Fundamental Study on Whole-Tree Pulping of *Pinus densiflora*

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アカマツ各部位のパルプ化に関する基礎的研究

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Résumé

In order to accumulate the fundamental data related to whole-tree utilization, a pulping study was made on each component from a tree of Akamatsu (*Pinus densiflora* Sieb. et Zucc.) in view of wood elements-sheet property relation. Pulps from juvenile wood in the bole as well as wood zone in the branches having more than 2 cm in diameter offered handsheets comparable to those of mature wood in the bole, while handsheets from the small branches and the bark had considerably low tear factor but high in breaking length. On the outer bark, it was found that phelloid cells are difficult to defibrate, and that the presence of their clump causes some defects in papermaking such as white spots and week points into the sheets.

要　　旨

林木の全体利用に関するデータを蓄積する目的で，アカマツ各部位のパルプ化試験を行い，材の構成要素と紙質の関係を追究した。樹幹の未成熟材部および直径 2 cm 以上の枝の材部からのパルプは樹幹の成熟材部のそれに匹敵するシートを与える一方，細枝および樹皮のシートは極めて低い引裂き強さを示した。外樹皮には解繊困難なフェロイド細胞が存在し，これが塊状となってシートの白色斑点や弱点のような欠陥を生ずることが判明した。

1. Introduction

Because of wood shortage predicting in nearly future, enormous interest has been paid on additional fiber resources such as whole-tree utilization[1,2,3], rapid-growth trees from short-rotation forestry[4),5),6)], and non-woody plants. It is true that whole-tree pulping offers a way of obtaining additional fiber by the use of components formerly left in the forest as waste, but some important problems may occur as the results of whole-tree utilization, such as decrescent nutrition in the forest, unusual fiber quality, and so on. The present study aims to accumulate fundamental data concerning whole-tree pulping and to evaluate papermaking properties of each component such as branches and bark pulp.

Whole-tree utilization involves pulping of small branches and bark in addition to juvenile wood that is important major component of the young tree grown in short-rotation forest. In the present paper, a 25 year-old tree of Akamatsu (*Pinus densiflora* Sieb. et Zucc.), one of the most popular coniferous species in Japan, was harvested and divided into several parts. Yield and quality of kraft pulps from each component were examined and discussed in view of wood elements-sheet property relation.

2. Experimental

An Akamatsu tree, 25 year-old *Pinus densiflora* Sieb. et Zucc. growing in Kamigamo Experimental Forest Station of Kyoto University Forest, was cut down at May, 1978, and divided into several parts including inner and outer bark within a few days of falling. The sample tree was about 9.5 m in height and 15 cm in breast-height diameter. According to the Sanio's rule[7], the bole contains about 26 % of juvenile-wood zone. The boundary layer between mature- and juvenile-wood zones corresponded to the 11-th annual ring from the pith[8], and all branches were less than 11 years old.

Chips having $2 \times 30 \times 30$ mm in size were carefully prepared from each component, and digested by kraft method. Pulping conditions for all samples were the same and as follows: total chemicals, 25.0%; sulfidity, 24.6%; liquid ratio, 5.0; maximum temperature, 170°C; and time at maximum temperature, 120 min. After removing bundled fibers by a flat screen with 8 inch-cut screen plate, the pulp obtained was delignified by sodium chlorite-acetic acid treatment.

Laboratory handsheets having 60 g/m^2 of basis weight were prepared according to JIS P 8209. Some sheet properties were measured according to TAPPI Standard methods.

3. Results and Discussion

3.1 Pulp from wood zone

Weight distribution of components in the sample tree is shown in Table 1, and yield and quality of the kraft pulps prepared from each component under the same cooking conditions are summarized in Table 2. Since a preliminary experiment showed that the needles give an unusual pulp, the most part of which consists of fines through 150 mesh wire, the needles were omitted from the pulping test.

PULP YIELD It may be estimated that, if whole components of the sample tree except the needles are pulped under the cooking condition used, about 18.8 kg of the

Table 1 Harvest of components in a tree of Akamatsu (*Pinus densiflora* Sieb. et Zucc.)

Component	Bole		Branches, >2 cm diam.		Branches, <2 cm diam.		Needles
	Wood	Bark	Wood	Bark	Wood	Bark	
Green weight, kg	69.2	7.7	5.8	2.0	8.8	6.0	12.3
Oven dry weight, kg	31.9	3.5	2.8	1.0	4.1	3.0	6.2
Yield based on whole tree, %	60.8	6.7	5.4	1.9	7.8	5.7	11.8

a) Oven dry basis.

unscreened, unbleached kraft pulp will be obtained. This corresponds to 40.6% of the oven dry components. The pulp may consist of 79.3% from wood zone of the bole, 4.8% from wood zone of the branches having more than 2 cm in diameter, 11.2% from the small branches containing bark, and 4.8% from the inner and outer bark. For each component, cooking yield of the kraft pulp decreased in order of mature wood in the bole, juvenile wood in the bole, the branches and the bark, and this tendency was promoted in screening and bleaching process because of loss of fines. The decrease in pulp yield may be attributed to higher levels of extractives and lignin in juvenile wood, branches and bark[3),4),6)].

PULP QUALITY Morphological characteristics of the components were observed using light and scanning electron microscopy. On wood zone of the bole, the tracheid of juvenile wood was shorter in fiber length and slightly thinner in cell wall thickness in comparison with that of mature wood. The branches which consist of juvenile wood contained substantial amount of reaction wood zone in the lower part of the branches. The tracheid in the reaction wood zone had thick cell wall and spiral cracks on inside of the cell wall.

As seen in Table 2, the results of handsheet test for unbeaten pulps suggest some fiber characteristics such as fiber dimensions and fiber flexibility. Pulp freeness decreased in order of decreasing pulp yield, that is, mature wood in the bole, juvenile wood in the bole, the branches and the bark, while sheet density and breaking length increased in that order. However, breaking length and fold endurance of wood pulp from the bole and the branches were very low compared with those of beaten handsheets, and this suggests that ability to form fiber-to-fiber bonds is not yet developed enough. Handsheet test for beaten pulps showed that pulps from juvenile wood in the bole and the branches having more than 2 cm in diameter will offer the handsheets comparable to those from mature wood in the bole. In contrast to this, handsheets from the small branches, wood plus bark, had low tear factor. The small branches consist of 65.8 % of wood zone, 27.3 % of pith zone, and 6.9 % of bark. It is supposed, therefore, that the low tear factor is due to high concentration of fines fraction from pith and bark in addition to thin-walled fibers from the wood zone.

Table 2 Yield and quality of kraft pulps from 25 year-old Akamatsu components

Component	Bole		Branches		Bark	
	Mature wood	Juvenile wood	Wood, >2 cm	Whole, <2 cm	Inner	Outer
Pulp yield						
Cooking yield, %	48.3	41.7	35.4	30.1	18.8	19.4
Screened yield, %	41.7	35.5	31.0	17.8	12.0	8.1
Quality of bleached, unbeaten pulp						
Freeness (CSF), ml	768	740	676	405	120	72
Sheet density, g/cm^3	0.381	0.410	0.501	0.639	0.836	0.593
Breaking length, km	2.03	2.56	3.92	6.06	8.89	7.82
Tear factor	152	171	158	102	53	31
Fold endurance (MIT)	3	8	51	344	2754	567
Brightness, %	80.9	78.6	88.2	86.3	72.4	74.3
Opacity, %	77.1	87.2	82.6	83.7	60.6	64.3
Quality of bleached, beaten pulp						
Freeness (CSF), ml	380	328	305	—	—	—
Sheet density, g/cm^3	0.614	0.637	0.678	—	—	—
Breaking length, km	8.84	10.29	9.43	—	—	—
Tear factor	176	143	104	—	—	—
Fold endurance (MIT)	1963	1644	2213	—	—	—

Table 3 Size distribution of bark elements defibrated by sodium chlorite-acetic acid treatment

Fraction, mesh	>24	24–48	48–100	100–300	<300
Inner bark, % (in weight)	75.1	8.1	5.1	6.8	4.8
Outer bark, % (in weight)	32.4	20.2	11.8	30.9	4.8

3.2 Pulp from bark

In the present study, the inner bark means all the tissues located between the cambium layer and the last-formed periderm, that is, the tissues of the secondary phloem of living region, whereas the outer bark means the tissues located outside the last-formed periderm. The major elements of Akamatsu inner bark are the fibrous sieve cell and the parenchyma cells because of lack of the bast fiber and the sclerotic cell (sclereid). The outer bark, however, comprises the cells formed in the phellogen such as cork cell, phelloid cell and phelloderm cell in addition to the elements of the inner bark.

The bark elements defibrated by sodium chlorite-acetic acid treatment were subjected on a dynamic drainage jar with various size of wire. Table 3 shows results of the classification test. As seen in Fig. 1, the fraction retained on 24 mesh wire from the inner bark consists of the fibrous sieve cell, whereas the fraction passed through 100 mesh wire includes the small parenchyma cells. On the outer bark, the ratio of fibrous sieve cell to total elements decreased remarkably, and the black mass, a clump of phelloid cells interlocked with adjacent cells in a cog-like manner, was found in the fraction

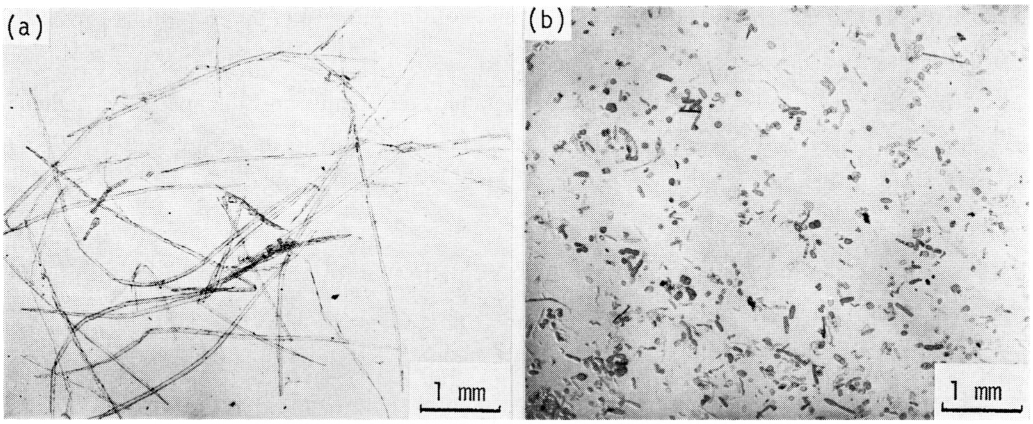

Fig. 1. Inner-bark elements defibrated by sodium chlorite-acetic acid treatment.
(a) The fraction retained on 24 mesh wire, and (b) the fraction passed through 100 mesh wire and retained on 300 mesh wire.

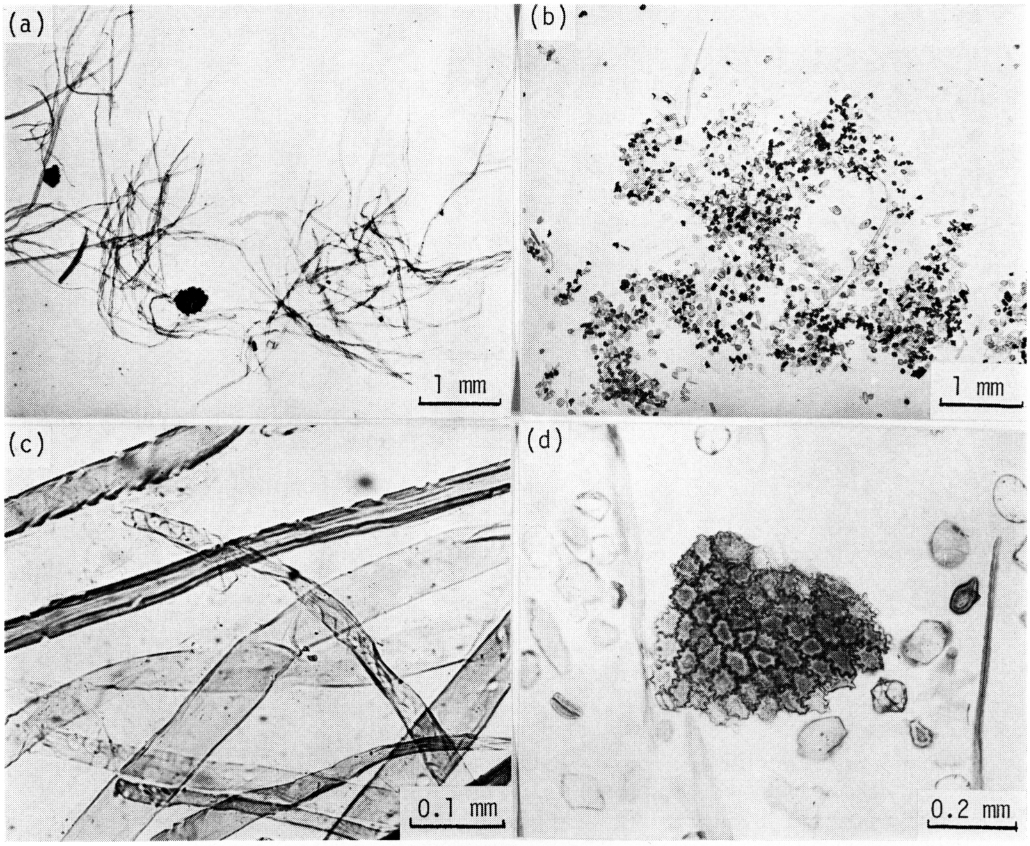

Fig. 2. Outer-bark elements defibrated by sodium chlorite-acetic acid treatment.
(a) The fraction retained on 24 mesh wire, (b) the fraction passed through 100 mesh wire and retained on 300 mesh wire, (c) fibrous cells, and (d) a clump of phelloid cells.

retained on 24 mesh wire (Fig. 2). The presence of the clump may suggest that phelloid cells are difficult to defibrate and subsequently will cause some trouble in papermaking.

This was also suggested by Harder, Einspahr and Parham[9] on several pines grown in North America.

Unbeaten kraft pulp from the inner bark gave a semitransparent, dense sheet, whereas white spots originated from the clump of phelloid cells took place in the outer-bark sheet. Unbeaten bark pulps had high breaking length comparable to beaten mature-wood pulp, but remarkably low tear factor (Table 2). Fold endurance of the outer-bark sheets was significantly low in compared with that of the inner-bark sheets, and this may be attributed to the presence of the clump that caused a defect on the sheet structure such as seen in Fig. 3.

Table 4 shows the effects of the inner-bark pulp on handsheet properties of the mature-wood pulp. Blending of the inner-bark pulp contributes to increase in breaking length and fold endurance, although causes to decrease in tear factor, and this may lead to the conclusion that the inner-bark pulp will act to reduce beating energy in some extent. Because the ratio of bark to wood is around 5 % in nature, special attention in the case of mixing of bark in wood chips should be paid on the presence of outer bark that produces the clump of phelloid cells rather than that of inner bark.

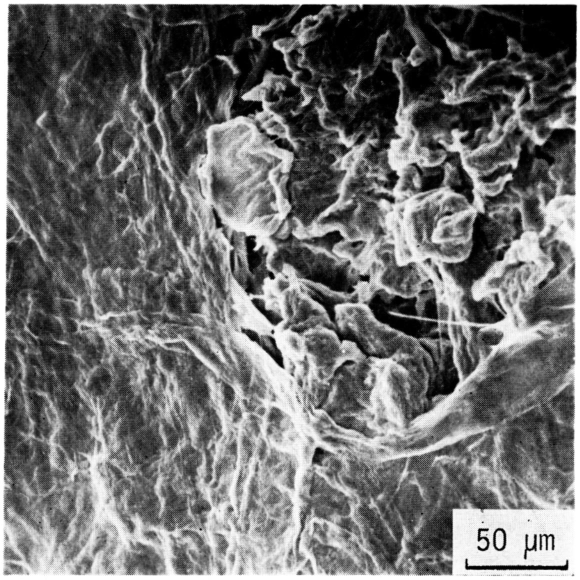

Fig. 3. Scanning electron micrograph of outer-bark handsheet showing a defect due to the presence of phelloid cell clump.

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Table 4 Some properties of handsheets prepared from mixed kraft pulps of mature wood in the bole and the inner bark retained on 24 mesh wire

Mature-wood pulp content, %	100	90	80	70	50
Bark pulp content, %	0	10	20	30	50
Sheet density, g/cm^3	0.381	0.402	0.475	0.525	0.585
Breaking length, km	2.03	3.42	4.50	5.56	6.37
Tear factor	152	134	110	121	89
Fold endurance (MIT)	3	18	144	599	1336

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