Effect of Incorporating Chinese Poplar in Wood Chips on Fiber Refining

Jun Hua
Guangwei Chen
Sheldon Q. Shi

Abstract

Poplar is a fast-growing, short-rotation species that has become a feedstock for pulping and for different composite wood products, such as fiberboard and particleboard. Because of the short rotation, unique characteristics, such as high content of juvenile wood, are present. The objective of this research was to investigate the effects that incorporating poplar in wood chips has on the resultant fiber quality and on fiber-refining energy consumption. Two different quantities of Chinese poplar (*Populus lasiocarpa* Oliv.) chips were separately mixed into wood chips consisting of a mixture of larch (*Larix* Mill.) and Masson pine (*Pinus massoniana* Lamb.). The mixed wood chips went through the refining process in a local medium-density fiberboard mill and refining parameters/conditions, energy consumption, and fiber size were examined at the production site. The results showed that the incorporation of poplar played a favorable role in terms of the fiber size and energy consumption. The higher the poplar content, the better the fiber quality and the lower the energy consumption during refining.

The manufacturing process of medium-density fiberboard (MDF) includes generation of wood chips, preheating (steaming) and refining of wood chips, fiber drying, and hot pressing. Refining is one of the crucial steps in regard to product quality and energy consumption. During the refining process, wood chips are first heated with steam in a heater, and then put through a mechanical breakdown process using two refining disks in the refiner. The chips are pushed into the center of the refiner and moved toward the periphery by centrifugal force as the disk rotates. The chips are first split into matchstick-like material, and then into more slender pin chips, larger fiber bundles, smaller bundles, and finally into separate fibers (May 1973).

A model of thermal energy consumption in MDF production was developed by Li et al. (2007a), from which the effects of various production capacities, product grades, operation times, refiner efficiencies, and fiber drying methods on the thermal energy consumption and distribution could be predicted.

The size of the refined fiber is one of the most important factors affecting the quality of MDF. If the fiber size is too large, it results in a poor board appearance, but if it is too small, the strength of the boards is reduced. Strand and Mokvist (1989) investigated the reduction of chip size during the refining process. Based on the comminution theory, they derived a mathematical model describing the reduction of each chip size as a function of impact intensity and chip strength.

The relationship between the mechanical properties of wood species and the mechanical pulping outcome was studied by Eskelinen et al. (1982). Two dynamic wood testing methods, which determined impact energy absorption and torsion pendulum, were used in the experiments. The results showed that a significant correlation existed between the energy consumption used for refining and the wood properties. Thus a property combining the transversal strength of wood and the energy absorption in failure was closely related to the fiber quality in mechanical pulping. No significant difference in impact energy with respect to the fracture direction (tangential, radial, or longitudinal) was found.

The effects of specimen thickness, tester gap, temperature, specific gravity, and moisture content on the impact strength of Norway spruce (*Picea abies*) were studied by Marton and Eskelinen (1982). The results revealed that the refining energy consumption was greatly affected by the chip thickness. For Norway spruce, the impact strength of cleavage was about a quarter that of forward shear. Thus it was suggested that changing the refining mode from shear to

The authors are, respectively, Professor and Graduate Assistant, College of Electromechanical Engineering, Northeast Forestry Univ., Harbin, China (huajun81@hotmail.com, gladiator429@yahoo.com.cn); and Assistant Professor, Forest Products Dept., Mississippi State Univ., Mississippi State (sshi@cfr.msstate.edu). This article was received for publication in January 2010. Article no. 10731.

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cleavage would be effective in reducing the energy consumption during refining.

The effect of impact velocity on the fracture of wood during refining was investigated by Berg (2001). The result confirmed that the size reduction of chips during refining was dependent on the refining intensity and the chip strength, which was affected by the fracture mode, impact direction, chip dimension, temperature, rate of deformation, etc. In this study, a falling weight impact tester was used. It was found that the increase in impact velocity from about 2.7 to 4.8 m/s resulted in an increase in impact strength of about 50 percent.

An analytical model was developed by Berg et al. (2009) to estimate the strain energy density required to defiberize the chips by uniaxial tension or shear load. The results illustrated that the energy consumption was dependent on the micro-fibril angle in the middle secondary wall layers, the loading direction, the thickness of cell wall layers, the fiber separation mode, moisture content, and temperature. The energy consumption for the fiber generated from earlywood was lower than that from latewood.

Some research has been conducted on incorporating short-rotation, fast-growing species into composite products. Su et al. (1995) tested wood chips from 2.5-year-old trees and from different growth periods of 9.5-year-old trees of white teak (*Gmelina arborea*) and compared their fiber morphology, chemical composition, kraft pulping behavior, and pulp properties. The results indicated that the younger wood gave higher pulp yields and had better properties due to the higher holocellulose content, lower lignin, and higher fiber strength.

The thermal conductivity, tension strength, compression strength, and formaldehyde content of insulating panels made from fast-growing willow tree (*Salix viminalis*) were examined by Frackowiak et al. (2008). The results showed that it was possible to make panels from chips obtained from willow to achieve comparable properties with panels made from conventional wood.

The properties of lignin in the fast-growing wood were investigated by Qian and McCarthy (1992). Compared with conventional cottonwood (*Populus trichocarpa* subsp. *trichocarpa*), lignin dissolved from the fast-growing hybrid *P. trichocarpa* × *P. deltoides* had a relatively low average molecular weight. However, no significant differences were found between the lignin of the cottonwood and its hybrid.

Poplar species are one of the most commonly planted tree species in China (Li et al. 2007b). There were about 6.67 million hectares of poplar plantations in 2006, accounting for 20 percent of the total timber plantations in the country. An area of 17 million hectares of planted poplar is expected by the year 2012. Poplar is a fast-growing species that can achieve a breast-height diameter of 40 to 60 cm in 20 years (Cheng et al. 1980). Poplar has been successfully used for plywood, dimension timber, pallets, and pulp/paper. However, few data are available on how this species would affect fiber quality for MDF fabrication.

The objective of this study was to investigate the effects that incorporating planted poplar in wood chips has on fiber-refining quality and energy consumption.

Materials and Methods

A 50-inch refiner with a 50SA002 tooth type was used in the experiment at a local MDF mill with an annual production of 150,000 m^3 in Northern China. The refiner, with a rated power of 2,500 kW, had two disks with a diameter of 1,270 mm and operated at 1,500 revolutions per minute. The information on the disks and teeth is presented in Table 1.

A common wood species mixture for MDF, larch (*Larix* Mill.), Masson pine (*Pinus massoniana* Lamb.), and Chinese poplar (*Populus lasiocarpa* Oliv.) was used in the experiments. To investigate the effect that incorporating poplar in wood chips has on the fiber size, two groups of wood chips, one with high poplar content (Group A) and the other with low poplar content (Group B), were tested. The poplar content in Group A chips was 42 to 47 percent, while the poplar content in Group B chips was 3 to 7 percent. The contents of the wood species for the chips were examined each day during the experiments. The refining conditions, such as steam pressure during preheating, the gaps between the two disks in the refiner, steam pressure at the entrance of the refiner, the power of the motor, and the screen mesh sizes of the fibers were determined every hour.

Based on industry practice, fiber screen mesh sizes between 20 and 120 are appropriate for the manufacture of MDF. Fibers larger than 20 screen meshes need to be further defiberized. Fibers smaller than 120 meshes have reduced fiber strength, resulting in downgraded MDF boards. Furthermore, the energy consumption is increased due to excess defiberization.

Results and Discussion

The results of the mill trial are shown in Tables 2 and 3. Each value in these tables represents the average of 20 determinations. Table 2 shows the quality of fibers obtained from chips in Group A under various production conditions. These data show that about 78 percent of fibers had mesh sizes of 20 to 120 (called good fibers in this article) when chips with 42 to 47 percent poplar were used.

Table 3 shows the quality of fibers obtained from chips in Group B. The production conditions used were the same as for Group A except for the motor power. The data showed that the proportion of good fibers was about 68 percent when 3 to 7 percent poplar chips were used.

A comparison of fiber quality from the two groups of chips is shown in Figure 1. Statistical analysis (ANOVA $\alpha = 0.05$) revealed a significant difference in fiber quality between Group A and Group B. As shown in Figure 1, and supported by the statistical analysis, the chips in Group A were more appropriate for refining compared with those in Group B (good fiber content of 78% for Group A vs. 68% for Group B). Comparing the motor power used for both groups during the refining process revealed that more power was used for Group B chips than for Group A chips (2,249 vs. 1,961 kW), suggesting that the chips in Group B required more energy to defiberize.

The characteristics of Chinese poplar, larch, and Masson pine were reviewed by Cheng et al. (1980), from which the

Table 1.—Information on the disk and teeth in the refiner.

Width of tooth (mm)	Width of groove (mm)	Height of tooth (mm)	Clearance angle of tooth (°)	No. of sections (pieces)	Internal diameter of disk (mm)
3.2	5.7	9.7	26	12	670

Table 2.—Fiber sizes made from chips with high poplar content (Group A).

Content of poplar (%)	Production conditions: Steaming pressure (MPa)	Gap between disks (mm)	Pressure of refiner (MPa)	Power of motor (kW)	% of fibers by screen mesh size: <20	20–120	>120	Notes
42	0.85	0.01	0.70	1,950	5.0	85.5	9.5	For 16-mm-thick boards
	0.85	0.01	0.68	1,970	5.1	80.9	14.0	
	0.81	0.01	0.64	1,800	4.9	83.7	11.4	
	0.85	0.01	0.67	1,770	5.5	82.5	12.0	
	0.85	0.01	0.67	1,700	3.2	81.2	15.6	
	0.85	0.01	0.68	1,800	5.3	82.5	12.2	
	0.85	0.01	0.67	1,130	7.0	83.5	9.5	
	0.85	0.01	0.67	1,300	3.8	81.5	14.7	
47	0.85	0.01	0.73	2,000	3.2	81.1	15.7	For 8-mm-thick boards
	0.85	0.01	0.73	2,050	8.2	75.3	16.5	
	0.85	0.01	0.71	1,900	8.7	71.3	20.0	
	0.85	0.01	0.76	2,350	8.5	69.5	22.0	
	0.85	0.01	0.73	2,370	9.9	72.3	17.8	
	0.85	0.01	0.77	2,400	8.5	72.9	18.6	
	0.85	0.01	0.76	2,480	7.5	71.6	20.9	
	0.85	0.01	0.77	2,400	9.3	70.2	20.5	
Avg	0.85	0.01	0.71	1,961	6.5	77.8	15.7	
SD	0.01	0.00	0.04	389.1	2.23	5.68	4.06	

physical and mechanical properties are summarized in Table 4.

Chinese poplar has low-density and low-strength properties. The tangential diameters for most tracheids of this species range from 80 to 105 μm, with an average diameter of 674 μm and a maximum diameter of over 126 μm. The average thickness of the cell walls is 3 μm, which is thinner than those of larch and Masson pine.

Larch wood has medium density and strength properties. The tangential diameters for most tracheids range from 35 to 50 μm, with a maximum diameter of over 60 μm. In earlywood, the tracheid length on the cross section is 4,535

Table 3.—Fiber sizes made from chips with low poplar content (Group B).

Content of poplar (%)	Production conditions: Steaming pressure (MPa)	Gap between disks (mm)	Pressure of refiner (MPa)	Power of motor (kW)	% of fibers by screen mesh size: <20	20–120	>120	Notes
3	0.85	0.01	0.73	2,415	11.6	68.9	19.5	For 9- and 12-mm-thick boards
	0.85	0.01	0.74	2,399	10.4	68.1	21.5	
	0.85	0.01	0.73	2,450	11.3	69.1	19.6	
	0.84	0.01	0.74	2,350	11.6	66.3	22.1	
	0.84	0.01	0.74	2,350	12.5	66.8	20.7	
	0.85	0.01	0.73	2,387	12.6	69.2	18.2	
	0.85	0.01	0.72	2,350	11.9	67.6	20.5	
	0.85	0.01	0.70	1,500	11.6	67.1	21.3	
5	0.85	0.01	0.73	1,750	13.3	65.3	21.4	For 4- and 9-mm-thick boards
	0.85	0.01	0.73	1,980	12.6	67.7	19.7	
	0.85	0.01	0.73	2,045	11.6	64.9	23.5	
	0.85	0.01	0.72	2,445	11.2	69.2	19.6	
	0.85	0.01	0.71	2,270	10.1	68.5	21.4	
	0.85	0.01	0.70	2,100	12.1	68.7	19.2	
	0.85	0.01	0.75	2,520	11.0	68.6	20.4	
	0.85	0.01	0.75	2,500	9.7	69.2	21.1	
7	0.85	0.01	0.72	2,200	10.3	68.6	21.1	For 6-mm-thick boards
	0.85	0.01	0.71	2,100	9.6	70.2	20.2	
	0.85	0.01	0.71	2,000	6.8	67.9	25.3	
	0.85	0.01	0.70	2,210	7.4	65.7	26.9	
	0.85	0.01	0.71	2,190	8.1	71.6	20.3	
	0.85	0.01	0.74	2,470	10.7	67.6	21.7	
	0.85	0.01	0.71	2,440	11.2	70.2	18.6	
	0.85	0.01	0.72	2,556	10.4	68.6	21.0	
Avg	0.85	0.01	0.72	2,249	10.8	68.2	21.0	
SD	0.003	0.00	0.01	258.15	1.62	1.59	1.96	

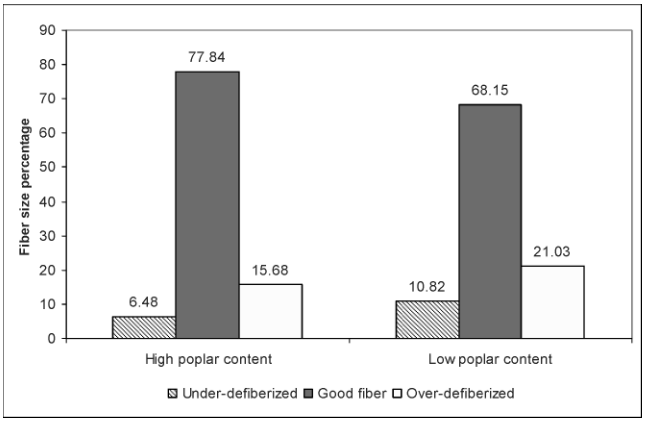

Figure 1.—A comparison in fiber quality from the chips with high and low poplar content.

Table 4.—Some physical and mechanical properties of the three species used in the experiments (Cheng et al. 1980).

Species	Basic density (kg/m^3)	Modulus of rupture (MPa)	Modulus of elasticity ($\times 10^3$ MPa)	Compression strength parallel to grain (MPa)
Chinese poplar	390	64	9.6	35
Larch	458	75	10.2	39
Masson pine	510	88	11.6	45

μm with diameters ranging from 21 to 27 μm. In latewood, the tracheid length on the cross section is 4,934 μm with diameters ranging from 8 to 12 μm.

Masson pine wood has properties of medium density and high strength. The tangential diameters for most tracheids range from 45 to 65 μm, with a maximum diameter of over 72 μm. In earlywood, the tracheid length on the cross section is 4,032 μm with diameters ranging from 20 to 28 μm. In latewood, the tracheid length on the cross section is 4,512 μm with diameters ranging from 7 to 13 μm.

The following list summarizes the structural differences for the three species.

1. Poplar has a lower strength compared with larch and Masson pine, which would contribute to lower power consumption and better fiber quality during refining. Berg et al. (2009) stated that the energy consumption for fiber refining of earlywood was less than that for latewood. It is well known that the fiber strength and density of earlywood are lower than those of latewood.
2. The fibers of poplar have thinner cell walls than the tracheids of larch and Masson pine. Thinner cell walls provide less resistance against the impact forces, causing them to be more easily separated and leading to lower energy consumption and better fiber quality for poplar. Berg et al. (2009) also indicated that the energy consumption was affected by the thickness of the cell walls.
3. The fibers of poplar are shorter in length and greater in diameter compared with those of larch and Masson pine. Since the forces acting on the chips are believed to arise mostly from compression and shear (Marton and Eskelinen 1982), cells in poplar will be easier to separate due to their greater diameters. This can also play a role in improving the process of defiberization and enhancing fiber quality.

Conclusions

The effects that incorporating planted Chinese poplar in a mixture of larch and Masson pine has on fiber quality and energy consumption during the refining process were investigated. The results showed that incorporation of poplar in the wood chip favorably affected fiber quality and energy consumption during the fiber-refining process. Wood chips with higher poplar content yielded higher quality fibers and consumed less energy during refining. This could be attributed to the lower density and strength properties, thinner cell wall, shorter length, and greater diameter of tracheids of poplar compared with larch and Masson pine.

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