short-rotation intensive culture poplars (Zarges et al. 1980; Stevens et al. 1983), the wood specific gravity of tree 2 of the 21XAA91 family is relatively high and the average value for the 1XAE91 family falls in the mid-range (between 0.330 to 0.405). Stevens et al. (1983) also found a wide range of variation in wood specific gravity among poplars.

The 1XAE91 family had a longer average fiber length (0.912 mm) than the other two families (0.893 mm and 0.886 mm, Table 2). Fiber length variation in the three aspen families, however, was only 2.85%. The composite average fiber lengths of the three aspen families are greater than the values reported for other short-rotation intensive culture poplars ranging from three to five years of age (Zarges et al. 1980; Snook et al. 1986). Based on the greater specific gravity and fiber length values, uniformity in these wood properties, and a fast growth rate, the 1XAE91 hybrid seems to be more suitable than the 21XAA91 and 9XAG91 families for pulp production.

### Kraft pulping

No difficulties were encountered pulping these short-rotation intensive culture materials with the pulping conditions used. Because wood chips were pulped thoroughly, and there were no apparent rejects, pulp properties were determined on unscreened pulps. The 1XAE91 family had a lower pulp yield (52.9%) than

the 21XAA91 family (54.6%) and a similar pulp yield to the 9XAG91 (53.9%) family (Table 2). Pulp yield values, based on debarked chips, are similar to values reported for other short-rotation intensive culture poplars pulped to a comparable Kappa number (Table 3). The kraft pulps from the three aspen families had Kappa numbers lower than 17, which is considered a level of delignification common for bleachable grade hardwood kraft pulps. Adequate pulp yields combined with an adequate degree of delignification indicated that these aspen hybrids and crosses are suitable for kraft pulping.

Keays and Hatton (1972) have shown that the maximum yield of kraft pulp from mature trembling aspen at a Kappa number 14.5 to 21 could be obtained with a suitable combination of a low amount of effective alkali (11%) and less than 60 min of cooking time at 170°C. Laundrie and Berbee (1972) also found that whole-tree chips of 3-year-old hybrid poplar required 14.2% effective alkali, while the debarked stemwood chips consumed only 12.5% effective alkali to obtain kraft pulps with a Kappa number of 20. Juvenile poplar wood frequently is known to contain a considerable amount of tension wood rich in cellulose and low in lignin. Such wood requires less pulping than more mature wood to reach the same level of delignification. Therefore, 17.5% effective alkali and 90 min at 170°C used in this study for 4-year-old hybrid aspens can be reduced considerably, making pulping of hybrid aspens more economical.

#### *Handsheets properties*

Sheet density was inversely correlated to wood specific gravity ( $r^2 = 0.820$ ), and pulp freeness was positively correlated to wood specific gravity ( $r^2 = 0.843$ ). Tree 2 of hybrid 21XAA91 had the highest specific gravity (0.418) (Table 2), highest pulp freeness (650 ml), and lowest sheet density (0.722), whereas tree 1 of hybrid 9XAG91 had the lowest specific gravity (0.291), lowest pulp freeness (550

ml), and second highest sheet density of 0.815 (Table 3).

Although specific gravity was correlated to sheet density and pulp freeness, there was no relationship between fiber length and the freeness, or between fiber length and the sheet density of pulp. Because of the strong influence by specific gravity, a large variation in unbeaten sheet properties was observed in all nine trees (Table 3). Although there were differences in fiber length among the nine trees (Table 2), these differences were too small to cause any effects on pulp freeness and sheet density (Table 3). Therefore, for the hybrid aspen juvenile materials studied, specific gravity (cell-wall thickness) dominated the physical properties of unbeaten kraft pulps.

Unbeaten pulp strength properties were not correlated to specific gravity, although tree 2 of hybrid 21XAA91 with the highest specific gravity was 38%, 36%, and 28% lower in tensile, burst, and tear strength, respectively, than tree 1 of hybrid 9XAG91 with the lowest specific gravity.

After PFI milling to near 400-ml freeness, the dominance of handsheet properties by specific gravity diminished. Variation in handsheet properties among all nine trees observed in the unbeaten pulps also was very much reduced after beating. Also, the three aspen families had similar handsheet properties except tear strength after beating (Table 3).

The kraft pulps of these three aspen materials were easy to refine, and on average, it took 10,000 PFI resolutions to reduce the pulp freeness from 620 ml to 400 ml (Table 3). Tree 1 of hybrid 9XAG91 had the lowest specific gravity, and it took only 5000 PFI resolutions to reduce freeness from 550 ml to 400 ml. Tree 2 of hybrid 21XAA91 was particularly difficult to beat; the pulp had to be processed at about 12,000 PFI resolutions to reach a freeness of 400 ml. Difficulty in beating the pulp from tree 2 of hybrid 21XAA91 even though it had the lowest amount of residual lignin is a further indication of the presence of tension wood.

TABLE 3. CS freeness, density, tensile strength, burst strength, and tear strength of unbeaten and beaten kraft pulps from hybrid aspens IXAE91 (Populus alba × Populus tremula) 2IXAA91 (Populus alba × Populus alba Bolleana), and 9XAG91 (Populus alba × Populus grandidentata).

Properties	Family IXAE91				Family 2IXAA91				Family 9XAG91			
	Tree1	Tree2	Tree3	Mean	Tree1	Tree2	Tree3	Mean	Tree1	Tree2	Tree3	Mean
<b>Unbeaten Pulps</b>												
CS Freeness (ml)	635	630	590	<b>620</b> A <sup>1</sup>	570	650	590	<b>605</b> A	550	630	640	<b>605</b> A
Density (g·cm <sup>-3</sup> )	0.764	0.778	0.780	<b>0.774</b> A	0.782	0.722	0.825	<b>0.776</b> A	0.815	0.757	0.788	<b>0.787</b> A
Tensile Index (N·mg <sup>-1</sup> )	57.4	62.3	58.6	<b>56.1</b> A	58.4	43.6	64.8	<b>55.6</b> A	70.7	49.1	55.4	<b>58.4</b> A
Burst Index (kPa·m <sup>2</sup> ·g <sup>-1</sup> )	2.52	2.09	2.46	<b>2.36</b> A	2.75	2.09	2.46	<b>2.43</b> A	3.28	1.95	2.35	<b>2.53</b> A
Tear Index (mN·m <sup>2</sup> ·g <sup>-1</sup> )	6.26	5.13	5.70	<b>5.70</b> A	5.27	4.81	5.91	<b>5.33</b> A	6.15	4.63	5.11	<b>5.30</b> A
<b>Beaten Pulps</b>												
PFI Revolutions	9500	11100	11500		60000	11800	8100		4000	11100	11100	
CS Freeness (ml)	402	380	404		393	406	385		406	369	383	
Density (g·cm <sup>-3</sup> )	0.880	0.888	0.908	<b>0.892</b> A	0.945	0.799	0.915	<b>0.886</b> A	0.915	0.868	0.839	<b>0.874</b> A
Tensile Index (N·mg <sup>-1</sup> )	91.1	78.9	80.2	<b>83.4</b> A	78.5	68.1	69.8	<b>72.1</b> A	79.6	65.7	83.7	<b>76.4</b> A
Burst Index (kPa·m <sup>2</sup> ·g <sup>-1</sup> )	7.12	5.85	6.96	<b>6.64</b> A	5.95	4.84	6.37	<b>5.72</b> A	5.98	4.94	5.17	<b>5.36</b> A
Tear Index (mN·m <sup>2</sup> ·g <sup>-1</sup> )	8.72	8.32	8.73	<b>8.61</b> A	7.67	8.21	8.18	<b>8.02</b> AB	7.81	7.29	7.96	<b>7.69</b> B

<sup>1</sup> Means within a row common with common letters are not different from one another at the 95% confidence level.

*Comparing the aspen hybrids with other poplar hybrids*

Because the 1XAE91 family had the most desirable properties of the three aspen families, we compared it with other poplar hybrids (Table 4). Selection of references from the literature was based mainly on ages of the materials and similarity in pulping and pulp refining conditions.

Mature cottonwoods and aspens have an average specific gravity of about 0.36 (Wood Handbook 1987) and an average fiber length of about 1.35 mm (Panshin and de Zeeuw 1980). Hybrid 1XAE91 had an average wood specific gravity of 0.366, which was about the same as that in mature trees and in the mid-range of values reported for some juvenile poplars (Einspahr et al. 1968; Zarges et al. 1980). The mean fiber length of 0.912 mm in the stemwood of hybrid 1XAE91, however, is much longer than values from 0.477 to 0.655 mm reported by Einspahr et al. (1968) and longer or similar to values from values (0.690 to 0.920 mm) reported by Zarges et al. (1980). The 52.9% pulp yield of hybrid 1XAE91 was 4.6% less than that of a mature aspen (Hunt and Keays 1973) but was similar to or greater than those of other juvenile poplars (Laundrie and Berbee 1972; Phelps et al. 1985; Zarges et al. 1980). The pulp from mature aspen, however, is 4 units higher in Kappa number than that of pulp from hybrid 1XAE91 (Table 4).

The pulp from hybrid 1XAE91 had the greatest tear strength values compared to other poplars (Table 4). The burst strength of 1XAE91 pulp was 26% greater, but the tensile strength was 29% lower than those of a mature aspen. The tensile strength of 1XAE91 pulp was slightly lower (4%) than that of 6-year-old hybrid (Phelps et al. 1985), but it was 45% greater than 3-year-old hybrid (Snook et al. 1986). The tensile strength of 1XAE91 pulp would be considered acceptable compared with those of the other reported short-rotation intensive culture poplars ranging from 3 to 6 years of age (Table 4). Strength properties of

TABLE 4. Comparison of properties of kraft pulps from other hybrid poplars from the previous literature with hybrid aspen 1XAE91 (*Populus alba* × *Populus tremula*).

Pulp sources	Specific gravity	Fiber length (mm)	Pulp yield (%)	Kappa number	CS freeness (ml)	Tensile index	Burst index (kPa·m <sup>2</sup> ·g <sup>-1</sup> )	Tear index (mN·m <sup>2</sup> ·g <sup>-1</sup> )	Reference
4-year-old hybrid (1XAE91)	0.366	0.912	52.9	16.5	400	83.4	6.64	8.61	Current study
3-year-old hybrid (NE-388)		0.717	48.6	17.7	400	46.1	2.42	5.59	Snook et al. 1986
5-year-old hybrid ( <i>P. alba</i> × <i>P. euramericana</i> )			48.8	18.3	350	116.7	7.54	6.86	Laundrie and Berbee 1972
5-year-old hybrid (NC-5332)	0.350	0.670	52.0	16.7	400	104.9	6.67	6.66	Zarges et al. 1980
6-year-old trembling aspen			55.0	21.1	300	113.7	5.59	6.66	Hunt and Keays 1973
6-year-old hybrid ( <i>P. tristis</i> No. 1 <sup>1</sup> )	0.350	0.700	48.0	18.4	235	87.3	6.20	6.10	Phelps et al. 1985
7-year-old trembling aspen	0.393		54.0	18.0	300	95.1	5.70	7.15	Bella and Hunt 1973
11-year-old hybrid ( <i>P. alba</i> × <i>P. euramericana</i> )		0.840	52.8	18.2	350	124.5	8.50	8.86	Laundrie and Berbee 1972
53-year-old aspen			57.3	20.5	300	107.8	4.93	8.52	Hunt and Keays 1973

pulps from 21XAA91 and 9XAG91 were not much lower than those of hybrid 1XAE91, and therefore would be ranked high if listed in Table 4.

#### CONCLUSIONS

All trees from the three experimental aspen hybrids and crosses produced high quality kraft pulps. Based on strength properties of kraft pulps, hybrid 1XAE91 ranked first, closely followed by 21XAA91 and 9XAG91. From the point of view of a wood scientist, the breeding of hybrid 1XAE91 is a success. These 4-year-old aspen hybrid trees produced uniform and desirable wood properties for pulp and paper production. Because use of short-rotation intensive culture materials for pulp and paper production is considered most economical at a rotation age between 10 and 15 years, a pulping study should be conducted when these trees reach that age.

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