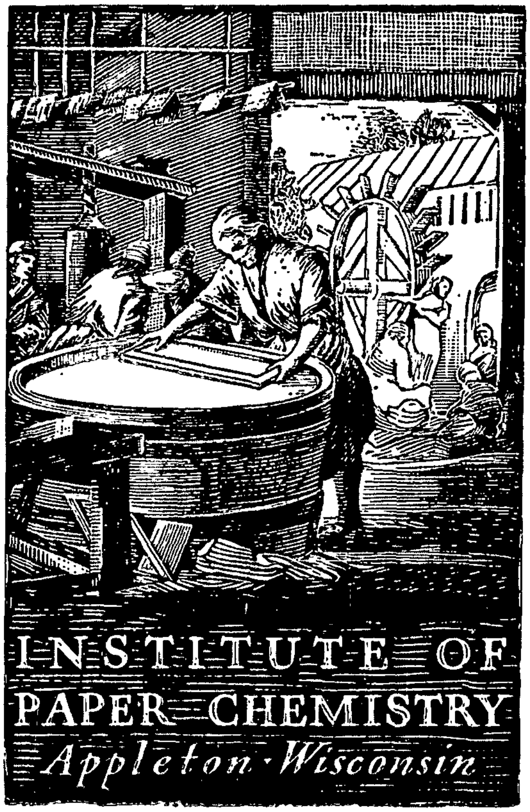

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Ten
A Progress Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

March 31, 1978

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

Red maple has a wood specific gravity of 0.51 and an average bark specific gravity of 0.60. Bark extractives levels average 19.6%. Morphologically, the bark contains a large amount of fiber and some sclereids. Pulping red maple bark gave a solids yield of 32%. Screening the bark pulp resulted in 12 grams of fiber being produced for every 100 grams of bark pulped. Mechanical treatment of the bark gave very poor results. When hammermilled and screened, wood loss averaged 4% while bark removed was only 18% when retaining the material on a 14-mesh screen. Water flotation segregation does not look promising either. There was only a narrow range (35-75% moisture content) at which segregation would be possible.

Black willow, based upon values in the literature and measurement data obtained from trees sampled as part of the project, has an average wood specific gravity of 0.36 and a bark specific gravity of 0.34. Extractives levels for wood and bark were 2.6 and 6.9%, respectively. Pulping black willow bark produced a solids yield of approximately 40%. Screening the bark resulted in 21 grams of fiber being produced for every 100 grams of bark pulped. This is the highest percentage of fiber produced from bark of any of the species examined and makes black willow a prime candidate for whole-tree chipping and pulping. Hammermilling gave poor results with a 4% wood loss but only a 13% reduction in bark when retaining the material on a 14-mesh screen, although it is possible that improvements could be made in screen design. Water flotation segregation would be possible but only at moisture contents of 150% or above.

Green ash was found to have a wood specific gravity of 0.56 and a bark specific gravity of 0.45. Extractives levels were 5.2 and 17.4%, respectively, for the wood and bark. The bark, when pulped, had a solids yield of approximately 38%. Screening the pulp resulted in 13% usable fiber being produced. Hammermilling gave intermediate results with 32% bark removed and 5% wood loss when material on the 14-mesh screen was retained. A useful approach with this species might be screening, hammermilling the fractions high in bark and rescreening. Segregation through water flotation might be possible but the range of moisture contents is quite narrow. At moisture contents of between 65 and 100%, wood chips would sink while the bark would still be floating.

Eastern white pine has a wood specific gravity of 0.32 and a bark specific gravity of 0.47. Extractives levels were 7.9 and 15.5%, respectively, for wood and bark. Morphologically, the bark contains no fiber but some sieve cells and phellem cells. Pulping eastern white pine bark resulted in a solids yield of 30.5%. Screening the bark resulted in 7.3% sieve cells and 0.4% phellem cells remaining on the 60- and 100-mesh screens. Hammermilling resulted in only a 29% reduction in levels of bark and a 4% wood loss but a useful approach might be to make a quick segregation by screening, hammermilling the fractions high in bark and then rescreening. Segregation through water flotation would be possible at moisture contents above 100%. Both fractions would float at lesser moisture contents.

A wood specific gravity of 0.40 and a bark specific gravity of 0.43 were determined as average values for eastern hemlock. Extractives levels of 3.7 and 25.4% were found to be appropriate for the wood and bark of this species. Pulping eastern hemlock bark gave a solids yield of 35%. The bark contained no fiber and screening the bark resulted in 16.3% sieve cells and 4.5% sclereids being produced.

Hammermilling wood and bark chips gave only modest results with a 5% wood loss and a 25% reduction in levels of bark. Water flotation segregation is not a feasible technique for eastern hemlock. Both wood and bark are too similar in density at various moisture contents.

Added again in this report is a section giving the Btu's, ash, calcium and silica levels for all 42 species investigated in this project. The planned summary report will compare Btu's, ash, calcium and silica of conifers and hardwoods and their relationship to extractives, etc. Also included are two tables giving the modulus of elasticity for all species investigated.

INTRODUCTION

Progress Report Ten completes the bark characterization research for the agreed-upon total of 42 pulpwood species. There remains one important activity, and that is to prepare a detailed summary report comparing specific gravity, extractives, pulp yield, fuel value and ash content for hardwoods and conifers. Another important function of this report will be to examine the relationships that exist between bark morphology and bark properties such as wood/bark adhesion, toughness, tensile strength and reaction to hammermilling, which have an important influence upon the selection of the most suitable wood/bark separation and segregation procedure for use with a particular tree species.

There is increasing evidence that the use of whole-tree chips will be required to meet our future fiber requirements for paper and board. To effectively and economically use such material with a minimum disruption in production and a minimum loss in product quality requires continued research on how best to handle this new source of fiber and the associated "bark" and "dirt" problems. We have really only scratched the surface of the bark problem in Project 3212. We have better defined the problem and it now remains for the resource manager and the mill manager to use this information in working out the "best" solution for their specific mill situation.

Future energy, fiber supply and fiber raw material requirements appear to be key factors in the present whole-tree harvesting and wood/bark segregation picture. Delivery of a quality finished product to the consumer at the lowest energy output requires consideration of harvesting, transporting, chipping, pulping, cleaning, beating, chemical recovery, equipment wear and energy recovery costs. Consideration must also be given to energy independence. Bark and low-quality chips, for example, have a considerable fuel value and, if handled and segregated by a dry process, could make a major contribution to the industry's overall energy requirements. The factors are many and, with the increasing cost of fiber and energy, it is critical that we have the very best information available in order to arrive at the most appropriate solutions for the industry's bark problem.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1), illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

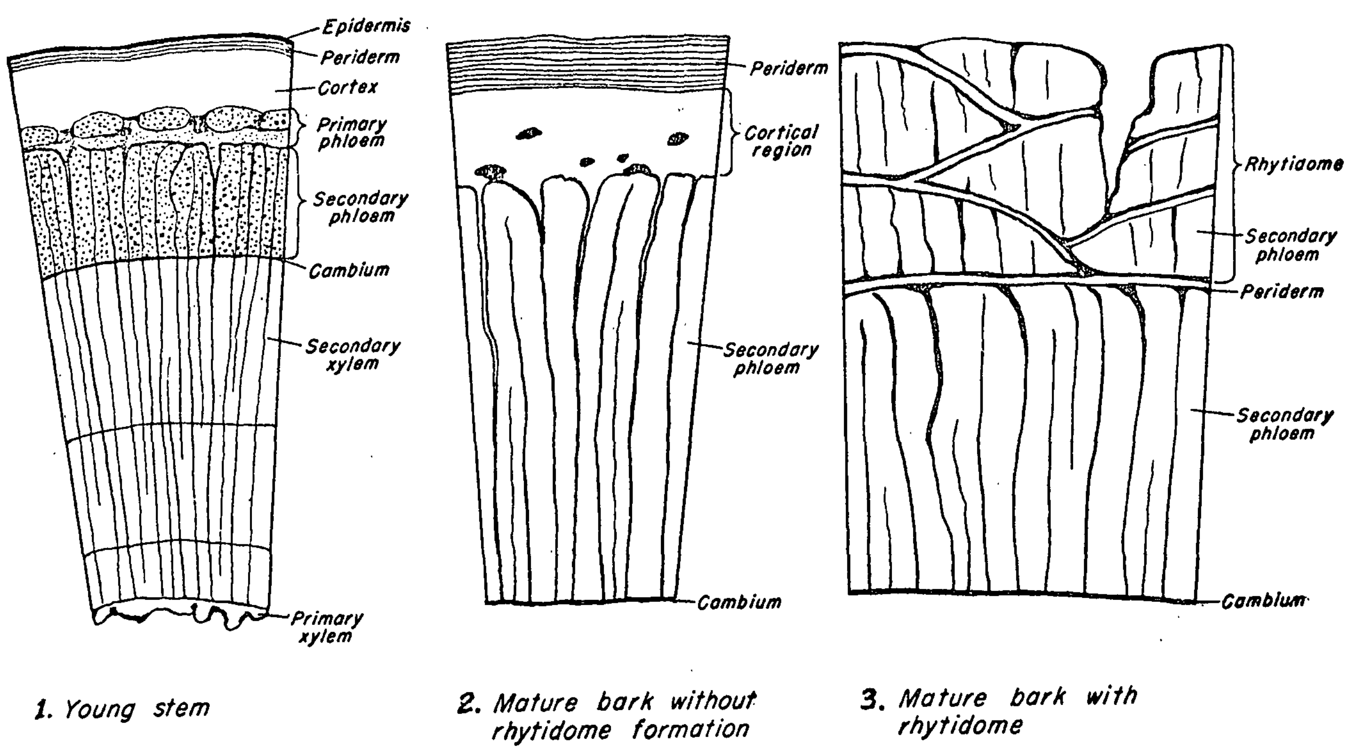


Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, Such as That in the Middle-aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique; that is, a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later anatomical examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(\underline{c} \cdot \underline{d})/[\underline{c}-(\underline{b}-\underline{a})]$ where:

$\underline{a}$ = weight of pycnometer + heptane

$\underline{b}$ = weight of pycnometer + heptane + chip

$\underline{c}$ = weight of chip (wet — before being placed in heptane)

$\underline{d}$ = density of heptane.

BARK AND WOOD PROPERTIES OF RED MAPLE

[Acer rubrum L.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Red maple grows under a wide variety of climatic conditions and is found almost everywhere east of the 100th meridian where precipitation is adequate. The range includes southern Florida to Canada and the Atlantic Ocean to the prairies. However, the tree reaches its best development in Kentucky, Tennessee and nearby states. Although it may reach 120 feet in height and five feet in diameter under ideal conditions, the average height is 75-90 feet and 1 1/2-2 1/2 feet in diameter. It is a tolerant species.

WOOD AND BARK MORPHOLOGY

Wood

The wide sapwood is white with a slight reddish-brown tinge while the heartwood is a light reddish-brown. Without characteristic odor or taste, the wood is soft to moderately hard and moderately heavy. The growth rings are delineated by a narrow, darker line of denser fibrous tissue and are not very distinct. The wood is diffuse-porous with small pores distributed throughout the growth ring. The pores are indistinct without a hand lens. Rays are visible with the naked eye, forming a pronounced close ray fleck on the radial surface and appearing as short, crowded lines on the tangential surface. Fibers are thin to moderately thick-walled, 16-30 μm in diameter and 0.7 mm in average length.

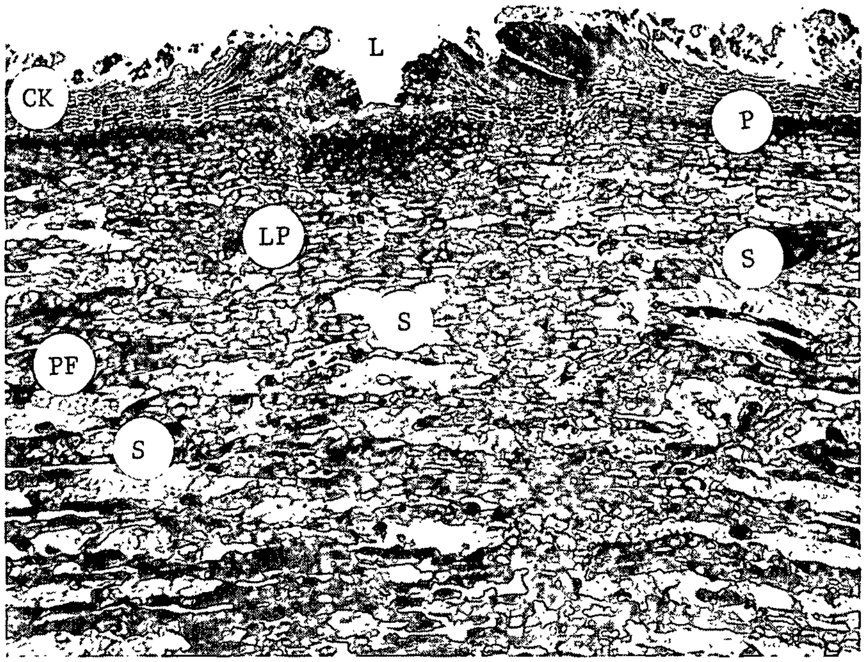
Bark

On young trees, the bark is smooth and light gray, while on old trunks the bark is thick, dark gray and separated by vertical ridges into large platelike scales. The outer bark, for the three trees examined, averaged 39% of the total bark on a dry weight basis, with a range from 8 to 70%. Tree 3212-135 had much thinner outer bark than the other two trees and was the youngest tree of the three, although not appreciably younger than 3212-146. The percentage of red maple bark in the stem and branches has been estimated at 16.1% on a dry weight basis (3). Figure 2 illustrates a cross section of red maple wood and bark. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

Near the cambium zone, sieve tube elements and companion cells are aggregated into tangential bands which alternate with almost uniseriate lines of parenchyma and irregular groupings of relatively few phloem fibers. A few small sclereids can be found here also. Progressing outward, one immediately encounters a greater frequency and crowding of fibers and sclereids, crushing of the sieve tube structure, and a general lack of cell patterns. One exception here is the greater tendency for interrupted but wider tangential lines of parenchyma. Near the outer bark, the only recognizable cell types are fibers, sclereids, and parenchyma. Ray structure terminates as such about half-way through the 4 mm of total inner bark, the cells becoming sclerotic and/or intergrading with other parenchyma. A single periderm with 1-6 phelloderm and 10+ tannin-filled cork cells neatly covers the inner bark on the sample examined. The outermost 3-5 cork cells retained in the periderm appear lignified. Lenticels can also be found along the periderm.

According to Chang (1), the barks of the maples he studied, including red maple, have the following characteristics in common: (1) the presence of thin-walled, suberized phellem and thick-walled peridermal cells, which are often repeated in alternate layers, (2) the development of rather advanced types of sieve tube



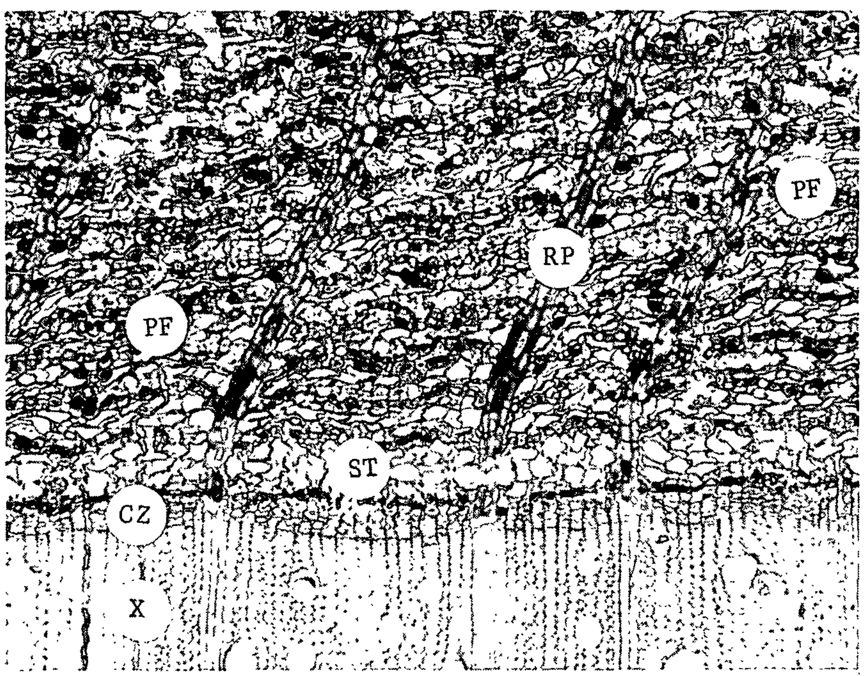


Figure 2. Cross Sections of Red Maple. Photograph on the Bottom Shows the Xylem (X), Cambium Zone (CZ) and Inner Bark. One Tangential Band of Sieve Tubes (ST) Appears to be Functional. Phloem Fibers (PF) Compose the Majority of Sclerenchyma in the Inner Bark. Ray Parenchyma (RP) are Evident. The Photomicrograph on Top Shows the Outer Zone of the Inner Bark. Illustrated are Sclereids (S) in a Dilated Ray, More Abundant Phloem Fibers (PF), Tangential Groups of Longitudinal Parenchyma (LP), a Single Periderm (P), Cork Cells (CK) and a Lenticel (L). Magnification — 75X

elements, (3) the presence of sclerotic cells with solitary crystals, (4) the development of typical phloem fibers which are variable in amount and in time of maturation in different species, (5) the homogeneous broad phloem rays, and (6) the persistence of cortical region.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table I summarizes the information available on wood and bark of red maple. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of red maple at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.51 appears appropriate for the wood of red maple. Our samples were divided into sapwood and heartwood and, in one case, into exterior and interior wood. For 3212-135, the interior wood constituted the first 28 rings out of a total of 41

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

rings. Our limited data showed the sapwood and heartwood to be very close in specific gravity.

TABLE I

RED MAPLE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References
0.50			0.54	Manwiller (4)
0.53				Maeglin (5)
0.52				Bendtsen and Ethington (6)
0.49				Isenberg (7)
0.49				IUFRO (8)
0.52 (exterior) 0.52 (interior)	0.57	0.63	0.63	IPC 3212-135
0.46 (sapwood) 0.46 (heartwood)	0.65	0.78	0.69	IPC 3212-141
0.58 (sapwood) 0.58 (heartwood)	0.58	0.60	0.60	IPC 3212-146
	0.75			Fournier and Goulet (9)
			0.53	Murphey, et al. (10)

The specific gravity of the total bark appears to be somewhat higher than that of the wood. However, due to the various values obtained from the literature, the average specific gravity for the total bark turned out to be less than that obtained for either inner or outer bark. The outer bark was higher in specific gravity than the inner bark on the three IPC trees examined. Despite the range in values in Table I, it appears that overall values for use in species comparisons should be 0.51 for wood and approximately 0.60 for total bark. Outer bark can be considered to be close to or slightly higher than total bark in specific gravity while inner bark is slightly less.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of red maple wood and bark. Table II summarizes existing data and includes the three IPC trees examined. Red maple wood is low in extractives and a level of 2.7% is suggested for use in between-species comparisons. Extractives work done on red maple bark in this project plus an additional value showed an average level of 19.6%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques. In contrast to red maple, silver maple (another soft maple) had extractives levels of 3.5% and 6.6%, respectively, for wood and bark. Sugar maple, a hard maple, had wood and bark extractives levels of 1.0% and 6.0%.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

TABLE II

RED MAPLE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.5	Rydholm (11)
Wood	2.5	Fengel and Grosser (12)
Wood	2.5	Forest Products Lab (13)
Wood	2.2	3212-135
Wood	3.5	3212-141
Wood	3.0	3212-146
Bark	13.1	Murphey, et al. (10)
Bark	20.4	3212-135
Bark	25.8	3212-141
Bark	19.0	3212-146

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped red maple bark.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, there was only a small percentage of sclereids remaining on the top two screens.

As a check on pulp yield and the nature of the material produced from red maple, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation. Micropulping red maple bark resulted in a yield of 31 to 33% solids. When screened, the coarse screens (60- and 100-mesh) retained mostly phloem fibers. The on 150-mesh screen contained primarily phloem fibers along with some sclereids. The on 200-mesh and through 200-mesh screens had a mixture of phloem fibers, sclereids, parenchymatous cells and sieve tube elements. Figure 3 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 32 grams of solids will result. Of this 32 grams, about 12.1 grams (12.1%) of phloem fibers and 0.9 gram (0.9%) of sclereids will be produced. This assumes that only the material on the 60 and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was considerably higher than the amount retained for silver or sugar maple and, in fact, was greater than that retained for most of the hardwoods. Average arithmetic length of the bark fibers was 1.1 mm, compared to a wood fiber length of 0.7 mm as reported by Isenberg (7). Bark fiber lengths were done on whole fibers, selected in an unbiased manner.

Chase *et al.* (14) studied the potential of Maine "puckerbrush" as a source of fiber. They found that red maple chipped with the bark included gave a good grade of pulp using the sulfate process. The pulp was at least equal to standard commercial pulps in strength characteristics. However, the yields were comparatively low and the pulps were difficult to bleach. Red maple puckerbrush

TABLE III

RED MAPLE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-135	3212-141	Remarks
Yield, % solids	31.0	33.0	
Fraction			
On 60 mesh, %	25.8	15.5	Fraction contained principally phloem fibers (95-97%), with a small percentage of sclereids (3-5%) and a trace of parenchymatous cells (<1%). Average arithmetic length of the phloem fibers was 1.1 mm.
On 100 mesh, %	17.3	22.7	Fraction contained principally phloem fibers (85-95%), with a small percentage of sclereids (5-15%), and traces of sieve tube elements (<1%), and parenchymatous cells (<1%).
On 150 mesh, %	8.5	11.9	Fraction contained a large percentage of phloem fibers (75-80%), with smaller percentages of sclereids (10-12%), sieve tube elements (5-10%), and parenchymatous cells (<5%).
On 200 mesh, %	6.3	6.3	Fraction contained a mixture of phloem fibers (50-60%), sclereids (20-30%), sieve tube elements (10-15%), and a small percentage of parenchymatous cells (5-10%).
Through 200 mesh, %	42.1	43.4	Fraction contained a large percentage of parenchymatous cells (60-65%), with smaller percentages of sclereids (20-30%), and phloem fibers (5-15%), and a trace of sieve tube elements (1%).

[a]Percentages given are on a dry weight basis.

with the bark included, and pulped using the kraft process, gave a yield of 34.5% and made a good handsheet (3).

Figure 3. The 60-Mesh Screen (Left) Contained Primarily Phloem Fibers (PF). The 150-Mesh Screen (Right) Contained a Larger Percentage of Phloem Fibers Plus Some Sclereids and Sieve Tube Elements (ST). The Clumping of the Fibers, Particularly Noticeable in the Photomicrograph on the Right, was Due to Slight Undercooking of the Bark Sample. Magnification — 75X

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for red maple samples collected November 7. After testing, the samples were examined to determine the location of the zone of failure. Figure 4 illustrates the zone of failure for red maple during the dormant season. The failure zone was located in the inner bark about 8-10 cells from the cambium zone. Failure occurred in an irregular, tangential line that interfaced fiber groups at various locations. Only a few fibers very close to the cambium zone were retained with the xylem. Adhesion measurements averaged 12.4 kg/cm^2, a moderate value and in between the values obtained for sugar maple and silver maple.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is, in turn, related to inner bark morphology.

The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with red maple. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

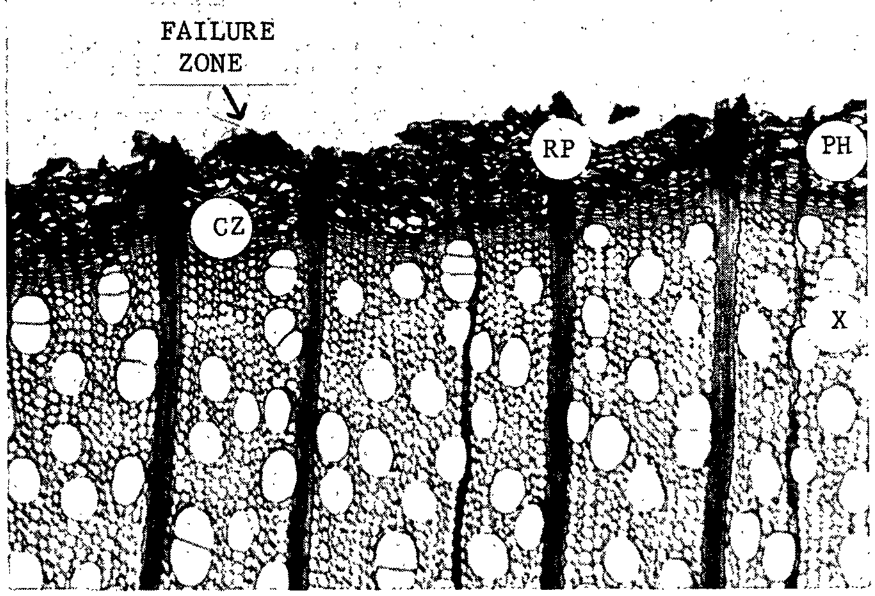


Figure 4. Illustrated is the Failure Zone for Red Maple During the Dormant Season. Failure Occurred in the Inner Bark About 8-10 Cells from the Cambium Zone. Magnification — 75X. Symbols Illustrate Cambium Zone (CZ), Ray Parenchyma (RP) and Phloem (PH)

Wilcox _et al_. (_15_) examined the seasonal variation in bark peeling of red maple and several other Adirondack species. They found that the onset of peeling for red maple was approximately May 4 and lasted for about 96 days. Peeling occurred shortly after the mean weekly temperature had risen above 40°F.

Erickson (16) reported that better wood/bark separation was achieved by chipping frozen winter-cut roundwood than by chipping unfrozen roundwood although more fines resulted. Unloosened bark averaged 1.8% of the total material.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of red maple. (Appendix Tables XXXIX and XL compare the modulus of elasticity of red maple bark with other species examined in this project.)

Bark strength values for red maple inner bark were relatively high compared to other species tested thus far and much higher than the bark strength values obtained for sugar maple inner bark (1.4 kg/cm^2). The value was also higher than the one obtained for the other soft maple, silver maple, examined in this project. The outer bark was too thin to test. Toughness values for the sapwood were intermediate and about half of the value obtained for sugar maple (1.20). Toughness values obtained for the inner and outer bark were relatively high. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the rather high specific gravity of the bark and the intermediate to high bark strength and toughness values, it appears hammermilling might not work too well with this species.

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF RED MAPLE[a]

Material	Strength	Toughness
Wood	--	0.63
Inner bark	11.3	0.41
Outer bark	--[a]	0.18

[a]Too thin to test.

Summarized in Table V are the results of the hammermilling tests run on red maple wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a small reduction in levels of bark. When the half-sized chips for the two trees (3212-135 and 3212-141) were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and an 18% reduction in levels of bark. This low reduction in bark

TABLE V

SUMMARY OF HAMMERMILLING TEST ON RED MAPLE

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-135	Bark	45.4	26.2	10.5	3.7	4.6	9.7	Fair amount of outer bark tended to stay attached to inner bark; some loose outer bark in small mesh screens. Unattached outer bark in rounder pieces while inner bark longer pieces
	Exterior	74.2	18.0	3.6	1.3	1.2	1.8	
	Interior	74.3	16.6	4.5	1.7	1.6	1.3	
3212-141	Bark	44.9	29.2	8.3	3.7	4.2	9.7	Same as above.
	Exterior	64.9	26.9	5.1	1.0	1.1	1.5	
	Interior	73.5	20.5	3.7	1.0	0.6	0.7	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

levels was expected from the strength and toughness measurements. Only a small amount of additional bark could be removed by retaining the material on the 10-mesh screen (27% bark removal). Figure 5 illustrates the effect of hammermilling on wood and bark of red maple. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of red maple with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two red maple trees (IPC

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

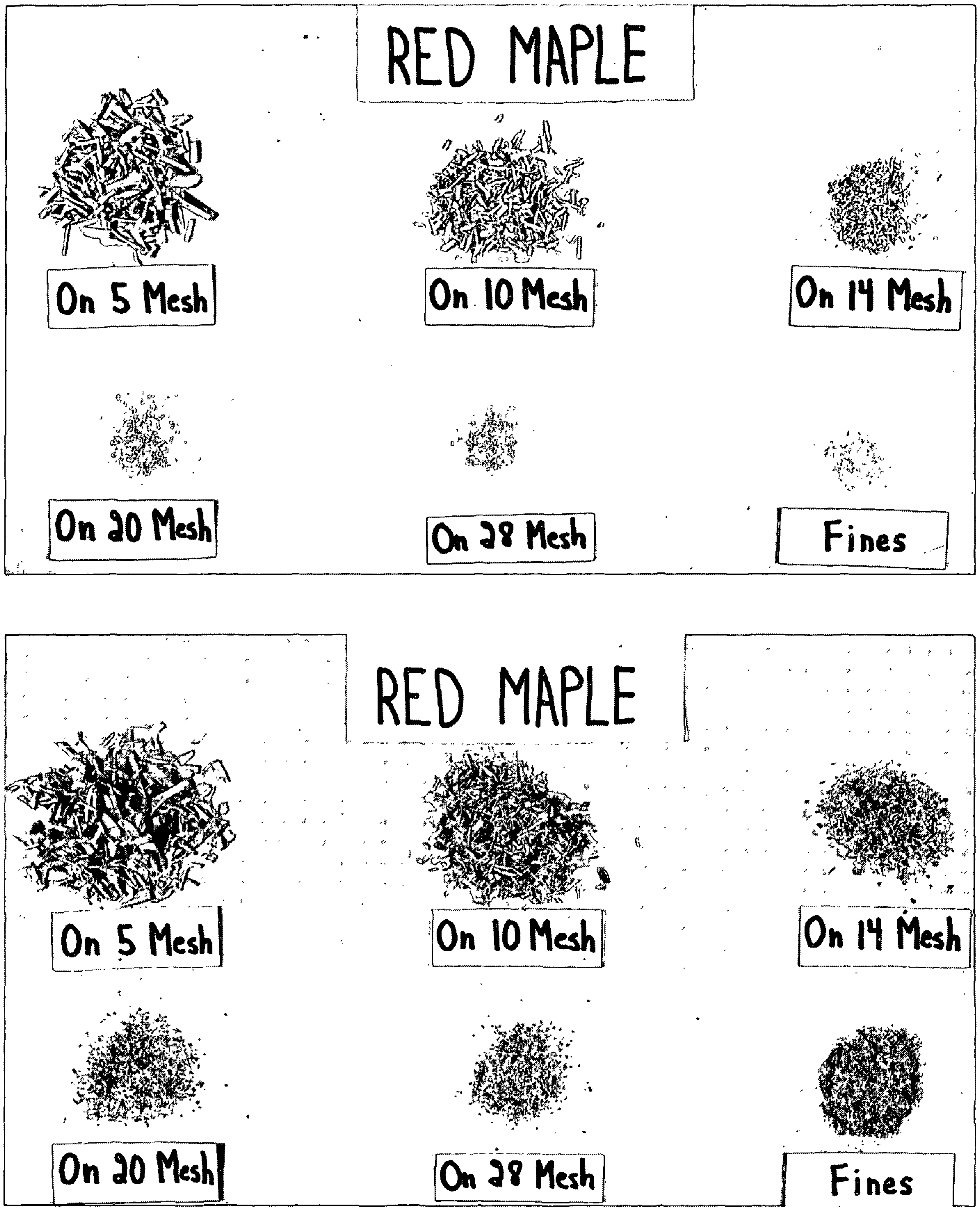


Figure 5. Illustrated is the Effect of Hammermilling on Red Maple Wood (Top) and Bark (Bottom)

3212-135 and IPC 3212-141) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were similar in density at comparable moisture contents.

Figure 6 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that there is a very narrow range of moisture contents at which segregation might be possible. At moisture contents of between 35 and 75%, bark chips would sink while the wood would still be floating. At higher moisture contents, both fractions would sink.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and

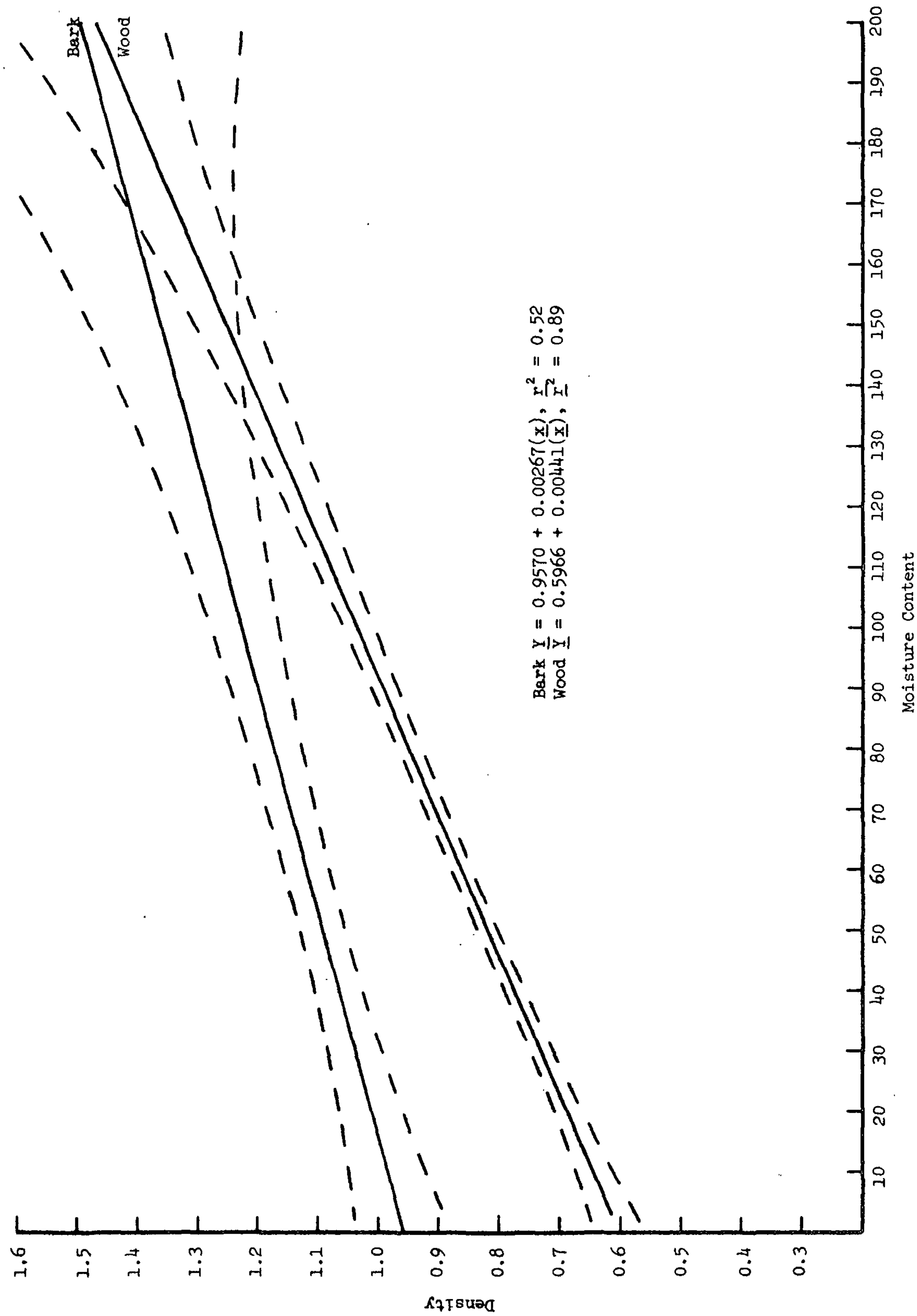


Figure 6. Illustrated is the Relationship Between Basic Density and Moisture Content for Red Maple. The Dashed Lines are Two Standard Deviations Above and Below the Mean

observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table VI summarizes the results for red maple. According to the density-moisture content curves, bark should sink at any moisture content above 10% while wood should sink at moisture contents above 90%. The bark for both trees did sink, but a good share of the wood was still floating, even at moisture contents above 100%. However, the curves are merely an indication of the flotation characteristics of a species and the dwell time results indicate segregation possibilities for red maple are slightly better than shown by the regression curve.

DATA INTERPRETATION

Red maple is one of those species where, if the bark is chipped with the wood, it would be difficult to segregate the fractions. Hammermilling wood and bark chips resulted in only 18% bark removed and a 4% wood loss when the material on the 14-mesh screen was retained. However, it would be possible to screen, concentrate the bark in the small-sized chip fractions, hammermill or compression debark (17-18) the selected fractions and then screen the hammermilled or compression debarked fractions to remove bark fines.

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR RED MAPLE

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
3212-135 Bark	92.6	after 5	96.8	3.2
		15	96.8	3.2
		60	96.8	3.2
		240	100	0
3212-135 Exterior wood	91.2	after 5	77.6	22.4
		15	77.6	22.4
		60	77.6	22.4
		240	77.6	22.4
3212-135 Interior wood	92.1	after 5	31.9	68.1
		15	31.9	68.1
		60	31.9	68.1
		240	31.9	68.1
3212-141 Bark	83.0	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
3212-141 Sapwood	87.8	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-141 Heartwood	111.8	after 5	2.7	97.3
		15	2.7	97.3
		60	2.7	97.3
		240	2.7	97.3

Pulping the bark remaining with the wood after mechanical treatment would increase the fibrous yield. Bark fiber length is good and handsheets made utilizing whole-tree chips had good strength properties. However, as usual with whole-tree chips, digester yield would decrease and bleaching requirements would increase. In addition, bark extractives are high and could cause a problem if concentrated amounts of bark were pulped.

Chipping frozen bolts gave good bark and wood separation in one study with unloosened bark averaging only 1.8% of the total material. Water flotation segregation is possible but only at moisture contents of between 35 and 75%, a very narrow range.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark mixtures. They include papers by Auchter and Horn (19), Hooper (20), Biltonen, et al. (21), Short, et al. (22), Miller (23), Vais and Vostrov (24), Arola and Erickson (25) and Arola, et al. (26). A good review on kraft pulping of rough wood chips is also given by Horn and Auchter (27). Investigated by Murphey, et al. (10) were chemical and physical properties of several species while Martin and Crist (28) looked at physical-mechanical properties of eastern tree barks. Bark volume was estimated by Koch (29) while bark moisture contents were estimated by Manwiller (30).

BARK AND WOOD PROPERTIES OF BLACK WILLOW

[_Salix nigra_ Marsh.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Black willow is the largest and most widely known of the approximately 70 species of willow native to North America. It will grow on almost any soil but its shallow, wide-spreading roots need an abundant and continuous supply of moisture. Best growth is achieved where the average yearly rainfall is 51 inches. Black willow grows along streams, lake shores, swamps, etc., throughout the Eastern United States and Canada. On the best sites in the Mississippi Valley, the tree will reach 140 feet in height and 4 feet in diameter. However, normally, it is 30-40 feet high, often with several clustered stems.

WOOD AND BARK MORPHOLOGY

Wood

The sapwood is whitish to creamy yellow and the heartwood is grayish brown or light reddish brown, often with darker streaks. Without characteristic odor or taste, the wood is uniform in texture and moderately soft and light. Growth rings are inconspicuous. The pores are numerous and small, semi-ring to diffuse-porous, solitary or in short radial groups of two or more. The rays are very fine, scarcely visible with a hand lens. Parenchyma are terminal, generally invisible at low magnification. Fibers are thin to moderately thick walled and average 16-32 μm in diameter and 1.1 mm in length.

Bark

Brown to nearly black, the bark is divided into deep fissures, separating thick, interlacing ridges. The total thickness of bark on old trees varies from

1 to 2 inches. The outer bark is soft and rather fibrous while the inner bark is light creamy yellow, turning darker after exposure. The outer bark, for the three trees examined, averaged 65% of the total bark on a dry weight basis, with a range from 48 to 84%. Figure 7 illustrates a cross section of black willow bark and wood. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

The inner bark is characterized by a very abundant supply of lignified phloem fibers. The latter occur in somewhat oblique tangential lines of varying lengths. These lines begin immediately outside the cambial zone and are separated radially by similarly oriented bands of tissue, composed of sieve tube elements, companion cells, and longitudinal parenchyma. These phloem cell types are only somewhat distorted and are not really crushed even at the outer bark. Phloem rays are uniseriate, and they maintain almost perfect radial alignment. The alternating, tangential bands of fibers and other phloem cells are spaced relatively close, but between groups of every seven or so bands of fibers, there appears a phloem band containing no fiber and about twice the normal width of similar adjacent bands. It is conceivable that these nonfiber-containing regions serve as growth markers for the periodic (perhaps annual) addition of secondary phloem.

The outer bark of black willow consists of relatively concentric periderms. The phelloderm is only 1-3 cells wide and the phellem cells number about 5-10. The latter are thin-walled with apparently very little contents. Tannin does appear to fill most of the few phelloderm cells, however, especially in the outer (older) periderms. As the periderms are manufactured, regions of secondary phloem are cut off to the outside, including fibers. Parenchyma here seem to dilate somewhat and many sieve tube elements are still uncrushed, giving a somewhat expanded appearance to the rhytidome in comparison to the inner bark.

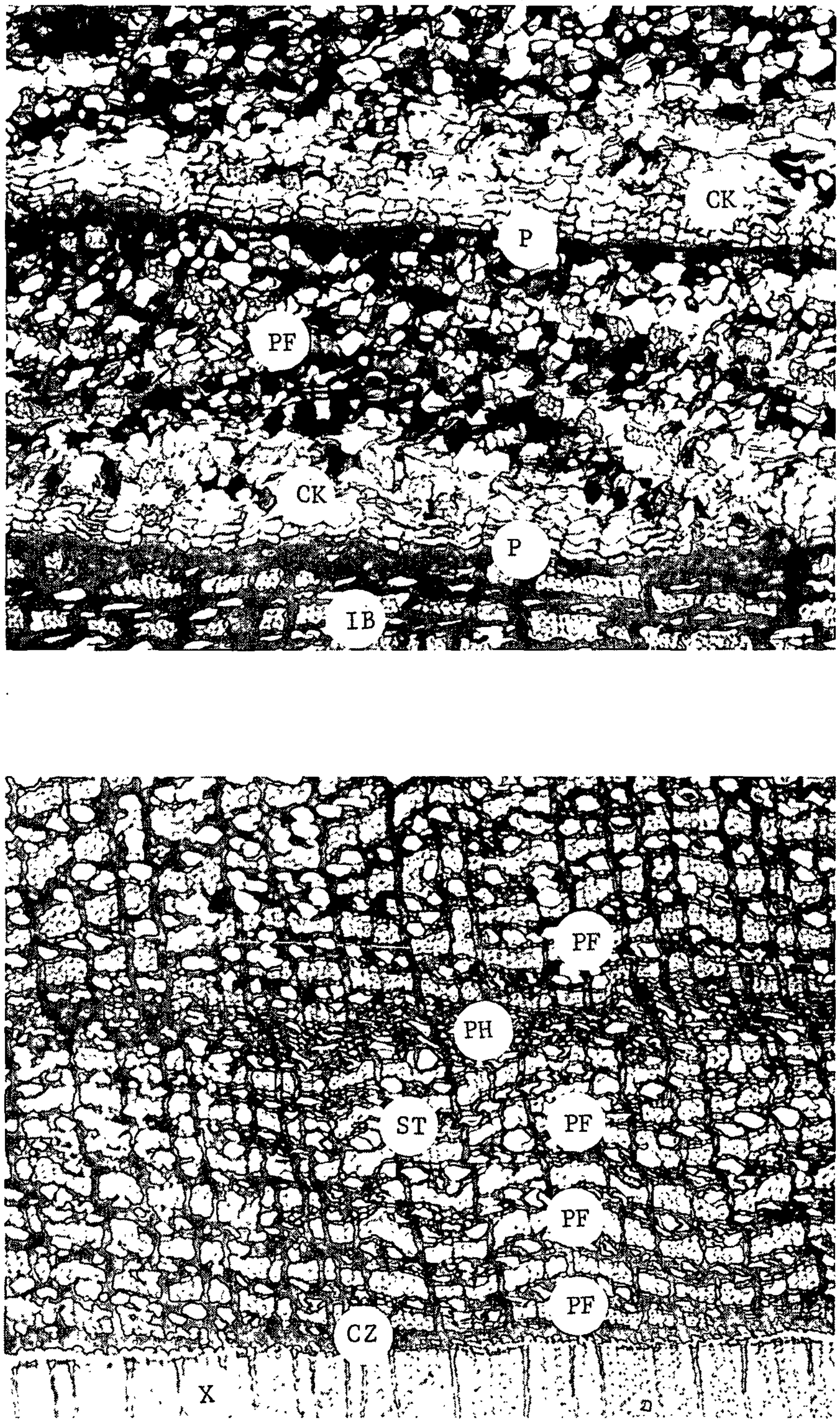


Figure 7. Cross Sections of Black Willow. Photograph on the Bottom Shows the Xylem (X), Cambium Zone (CZ), Tangential Bands of Phloem Fibers (PF), Sieve Tube Elements (ST) and Tangential Bands of Nonfiber Phloem (PH). The Photograph on Top Shows Outer Bark Detail with Two Periderms (P), Inner Bark (IB), Cork Cells (CK) and Phloem Fibers (PF). Magnification — 75X

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table VII summarizes the information available on wood and bark of black willow. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of black willow at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.36 appears appropriate for the wood of black willow. Our samples were divided into sapwood and heartwood and, in one case, into exterior and interior wood. For 3212-149, the interior wood constituted the first 6 rings out of a total of 13 rings. Our limited data showed the sapwood to be slightly lower in specific gravity than the heartwood. However, the exterior wood for 3212-149 was higher in specific gravity than the interior wood, but the interior wood was stained and did not appear to be entirely normal.

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*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

TABLE VII

BLACK WILLOW SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References
0.34				Isenberg (7)
0.34				IUFRO (8)
0.38 (sapwood) 0.39 (heartwood)	0.39	0.28	0.34	IPC 3212-140
0.34 (sapwood) 0.42 (heartwood)	0.45	0.32	0.37	IPC 3212-144
0.39 (exterior) 0.36 (interior)	0.35	0.25	0.32	IPC 3212-149
			0.42[a]	Choong and Cassens (31)

[a]Ovendry weight and volume — *Salix* spp.

The specific gravity of the total (inner + outer) bark of black willow is close to but slightly lower than that of the wood. The outer bark was considerably lower in specific gravity than the inner bark on all three IPC trees examined. Overall values suggested for use in species comparisons are 0.36 for wood and 0.40, 0.28 and 0.34 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of black willow wood and bark. Table VIII summarizes existing data and includes the three IPC trees examined. Black willow wood is low in extractives and a level of 2.6% is suggested for use in between-species comparisons. Extractives work done on black willow bark in this project plus an additional value showed an average level of 6.9%. This is a relatively low value and extractives should not be a serious problem when the bark of this species is pulped.

TABLE VIII

BLACK WILLOW EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.2	McGovern and Keller (32)
Wood	2.5	3212-140
Wood	2.7	3212-144
Wood	3.2	3212-149
Bark	5.4	Chang and Mitchell (33)
Bark	10.4	3212-140
Bark	4.5	3212-144
Bark	7.2	3212-149

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped black willow bark and amount to 29.6% of the secondary phloem according to Chang (1).

The thin-walled sieve tube elements (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. Although only a small percentage of sieve tube elements were noted in the pulped bark of black willow, it was extremely difficult to distinguish parenchyma from sieve tube fragments. Consequently, the percentage of sieve tube elements in the pulped bark may be greater. Using cross sections, Chang (1) estimated the percentage of sieve tube elements in the secondary phloem of black willow to be 28.6%.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Although sclereidlike elements were noted in the pulped bark of black willow, these probably were lignified parenchyma cells. Chang (1) reported these to be present in the outer bark and said they were not quite like typical sclerotic cells.

As a check on pulp yield and the nature of the material produced from black willow bark, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table IX summarizes the results of this investigation. Micropulping black willow bark resulted in a yield of 38 to 42% solids. When screened, the coarse screens retained mostly phloem fibers. The on 150-mesh screen contained many phloem fibers along with some sclereidlike elements and parenchymatous cells. The on 200-mesh and through 200-mesh screens had large numbers of parenchymatous cells plus some phloem fibers, sclereidlike elements, crystalliferous parenchyma and sieve tube elements. Figure 8 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 40 grams of solids will result. Of this 40 grams, about 21.2 grams (21.2%) of phloem fibers and 0.3 gram (0.3%) of sclereidlike material will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was higher than for any other hardwood species characterized. Because

TABLE IX

BLACK WILLOW MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-140	3212-144	Remarks
Yield, % solids	38.0	41.8	
Fraction			
On 60 mesh, %	34.7	60.6	Fraction contained principally phloem fibers (99%), with a trace of sclereidlike elements (<1%). Average arithmetic length of the phloem fibers was 1.2 mm.
On 100 mesh, %	6.1	6.4	Fraction contained principally phloem fibers (90-95%), with smaller percentages of sclereidlike elements (3-5%), crystalliferous parenchyma (<5%), and traces of sieve tube elements (1-2%), and parenchymatous cells (1-3%).
On 150 mesh, %	1.8	2.3	Fraction contained a large percentage of phloem fibers (60-70%), with smaller percentages of sclereidlike elements (5-15%), parenchymatous cells (10-20%), and almost equal percentages of sieve tube elements (5-7%) and crystalliferous parenchyma (5-6%).
On 200 mesh, %	1.7	3.0	Fraction contained a large percentage of parenchymatous cells (50-60%), with smaller percentages of phloem fibers (20-25%), sclereidlike elements (5-10%), crystalliferous parenchyma (5-10%), and sieve tube elements (3-8%).
Through 200 mesh, %	55.7	27.7	Fraction contained principally parenchymatous cells (85-90%), with small percentages of phloem fibers (<5%), sclereidlike elements (<5%), sieve tubes (<5%), and crystalliferous parenchyma (5%).

[a]Percentages given are on a dry weight basis.

of the large amount of bark fiber, this species is a prime candidate for whole-tree pulping, possibly after some segregation of the outer bark through mechanical treatment. Average arithmetic length of the bark fibers was 1.2 mm, compared to a wood fiber length of 1.1 mm as reported by Isenberg (7). Bark fiber lengths were measured on whole fibers, selected in an unbiased manner.

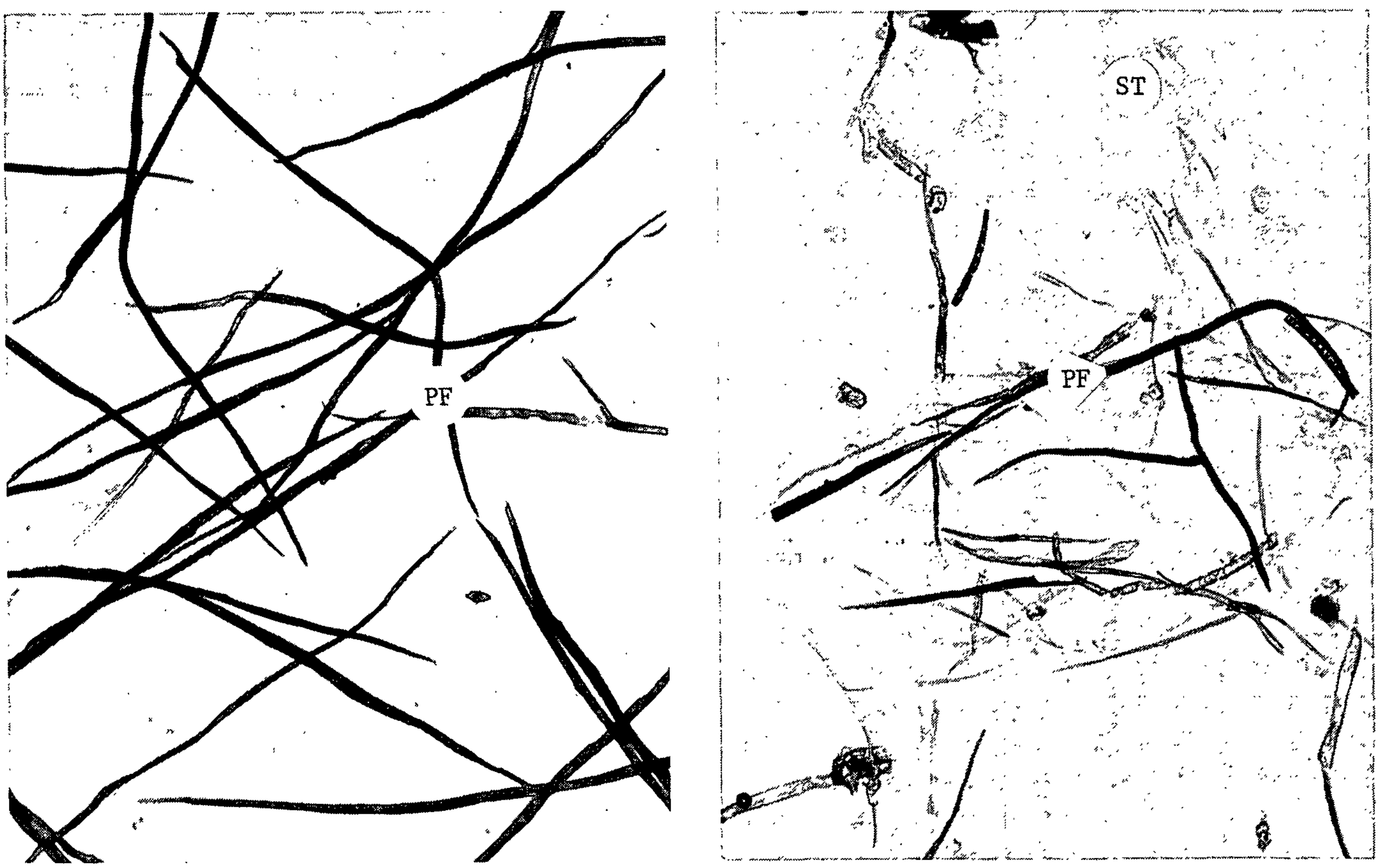


Figure 8. The 60-Mesh Screen (Left) Contained Principally Phloem Fibers (PF). The 150-Mesh Screen (Right) Contained Phloem Fibers, Sieve Tube Elements (ST) and Parenchymatous Cells. Magnification — 75X

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for black willow samples collected October 15, November 16 and January 23. After testing, the samples were examined to determine the location of the zone of failure. Figure 9 illustrates the zone of failure for black willow during the dormant season. The failure zone was located in the inner bark at the interface of fibers and longitudinal parenchyma. Separation was fairly close to the cambium zone, however, and along a sinuous line that permitted only 1-3 tangential lines of fibers to be retained with the xylem. Adhesion measurements averaged 17.6 kg/cm^2, a moderate value.

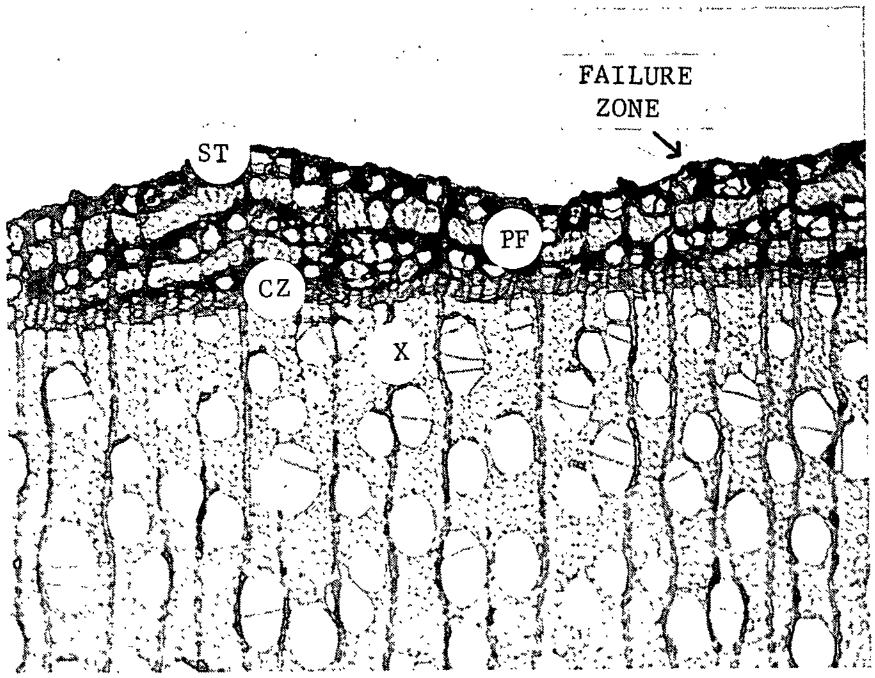


Figure 9. Illustrated is the Failure Zone for Black Willow During the Dormant Season. Failure Occurred in the Inner Bark at the Interface of Fibers and Longitudinal Parenchyma. Magnification — 75X. Symbols Illustrate Cambium Zone (CZ), Sieve Tube Elements (ST), Xylem (X) and Phloem Fibers (PF)

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with black willow. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of black willow. (Appendix Tables XXXIX and XL compare the modulus of elasticity of black willow bark with other species examined in this project.

Inner and outer bark strength values for black willow were relatively high compared to other species tested thus far. Toughness values for the sapwood were rather low. However, inner bark toughness was rather high while outer bark toughness was intermediate. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling.

High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the lower specific gravity of the bark and intermediate to high bark strength and toughness values, it appears hammermilling might not work well on this species.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF BLACK WILLOW

Material	Strength	Toughness
Wood	--	0.44
Inner bark	10.4	0.32
Outer bark	8.7	0.12

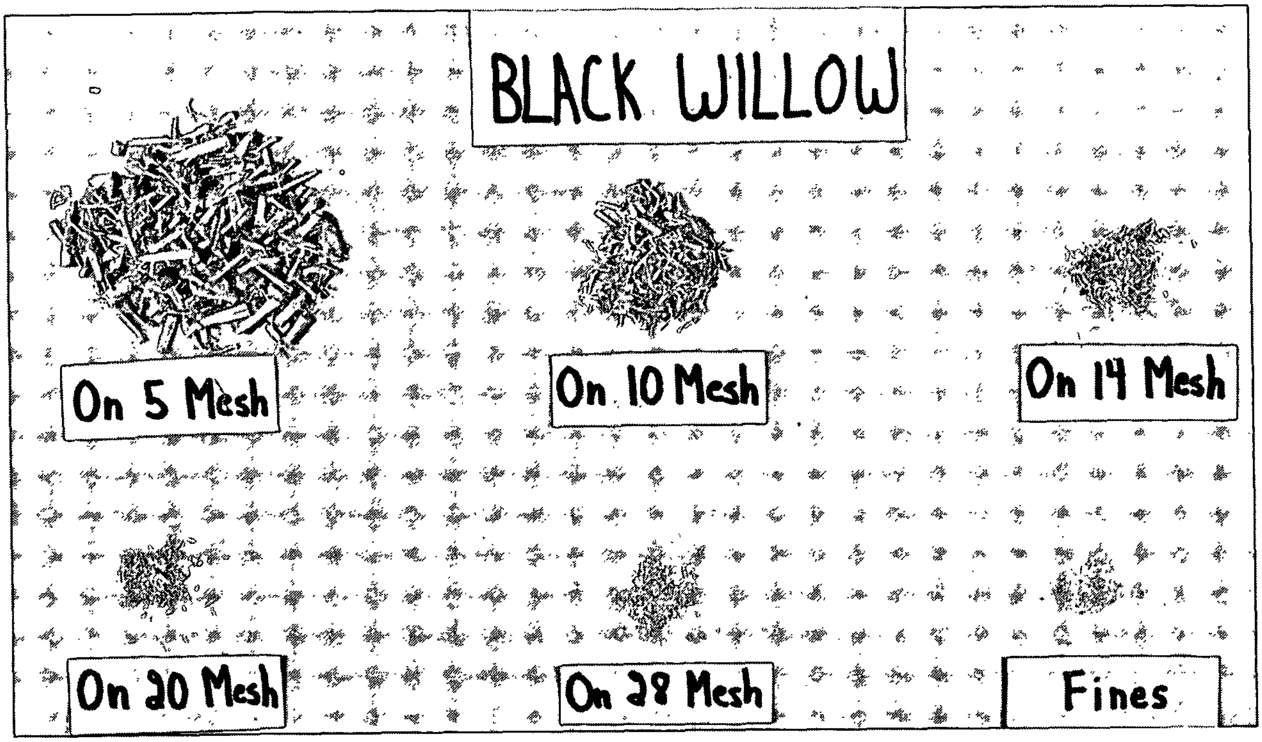
Summarized in Table XI are the results of the hammermilling tests run on black willow wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a small reduction in levels of bark. When the half-sized chips for the two trees (3212-140 and 3212-144) were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and a 13% reduction in levels of bark. This low reduction in bark levels was expected from the strength and toughness measurements. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but it still wouldn't amount to a major reduction in levels of bark (18% bark removal and 7% wood loss). It is possible that improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 10 (34-36). This would require changes in screen design and would tend to remove the outer bark which is the source of grit and dirt problems

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON BLACK WILLOW

Tree No.	Material	Fraction Retained on Standard Screen[a], %						Remarks
		5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	
3212-140	Bark	61.8	24.9	6.4	1.8	2.2	6.7	More inner bark on larger-mesh screens; increasing amounts of outer bark on smaller mesh screens; inner bark stringy in appearance.
	Sapwood	82.5	13.6	1.7	1.1	0.6	0.6	
	Heartwood	78.5	16.1	2.2	1.1	1.1	1.1	
3212-144	Bark	63.8	16.5	4.6	1.9	3.1	10.2	Same as above.
	Sapwood	76.2	13.8	5.0	1.7	1.2	2.2	
	Heartwood	73.2	19.2	3.9	1.3	1.0	1.4	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



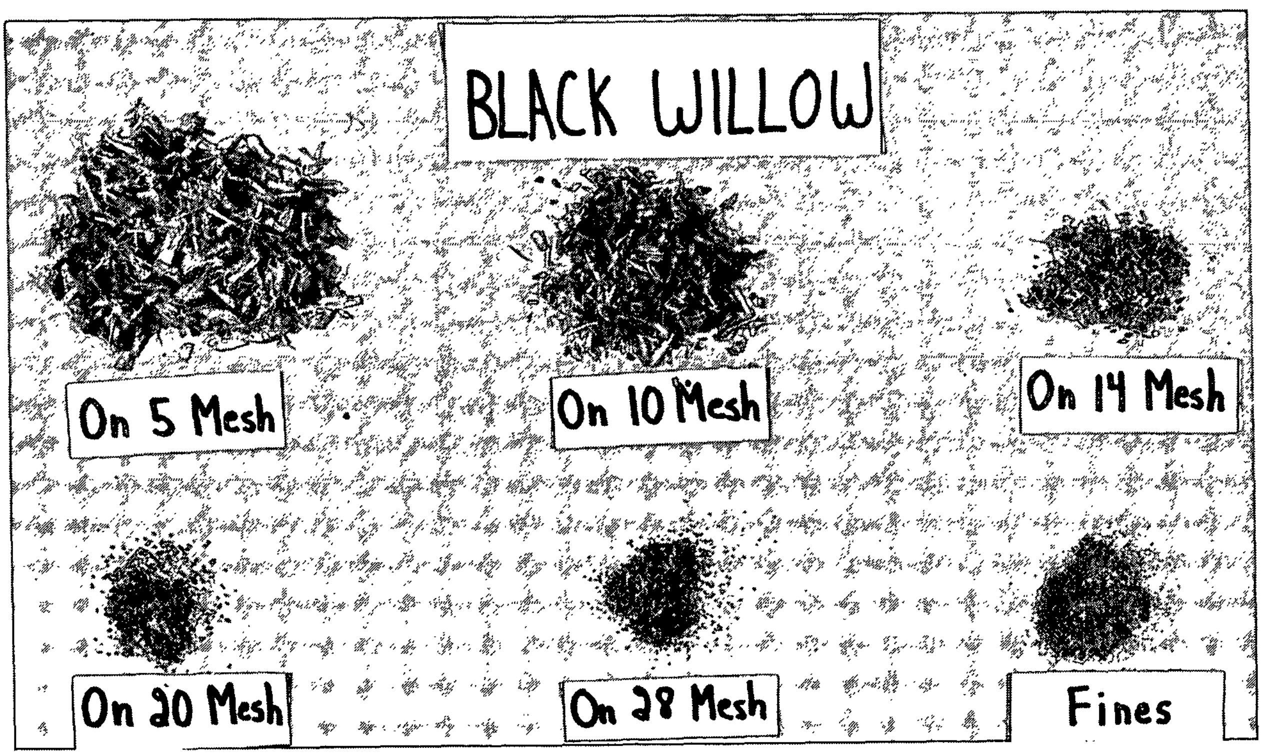


Figure 10. Illustrated is the Effect of Hammermilling on Black Willow Wood (Top) and Bark (Bottom)

while retaining the fiber-rich inner bark. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of black willow with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two black willow trees (IPC 3212-140 and IPC 3212-149) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The outer bark was similar to the total bark in density at comparable moisture contents while the inner bark was somewhat higher in density.

Figure 11 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that the bark is very low in density and would not sink even at moisture contents above 150%. The wood, however, would sink at moisture contents of 150% or above.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected.

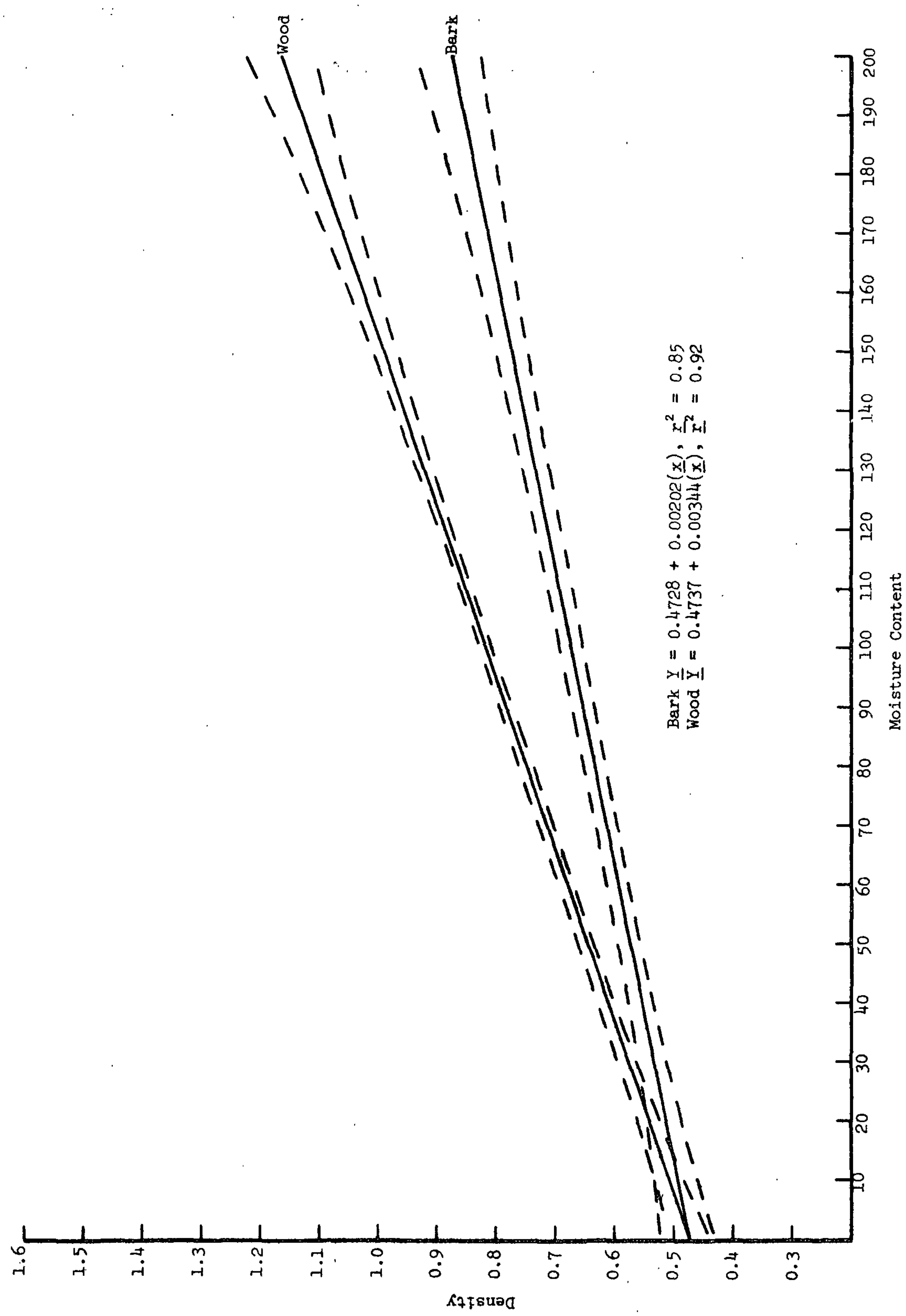


Figure 11. Illustrated is the Relationship Between Basic Density and Moisture Content for Black Willow. The Dashed Lines are Two Standard Deviations Above and Below the Mean

A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XII summarizes the results for black willow. Both trees behaved as expected, with all the bark and most of the wood floating at starting moisture contents from 85 to 165%.

DATA INTERPRETATION

The amount of fiber in black willow bark was a surprising 21% of an equally surprising total solids yield of 40%. In addition to the high fibrous yield, the amount of sclereids retained was low, only about 0.3%. Considering also the low bark extractives, this species is a good candidate for whole-tree chipping. The amount of usable bark fiber in black willow was higher than for any of the 42 species examined in this project.

Although hammermilling did not work well on this species, there were differences in the configuration of the inner and outer bark. The inner bark was stringy in appearance while the outer bark was in rounder pieces. It would be possible to chip, screen the chips, hammermill the fractions high in bark and rescreen. Retained with the wood would be the fiber-rich inner bark.

Segregation of wood and bark chips through water flotation was possible with this species but only at moisture contents above 150%.

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR BLACK WILLOW

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
3212-140 Bark	100.8	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-140 Sapwood	92.8	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-140 Heartwood	87.3	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-144 Bark	165.2	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-144 Sapwood	90.8	after 5	0	100
		15	0	100
		60	0	100
		240	2.4	97.6
3212-144 Heartwood	98.5	after 5	0	100
		15	0	100
		60	0	100
		240	0	100

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark mixtures. They include papers by Auchter and Horn (19), Hooper (20), Biltonen, et al. (21), Short, et al. (22), Miller (23), Vais and Vostrov (24), Arola and Erickson (25) and Arola, et al. (26). A good review on kraft pulping of roundwood chips is also given by Horn and Auchter (27).

BARK AND WOOD PROPERTIES OF GREEN ASH

[Fraxinus pennsylvanica Marsh.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Green ash is the most widely distributed, but not the most common, ash in North America. Its range extends from Nova Scotia to southeastern Alberta and Montana south to central Texas and northern Florida. Although natural stands are confined to bottomlands, it grows well when planted on moist upland sites. In most areas, this species reaches heights of 50-60 feet with diameters of 1 1/2-2 feet. In this report, we have considered green and red ash to be the same species and have identified it as follows: leaves — silky-downy beneath, petioles stout and pubescent, leaf scars usually straight on upper edge; twigs — first season's twigs more or less velvety; buds — small, rusty-brown, tomentose.

WOOD AND BARK MORPHOLOGY

Wood

The heartwood varies from brown to grayish brown while the sapwood is light-colored or nearly white. Growth rings are distinct and the wood has no characteristic odor or taste. Summerwood pores are barely visible to the naked eye. Second-growth trees have a large proportion of sapwood while old-growth trees, which are scarce, characteristically have little sapwood.

Bark

Ash bark is usually gray and, on mature trees, it is finely furrowed into diamond-shaped areas, separated by narrow, interlacing ridges. On young stems it may have an orange tinge. The outer bark, for the three trees examined, averaged

52% of the total bark on a dry weight basis, with a range from 40 to 64%. Figure 12 illustrates a cross section of green ash wood and bark. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

The inner bark of the specimen examined was quite thick, about 5 mm, and was composed of neatly arranged tissue containing sieve tube elements, companion cells, and longitudinal parenchyma. It was crossed in the radial direction by rays 1-3 cells wide and tangentially by interrupted lines of lignified fibers. Among the fibers were found only a few sclereids.

The outer bark or rhytidome system was very similar in morphology to the inner bark except for the presence of numerous, thin-walled periderms. The latter were almost concentric, were not very obvious (3-6 cells wide), but did appear to be lignified along with all other cells in the rhytidome.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIII summarizes the information available on wood and bark of green ash. Specific gravity is most often expressed in terms of ovendry weight divided

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

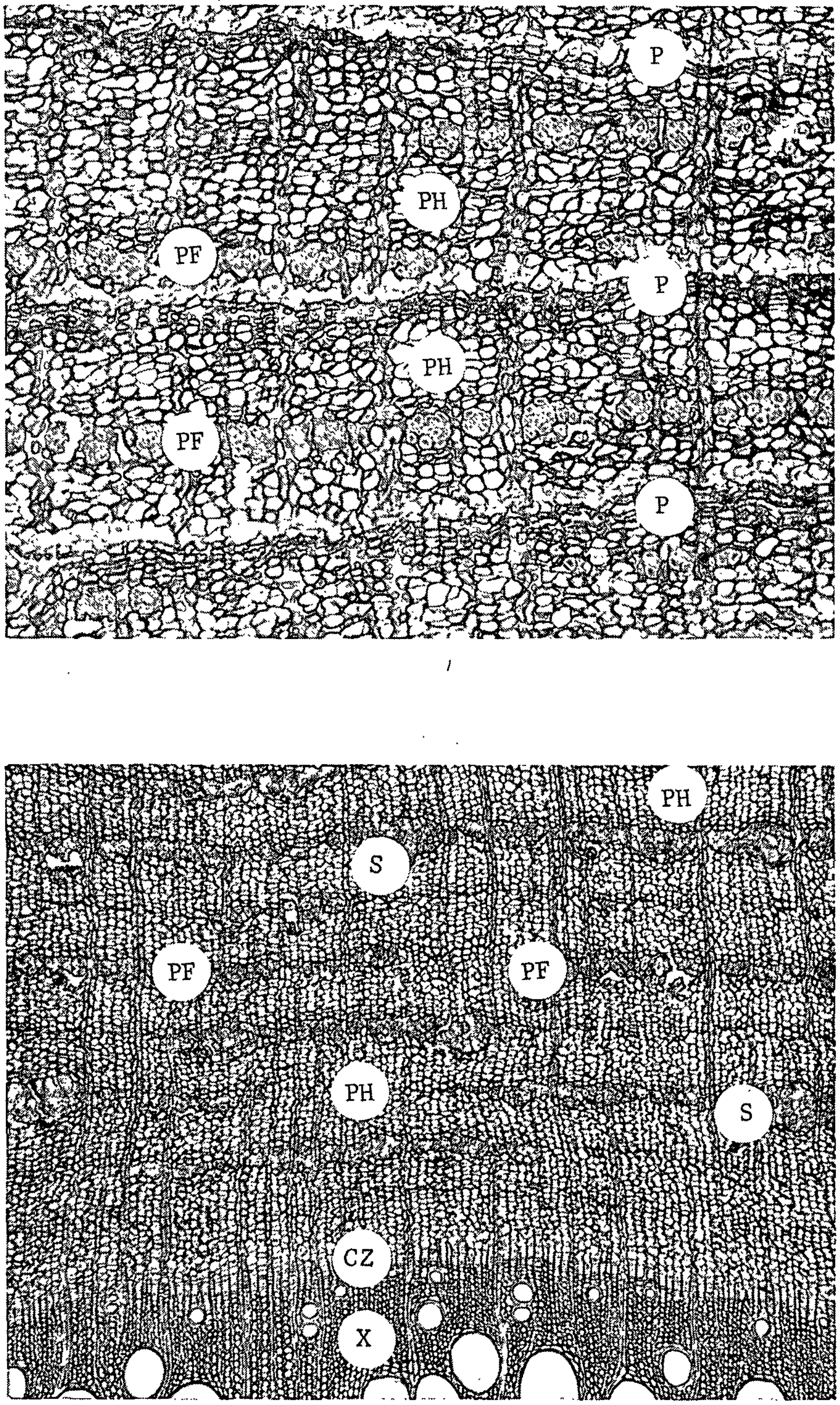


Figure 12. Cross Sections of Green Ash. Photograph on the Bottom Shows the Xylem (X), Cambium Zone (CZ), Discontinuous Lines of Phloem Fibers (PF), Nonfiber Phloem (PH) and Intermittent Sclereids (S). The Photograph on Top Shows the Outer Bark with Thin-Walled Periderms (P), Phloem Fibers (PF), and Nonfiber Phloem (PH). Magnification — 75X Top, 40X Bottom

by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of green ash at several moisture contents.

TABLE XIII

GREEN ASH SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References
0.53				IUFRO (8)
0.56			0.41	Manwiller (4)
0.54				Bendtsen and Ethington (6)
0.55				Maeglin (5)
		0.31		Fournier and Goulet (9)
0.59 (sapwood) 0.58 (heartwood)	0.54	0.37	0.46	IPC 3212-138
0.55 (sapwood) 0.61 (heartwood)	0.44	0.39	0.44	IPC 3212-139
0.60 (sapwood) 0.62 (heartwood)	0.50	0.32	0.49	IPC 3212-145
			0.65[a]	Choong and Cassens (31)

[a]Ovendry weight and volume — Fraxinus spp.

An average specific gravity (ovendry weight/green volume) of approximately 0.56 appears appropriate for the wood of green ash. Our samples were divided into sapwood and heartwood and specific gravity determinations made on each. Our limited data showed the sapwood and heartwood to be very close in specific gravity.

The specific gravity of the total (inner + outer) bark of green ash is somewhat lower than that of the wood. The outer bark was lower in specific gravity than the inner bark on all three trees examined in this project. Overall values suggested for use in species comparisons are 0.56 for wood and 0.49, 0.35 and 0.45 for inner, outer and total bark. These values are comparable to the ones obtained for white ash (0.57 for wood and 0.51, 0.43 and 0.48 for inner, outer and total bark).

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of green ash wood and bark. Table XIV summarizes existing data and includes the three IPC trees examined. Green ash wood is moderate in extractives and a level of 5.2% is suggested for use in between-species comparisons. Extractives work done on green ash bark in this project plus an additional value showed an average level of 17.4%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques. In contrast to green ash, white ash wood and bark had extractives levels of 4.0 and 12.6%, respectively.

TABLE XIV

GREEN ASH EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	6.2	Manwiller (4)
Wood	5.1	IPC 3212-139
Wood	5.7	IPC 3212-145
Wood	3.9	IPC 3212-138
Bark	17.5	Manwiller (4)
Bark	13.5	IPC 3212-139
Bark	24.8	IPC 3212-145
Bark	14.0	IPC 3212-138

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped green ash bark.

The thin-walled sieve tube elements (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. There appears to be a higher level of sclereids in green ash than was found in white ash. However, the amounts in both species are very small and should not be much of a problem when pulping the bark of either.

As a check on pulp yield and the nature of the material produced from green ash bark, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XV summarizes the results of this investigation. Micropulping green ash bark resulted in a yield of 35 to 41% solids. When screened, the coarse screens retained mostly phloem fibers. The on 150-mesh screen contained many phloem fibers along with some sieve tube elements, sclereids and parenchyma and peridermal cells. The on 200-mesh and through 200-mesh screens had large percentages of sieve tube elements, parenchyma and peridermal cells and smaller amounts of phloem fibers, and sclereids. Figure 13 illustrates the type of material on the 60- and 150-mesh screens.

TABLE XV

GREEN ASH MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-139	3212-145	Remarks
Yield, % solids	35.0	41.0	
Fraction			
On 60 mesh, %	18.4	42.5	Fraction contained principally phloem fibers (95-97%), with a smaller percentage of sclereids (2-5%), and a trace of sieve tube elements (1%). Average arithmetic length of the phloem fibers was 1.0 mm.
On 100 mesh, %	6.7	4.8	Fraction contained principally phloem fibers (80-90%) with smaller percentages of sclereids (5-15%), and sieve tube elements (1-3%). There was also a trace of parenchymatous cells (<1%).
On 150 mesh, %	4.6	4.2	Fraction contained a mixture of phloem fibers (40-50%) and sieve tube elements (25-30%), with smaller percentages of sclereids (10-20%), and parenchyma and peridermal cells (5-10%).
On 200 mesh, %	4.1	5.7	Fraction contained a large percentage of sieve tube elements (50-55%) with lower percentages of phloem fibers (10-15%), parenchyma and peridermal cells (15-20%) and sclereids (15-20%).
Through 200 mesh, %	66.2	42.8	Fraction contained a large percentage of parenchyma and peridermal cells (65-75%), with smaller percentages of sclereids (10-20%), and sieve tube elements (5-15%). There was only a small proportion of phloem fibers (<5%).

[a]Percentages given are on a dry weight basis.

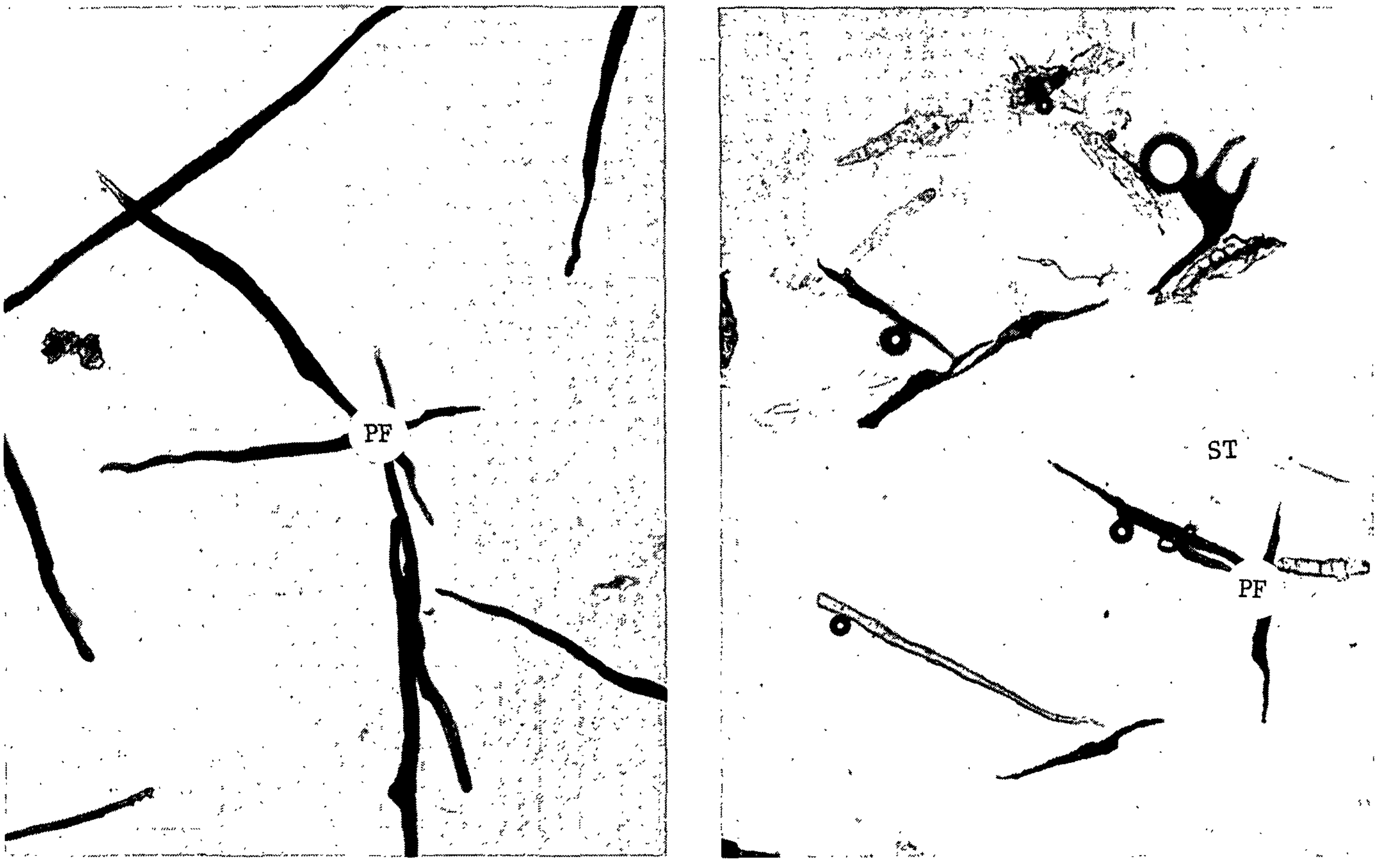


Figure 13. The 60-Mesh Screen (Left) Contained Primarily Phloem Fibers (PF). The 150-Mesh Screen (Right) Contained a Mixture of Phloem Fibers and Sieve Tube Elements (ST). Magnification — 75X

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 38 grams of solids will result. Of this 38 grams, about 12.9 grams (12.9%) of phloem fibers, 0.8 gram (0.8%) sclereids and 0.1 gram (0.1%) sieve tube elements will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for green ash samples collected October 15 and November 16. After testing, the samples were examined to determine the location of the zone of failure. Figure 14 illustrates the zone of failure for green ash during the dormant season. The failure zone was located in the inner bark about 1-2 mm from the cambium zone with the separation appearing to parallel the discontinuous, tangential lines of sclerenchyma for most of the samples tested. One sample did, however, fail in the cambium zone. Adhesion measurements averaged 17.4 kg/cm^2, a moderate value.

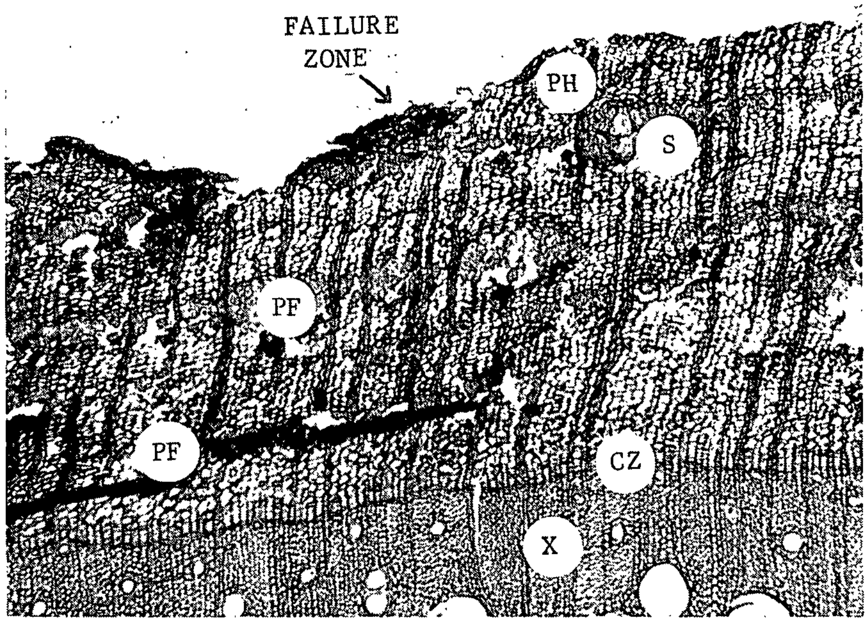


Figure 14. Illustrated is the Failure Zone for Green Ash During the Dormant Season. Failure Commonly Occurred in the Inner Bark About 1-2 mm from the Cambium Zone. Magnification — 40X. Symbols Illustrate Xylem (X), Cambium Zone (CZ), Phloem Fibers (PF), Sclereids (S), and Nonfiber Phloem (PH)

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with green ash. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of green ash. (Appendix Tables XXXIX and XL compare the modulus of elasticity of green ash bark with other species examined in this project.)

Bark strength values for green ash inner bark were relatively high compared to other species tested thus far while the outer bark was intermediate in strength. Toughness values for the sapwood were intermediate. However, inner and outer bark toughness values were rather high. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling.

High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength give poor bark removal. Based upon the lower specific gravity of the bark and the intermediate to high bark strength and toughness values, it appears hammermilling might not work well on this species.

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF GREEN ASH

Material	Strength	Toughness
Wood	--	0.64
Inner bark	12.6	0.36
Outer bark	6.4	0.22

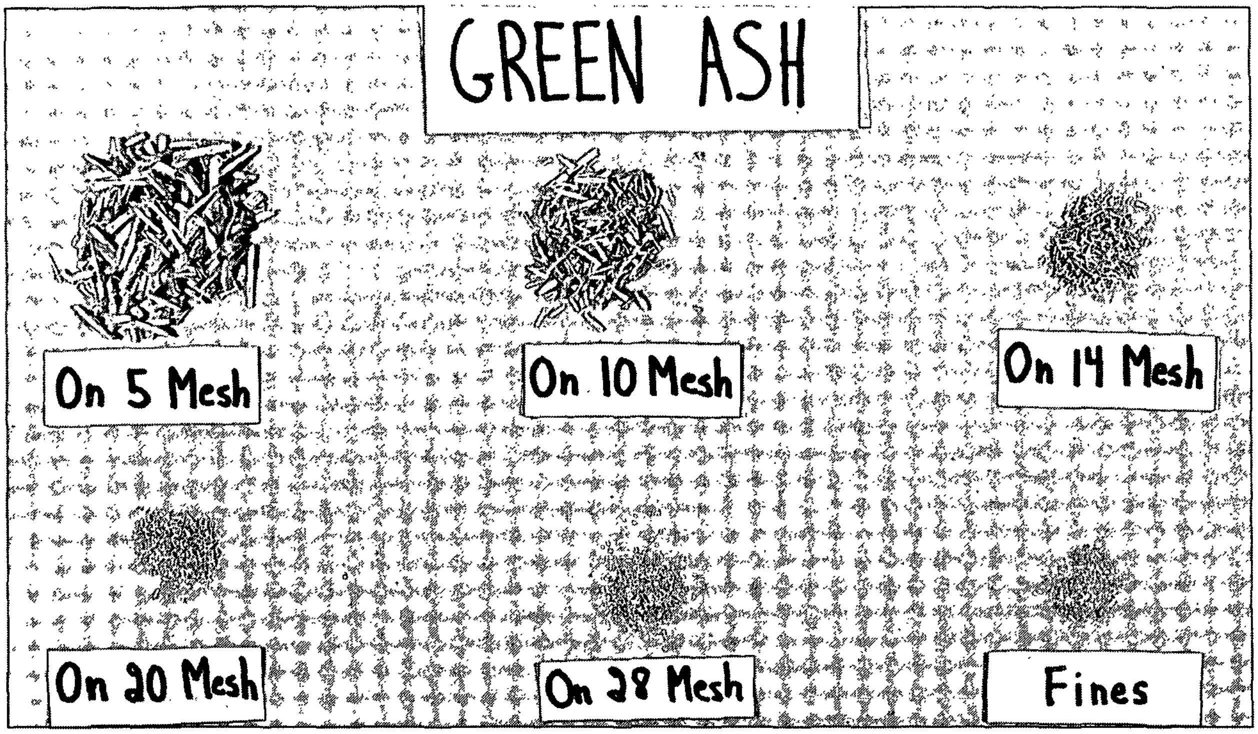
Summarized in Table XVII are the results of the hammermilling tests run on green ash wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a modest reduction in levels of bark. When the half-sized chips for the two trees (3212-139 and 3212-145) were hammermilled and the material on the 14-mesh screen retained, the result was a 5% wood loss and a 32% reduction in levels of bark. (This compares to a 24% reduction in bark for white ash and a 6% wood loss.) A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (42% bark removal and 9% wood loss). Figure 15 illustrates the effect of hammermilling on wood and bark of green ash. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON GREEN ASH

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-139	Bark	18.6	36.8	13.0	6.0	6.7	18.9	More inner bark on larger-mesh screens. Inner bark stringy; outer bark in chunks.
	Exterior	62.6	28.3	3.6	0.4	1.2	4.0	
	Interior	72.0	21.4	2.8	0.8	0.8	2.2	
3212-145	Bark	32.0	21.7	13.0	7.0	8.4	17.9	Same as above.
	Exterior	70.7	19.8	4.2	1.5	1.4	2.3	
	Interior	63.8	26.6	5.3	0.5	1.6	2.1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



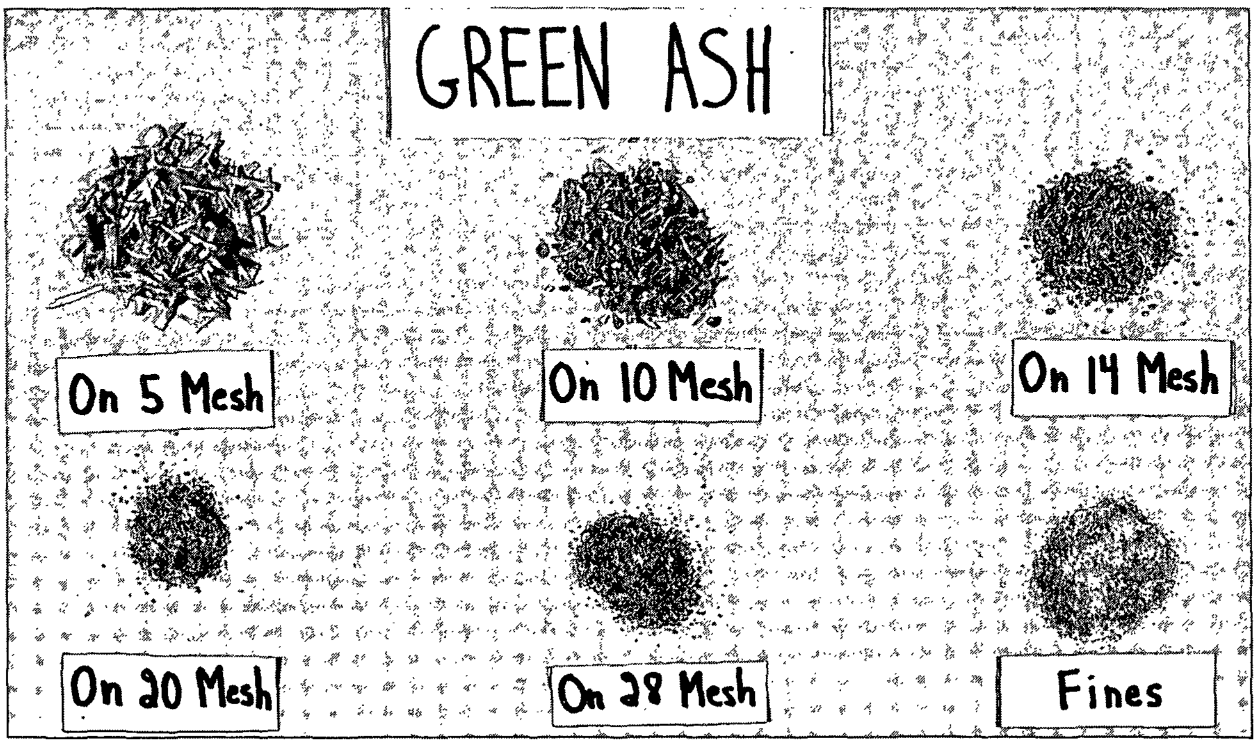


Figure 15. Illustrated is the Effect of Hammermilling on Green Ash Wood (Top) and Bark (Bottom)

improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 15 (34-36). This would require changes in screen design. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of green ash with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of wood and bark chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

<u>Density Determinations</u>

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two green ash trees

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

(IPC 3212-139 and IPC 3212-145) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The outer bark was similar to or slightly lower than the total bark in density at comparable moisture contents.

Figure 16 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that there is a narrow range of moisture contents at which segregation might be possible. At moisture contents of between 65 and 110%, wood chips would sink while the bark would still be floating. At higher moisture contents, both fractions would sink while at lower moisture contents both would float. Interestingly, white ash results were very similar, with segregation possible at moisture contents of between 60 and 110%.

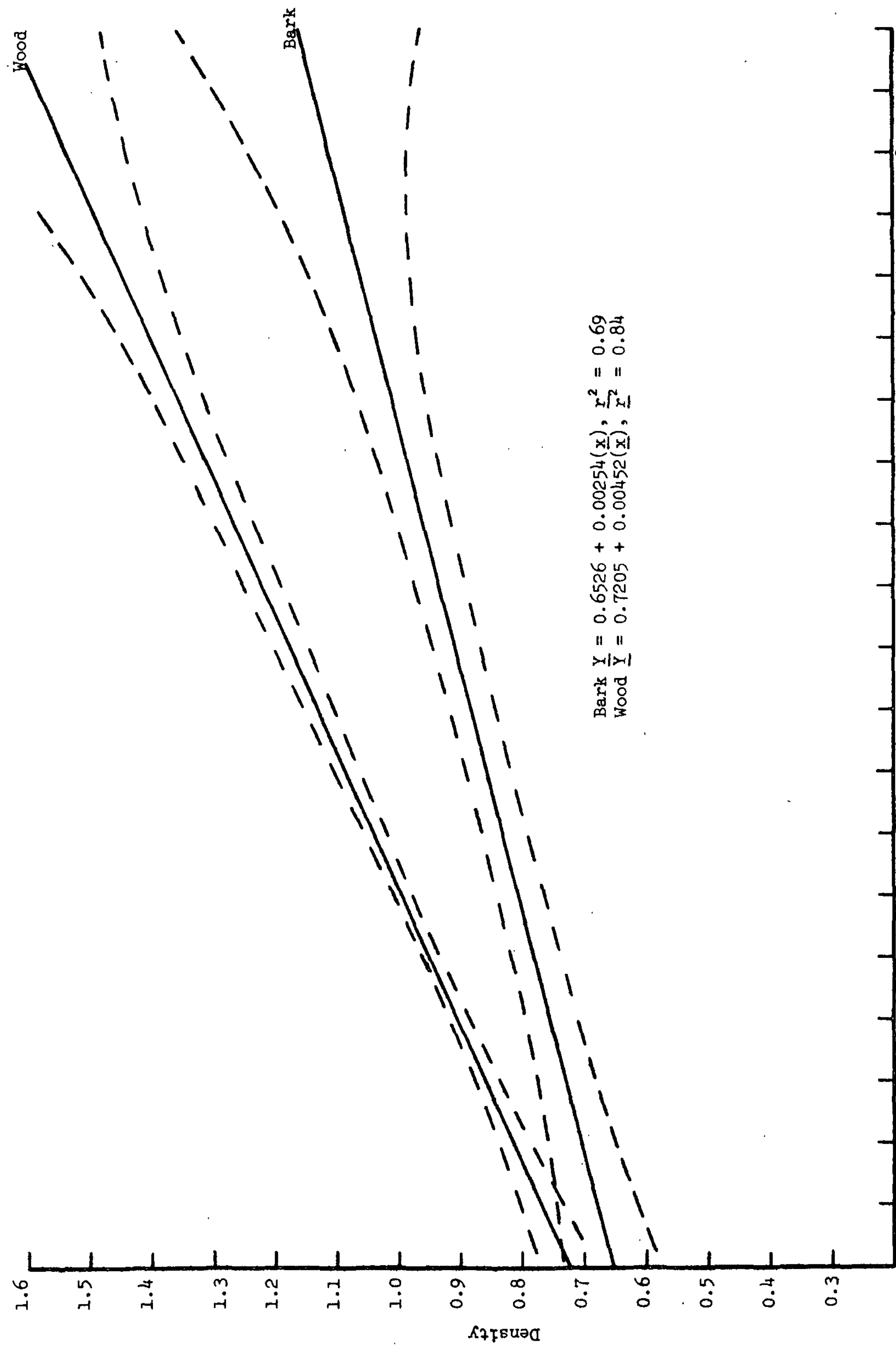


Figure 16. Illustrated is the Relationship Between Basic Density and Moisture Content for Green Ash. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washig procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XVIII summarizes the results for green ash. Tree 3212-145 behaved as expected from the density-moisture content curves. However, tree 3212-139 had more heartwood floating than would have been expected. The densities for this particular tree at various moisture contents was slightly less than that obtained for 3212-145 and may be a factor in its deviation from the curve which is based upon a combination of the two trees. This emphasizes again that the density-moisture content curves are merely an indication of the flotation characteristics of a particular species.

DATA INTERPRETATION

Fiber yield from green ash bark is reasonably good and the level of sclereids retained is relatively low (13% fibers and 0.8% sclereids retained on a 100-mesh screen). However, since green ash is high in extractives, it may be desirable to remove at least part of the bark.

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR GREEN ASH

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
3212-139	98.3	after 5	0	100
Bark		15	0	100
		60	0	100
		240	0	100
3212-139	81.1	after 5	71.4	28.6
Sapwood		15	71.4	28.6
		60	83.1	16.9
		240	92.6	7.4
3212-139	62.0	after 5	41.6	58.4
Heartwood		15	41.6	58.4
		60	41.6	58.4
		240	48.7	51.3
3212-145	88.0	after 5	19.2	80.8
Bark		15	19.2	80.8
		60	19.2	80.8
		240	19.2	80.8
3212-145	76.0	after 5	52.5	47.5
Sapwood		15	52.5	47.5
		60	55.6	44.4
		240	70.3	29.7
3212-145	65.6	after 5	77.9	22.1
Heartwood		15	77.9	22.1
		60	77.9	22.1
		240	77.9	22.1

The mechanical treatment investigated in this project to separate and segregate wood and bark gave moderate results with a 32% reduction in levels of bark and a 5% wood loss by retaining material on the 14-mesh screen. However, it appears green ash could be handled with some success by screening the whole-tree chips to concentrate most of the bark in the small chip fractions, mechanically treating that fraction and rescreening. Retained with the wood would be the stringy, fiber-rich inner bark.

Segregation through water flotation proved to be a feasible technique with segregation possible at moisture contents between 65 and 110% (o.d. basis). At these moisture contents, the wood would sink while the bark would still be floating.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark mixtures. They include papers by Auchter and Horn (19), Hooper (20), Biltonen, *et al*. (21), Short, *et al*. (22), Miller (23), Vais and Vostrov (24), Arola and Erickson (25) and Arola, *et al*. (26). A good review on kraft pulping of rough wood chips is also given by Horn and Auchter (27). Investigated by Martin and Crist (28) were the physical-mechanical properties of eastern tree barks while Manwiller (30) looked at bark moisture contents.

BARK AND WOOD PROPERTIES OF EASTERN WHITE PINE

[*Pinus strobus* L.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Eastern white pine grows across southern Canada from southeastern Manitoba to Newfoundland, through northern and eastern United States, from Minnesota and northeastern Iowa to the Atlantic Ocean and south along the Appalachians to northern Georgia. This species grows in a cool and humid climate with a growing season from 100-200 days. It is a long-lived tree and will commonly reach 200 years in age. Although capable of attaining a larger size, trees generally reach 80-100 feet in height and 2-3 1/2 feet in diameter.

WOOD AND BARK MORPHOLOGY

Wood

The heartwood is light brown, often with a reddish tinge, and turns considerably darker upon exposure to air. The sapwood is white to pale yellowish white. The wood has a comparatively uniform texture and is soft and straight grained. It has a resinous, noncharacteristic odor and no taste. The springwood is wide and the transition to summerwood is gradual. Rays are very fine and not visible to the naked eye except where they include a horizontal resin canal. Both horizontal and longitudinal resin canals are present. Parenchyma cells are absent. Average fiber measurements are 25-35 μm in diameter and 3.0 mm in length.

Bark

The bark on young trees is thin, smooth, greenish and lustrous. With increasing age, the bark becomes thicker, deeply furrowed and darker. Although generally 1-2 inches thick, the bark may sometimes reach a thickness of 3 inches.

The outer bark, for the three trees examined, averaged 83% on a dry weight basis, with a range from 68 to 92%. Figure 17 illustrates a cross section of eastern white pine wood and bark. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

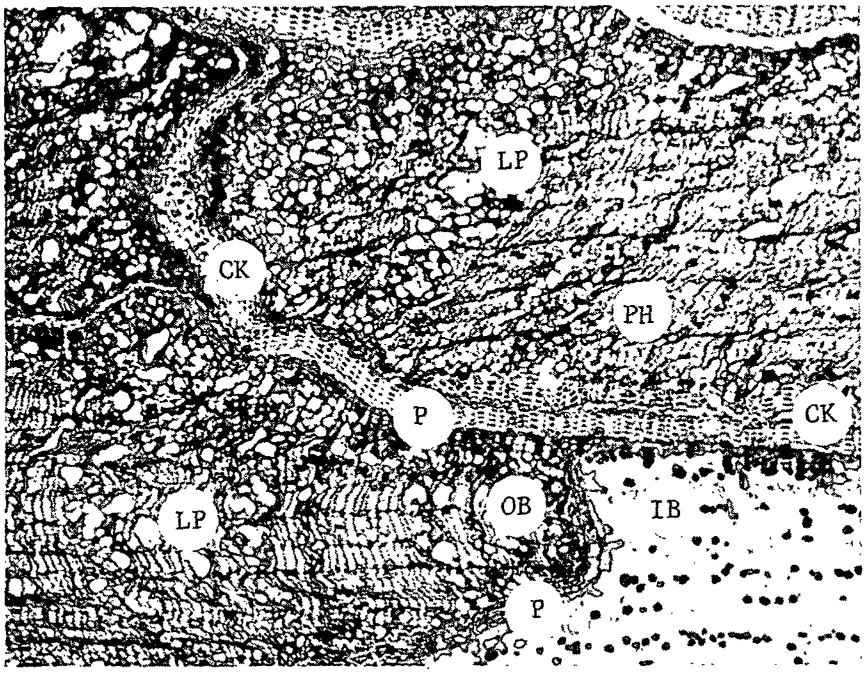
The secondary phloem of eastern white pine lacks fibers or sclereids. No resin ducts were observed in the 1.5-3 mm of inner bark on the specimen examined either. However, this may have been due to the fact that there was no cortex in the sample. Sieve cells were aligned radially and were crossed by tangential lines of longitudinal parenchyma, most cells of which contained tannin. Some longitudinal parenchyma dilated near the rhytidome, but ray cells appeared to remain living all the way to the outer bark. The phloem was somewhat crushed just exterior to the most recent annual addition.

The rhytidome in white pine is composed of overlapping, arc-like periderms consisting of only a few phelloderm cells but with 3-10 phellem cells per periderm; these cork cells are very sclerotic and contain tannin. Isolated zones of secondary phloem are common between successive periderms, and most of the rhytidome system appears to be lignified.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark of wood fraction from wood/bark mixtures.



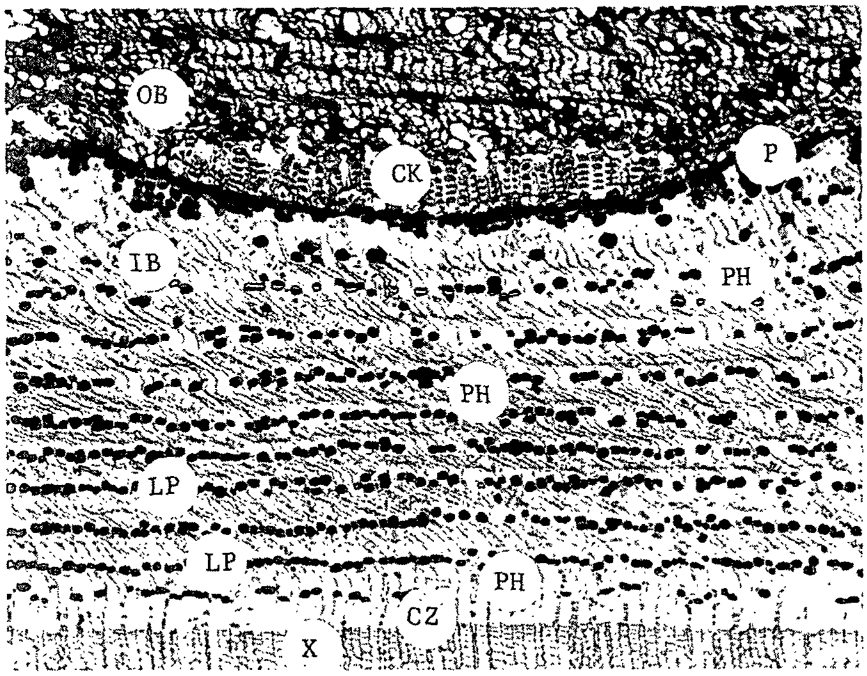


Figure 17. Cross Sections of Eastern White Pine. Photograph on the Bottom Shows the Wood and Inner and Outer Bark. Note the Distorted and Crushed Secondary Phloem (PH). Longitudinal Parenchyma (LP) are Filled with Tannin and are Aligned Tangentially. No Sclerenchyma are Present Except for Sclerotic Cork Cells (CK) in the Outer Bark (OB). Other Symbols Illustrate the Xylem (X), Cambium Zone (CZ) and a Periderm (P). The Photograph on Top Shows the Innermost Periderms (P) and the Cutoff of Secondary Phloem (PH) in the Outer Bark (OB). Some Longitudinal Parenchyma (LP) have Dilated. Magnification — 30X Top, 40X Bottom

Specific Gravity

Table XIX summarizes the information available on wood and bark of eastern white pine. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of eastern white pine at several moisture contents.

TABLE XIX

EASTERN WHITE PINE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References
0.31 (diam. class 4.6-8.9)				Wahlgren, et al. (37)
0.33 (diam. class 9.0-12.9)				Wahlgren, et al. (37)
0.32				Maeglin (5)
0.34				IUFRO (8)
0.34				Isenberg (7)
		0.50		Fournier and Goulet (9)
0.32 (exterior) 0.33 (interior)	0.33	0.55	0.53	IPC 3212-137
0.29 (sapwood) 0.28 (heartwood)	0.29	0.60	0.48	IPC 3212-143
0.29 (sapwood) 0.28 (heartwood)	0.35	0.47	0.41	IPC 3212-148
			0.57[a]	Harkin and Rowe (38)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.32 appears appropriate for the wood of eastern white pine. The samples were divided into sapwood and heartwood and, in one case, into exterior and interior wood. For 3212-137, the exterior wood constituted the outer 16 rings out of a total of 26 rings. The limited data on sapwood and heartwood indicated close agreement in specific gravity.

The specific gravity of the total (inner + outer) bark of eastern white pine is somewhat higher than that of the wood. The outer bark was higher in specific gravity than the inner bark on all three trees examined in this project. Overall values suggested for use in species comparisons are 0.32 for wood and 0.32, 0.53 and 0.47 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of eastern white pine wood. Table XX summarizes existing data and includes the three IPC trees examined. Eastern white pine wood has higher extractives levels than any species examined in this project. A level of 7.4% is suggested for use in between-species comparisons. Extractives work done on eastern white pine bark in this project showed an average level of 15.5%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques. Tree 3212-143 had an unusually high pitch content in the bark which undoubtedly contributed to its high extractives level.

TABLE XX

EASTERN WHITE PINE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	6.0	Skoggard and Libby (39)
Wood	6.7	IPC 3212-137
Wood	8.6	IPC 3212-143
Wood	8.1	IPC 3212-148
Bark	9.5	IPC 3212-137
Bark	23.8	IPC 3212-143
Bark	13.2	IPC 3212-148

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of eastern white pine having an effect on the pulp are sieve cells and phellem cells. There are no fibers in the bark of eastern white pine.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

There is also a minor amount of thick-walled, cogwheel-shaped phellem cells in eastern white pine similar to those found in the southern pines. The amount of this type of cell remaining in the pulp would vary, depending upon the degree of cooking, refining, etc., of the bark sample. Under typical kraft pulping (48-52% yield), phellem cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high-yield pulping, many of these phellem cells could remain in clumps and cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, spruce).

As a check on pulp yield and the nature of the material produced from eastern white pine, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXI summarizes the results of this investigation. Micropulping of eastern white pine bark resulted in a yield of 26 to 35% solids. When screened, the coarse screens (60- and 100-mesh) retained mostly

TABLE XXI

EASTERN WHITE PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-137	Sample No. 3212-143	Remarks
Yield, % solids	35.0	26.0	
Fraction			
On 60 mesh, %	21.0	20.9	Fraction contained principally sieve cells (95-99%), a small percentage of thick-walled, cogwheel-shaped phellem cells (<5%), and a trace of parenchyma and thin-walled peridermal cells. Average arithmetic length of the sieve cells was 1.6 mm.
On 100 mesh, %	3.8	5.0	Fraction contained principally sieve cells (90-95%), with a smaller percentage of thick-walled phellem cells (5-10%), and a very small percentage of parenchyma and thin-walled peridermal cells (1-2%).
On 150 mesh, %	3.2	12.1	Fraction contained principally sieve cells (60-65%) with a large amount of thick-walled phellem cells (20-25%), and a smaller percentage of parenchyma and thin-walled peridermal cells (10-15%).
On 200 mesh, %	10.3	6.5	Fraction contained large percentages of thick-walled phellem cells (60-65%), parenchyma and thin-walled peridermal cells (20-25%), and a smaller percentage of sieve cells (10-15%).
Through 200 mesh, %	61.7	55.5	Fraction contained principally cogwheel-shaped phellem cells (75-80%), with a smaller percentage of parenchyma and thin-walled peridermal cells (20-25%), and a trace of sieve cells (<1%).

[a]Percentages given are on a dry weight basis.

sieve cells with a smaller percentage of phellem cells. The on 150-mesh screen retained mostly sieve cells with a larger percentage of phellem cells. The on 200-mesh and through 200-mesh screens contained principally phellem cells, with some parenchyma and peridermal cells. Figure 18 illustrates the type of material on the 60- and 150-mesh screens. Figure 19 is a greatly magnified photomicrograph of the phellem cells found in eastern white pine.

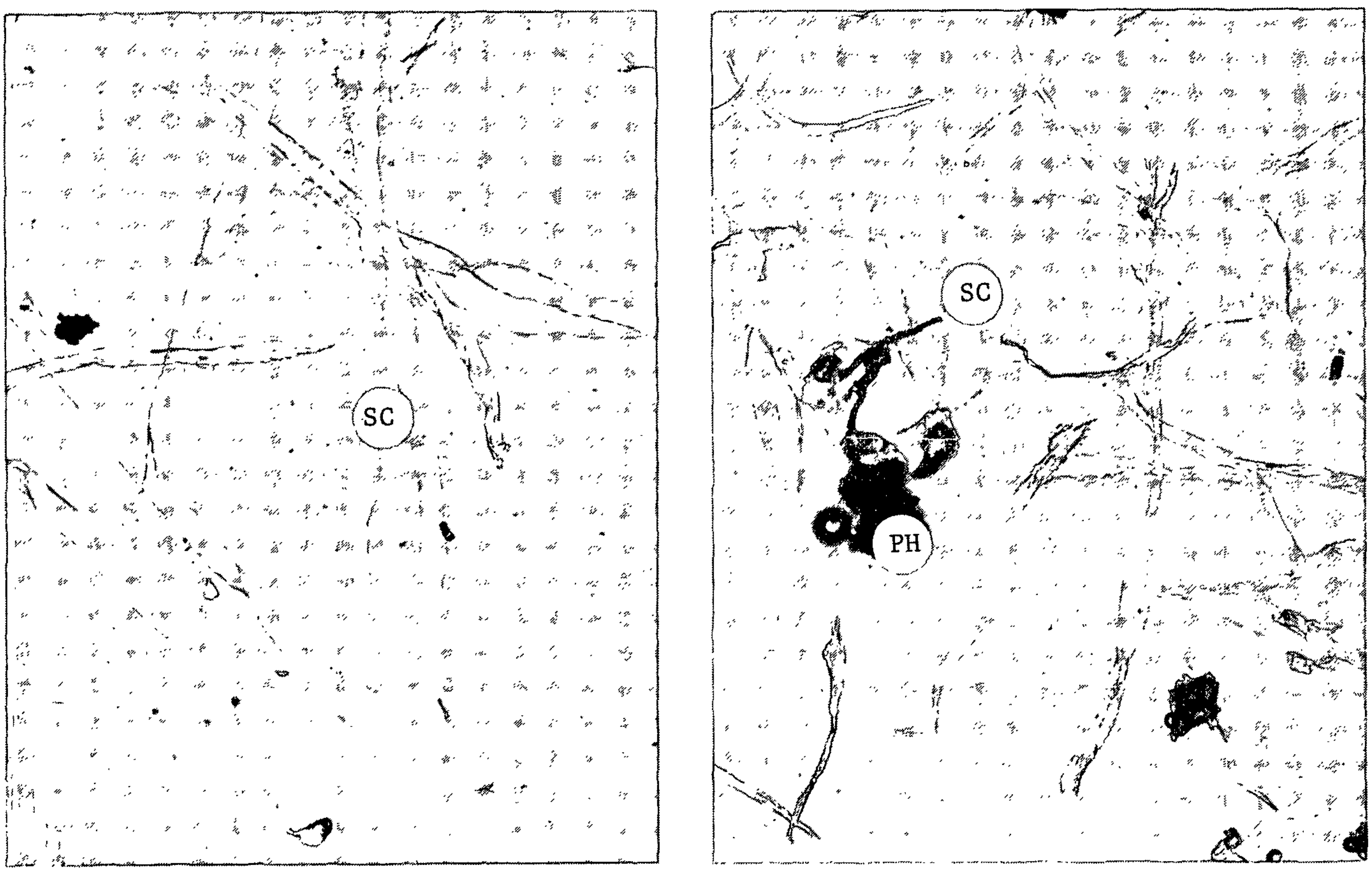


Figure 18. The 60-Mesh Screen (Left) Contained Primarily Sieve Cells (SC). The 150-Mesh Screen (Right) Contained a Large Percentage of Sieve Cells with Smaller Percentages of Phellem Cells (PH). Magnification — 75X

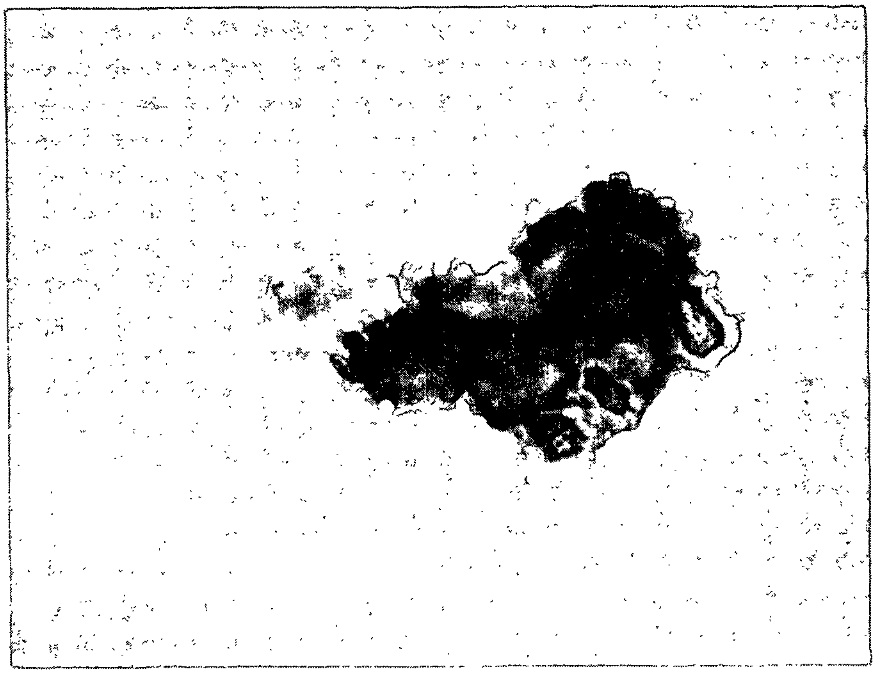


Figure 19. Illustrated is the Appearance of the Thick-Walled, Cogwheel-Shaped Phellem Cells Present in the Bark of Eastern White Pine. Magnification — 300X

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, an average of 30.5 grams of solids will result. Of this 30.5 grams, about 7.3 grams (7.3%) of sieve cells and 0.4 gram (0.4%) of phellem cells will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

Hyland (40), in pulping conifer needles, found they added little or nothing to the fibrous mass when included as a component. When needles were pulped alone, the yield for eastern white pine was 19.6%. The fibers were very long and lighter in color than balsam fir, hemlock or spruce. However, there was poor formation in the handsheet due to flocculation of the long fibers. Fiber strength was relatively good.

Chase and Young (41), investigating the potential of softwood thinnings, concluded that pulp from softwood thinnings is not as well delignified as most commercial pulps, lower yields may be expected, chemical consumption is higher and pulp from thinnings generally compares favorably with standard pulps in strength properties.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for eastern white pine samples collected November 9. After testing, the samples were examined to determine the location of the zone of failure. Figure 20 illustrates the zone of failure for eastern white pine during the dormant season. The failure zone was located in the inner bark about 1-1.3 mm into the phloem in an irregular tangential pattern, probably occurring frequently through zones of crushed sieve cells. Adhesion measurements averaged 7.3 kg/cm^2, a relatively low value.

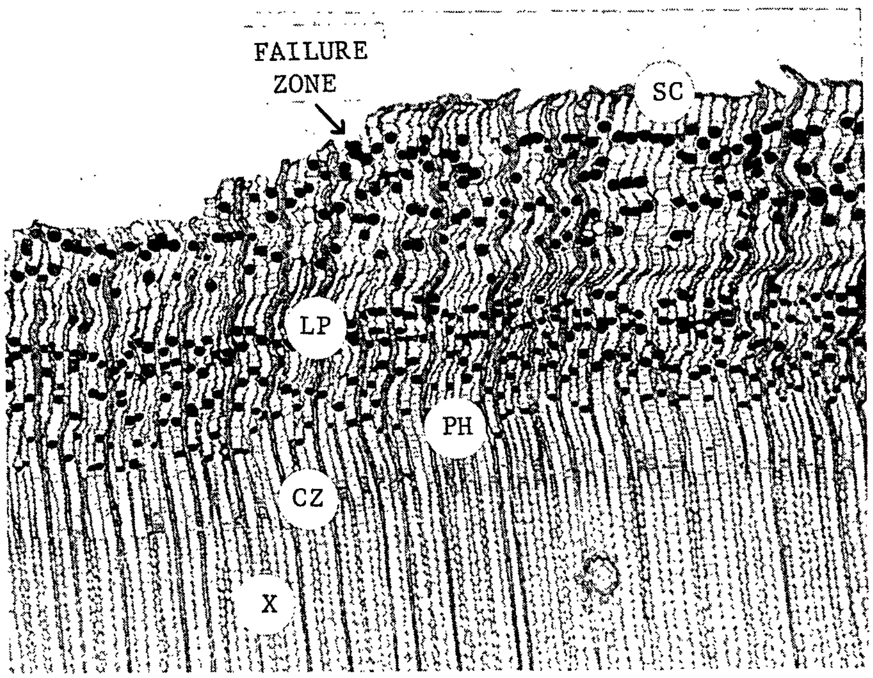


Figure 20. Illustrated is the Failure Zone for Eastern White Pine During the Dormant Season. Failure Occurred in the Inner Bark about 1-1.3 mm into the Phloem in an Irregular, Tangential Pattern. Magnification — 40X. Symbols Illustrate Xylem (X), Cambium Zone (CZ), Secondary Phloem (PH), Longitudinal Parenchyma (LP), and Sieve Cells (SC)

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated, including eastern white pine, appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of eastern white pine. (Appendix Table XXXIX and XL compare the modulus of elasticity of eastern white pine bark with other species examined in this project.)

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF EASTERN WHITE PINE

Material	Strength	Toughness
Wood	--	0.36
Inner bark	5.6	0.20
Outer bark	5.3	0.14

Bark strength values for eastern white pine inner and outer bark were moderate compared to other species tested thus far. Toughness values for both the sapwood and the inner bark were also intermediate while the outer bark toughness values were relatively high. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the moderate specific gravity of the bark and the intermediate to high bark strength and toughness values, it appears hammermilling might not work too well with this species.

Toughness tests on a number of species, as reported by Wood Handbook (42), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test is done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. Shown in Table XXIII is a comparison of IPC and Wood Handbook values for conifers. When the planned summary report is written, correlations will be run between IPC values and hammermilling results.

TABLE XXIII

COMPARISON OF TOUGHNESS VALUES

Species	I.P.C. Values Moisture Content, %	I.P.C. Values Toughness	Wood Handbook Values Moisture Content, %	Wood Handbook Values Toughness
Eastern white pine	20	0.36	12	120
Loblolly pine	20	0.54	11-13	260
Slash pine	20	0.54	11-13	320
Jack pine	20	0.34	11-13	240
Ponderosa pine	20	0.26	11-13	190
Engelmann spruce	20	0.26	11-13	180
Shortleaf pine	20	0.94	13	230
Virginia pine	20	0.61	12	250

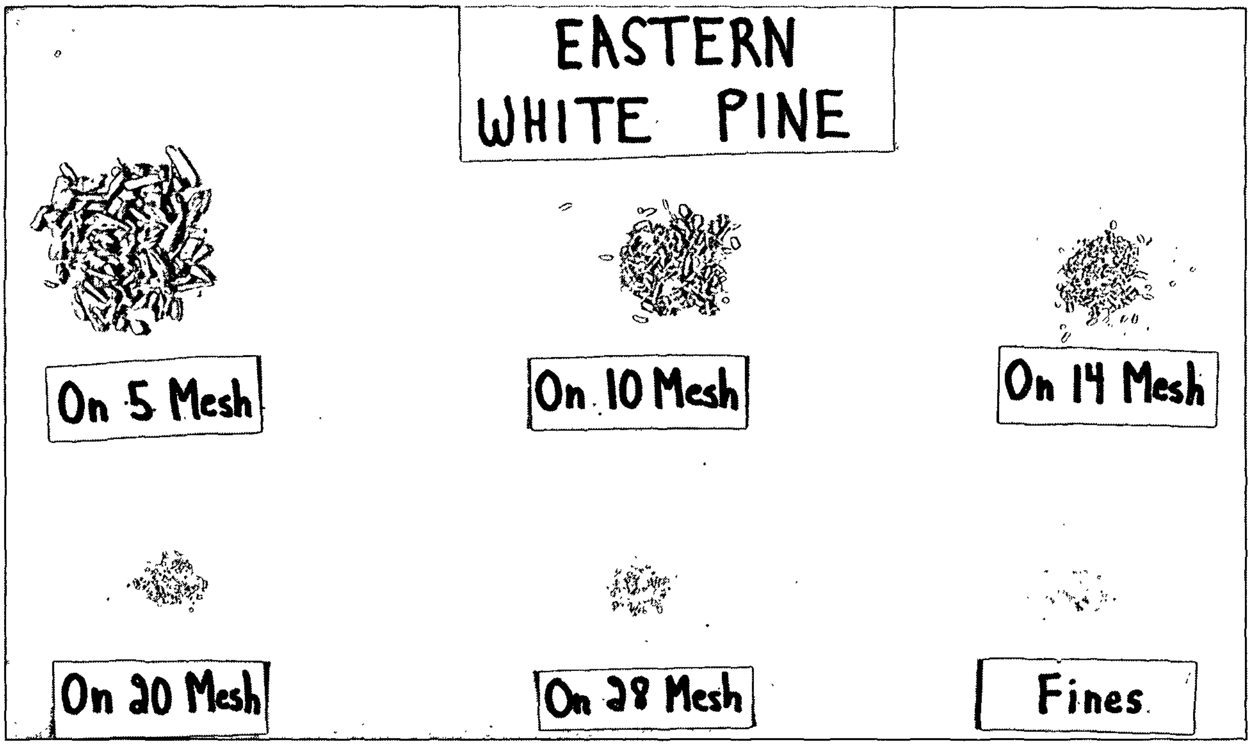
Summarized in Table XXIV are the results of the hammermilling tests run on eastern white pine wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a modest reduction in levels of bark. When the half-sized chips for the two trees (3212-137 and 3212-143) were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and a 29% reduction in levels of bark. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (47% bark removal and 10% wood loss). Figure 21 illustrates the effect of hammermilling on wood and bark of eastern white pine. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. Summary Table XXXV compares strength, toughness and reaction to hammermilling of eastern white pine with other species tested thus far.

TABLE XXIV

SUMMARY OF HAMMERMILLING TEST ON EASTERN WHITE PINE

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-137	Bark	20.4	33.4	17.0	8.8	8.2	12.1	More inner bark on larger-mesh screens. Increasing amounts of outer bark on smaller-mesh screens.
	Exterior	74.6	18.7	3.9	0.3	1.1	1.4	
	Interior	69.2	20.3	5.2	1.6	1.3	2.3	
3212-143	Bark	18.2	33.9	19.1	9.0	8.4	11.3	Same as above.
	Exterior	60.8	29.4	5.8	2.0	1.0	0.9	
	Interior	56.6	30.9	8.0	1.8	1.3	1.5	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



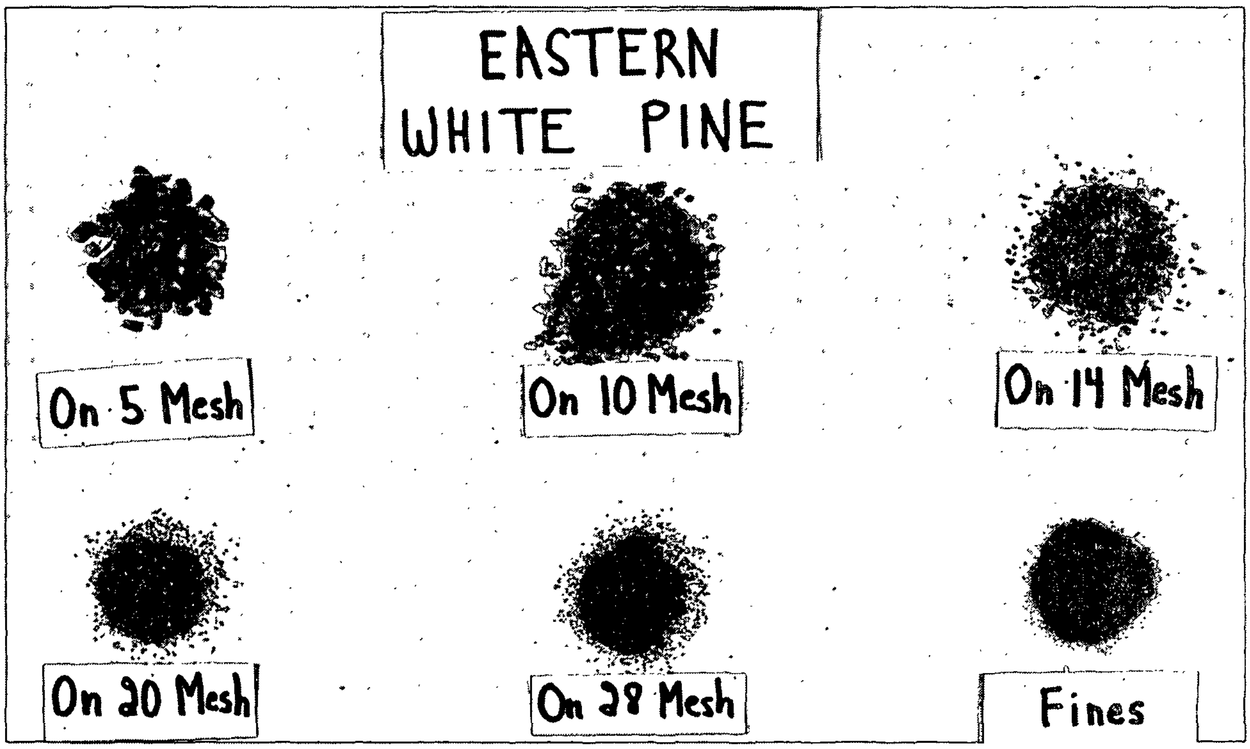


Figure 21. Illustrated is the Effect of Hammermilling on Eastern White Pine Wood (Top) and Bark (Bottom)

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two eastern white pine trees (IPC 3212-137 and IPC 3212-143) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were similar in density at comparable moisture contents.

Figure 22 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation is possible only at moisture contents above 100%. At lesser moisture contents, both fractions would still be floating. However, this is essentially the moisture content of fresh chips.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and

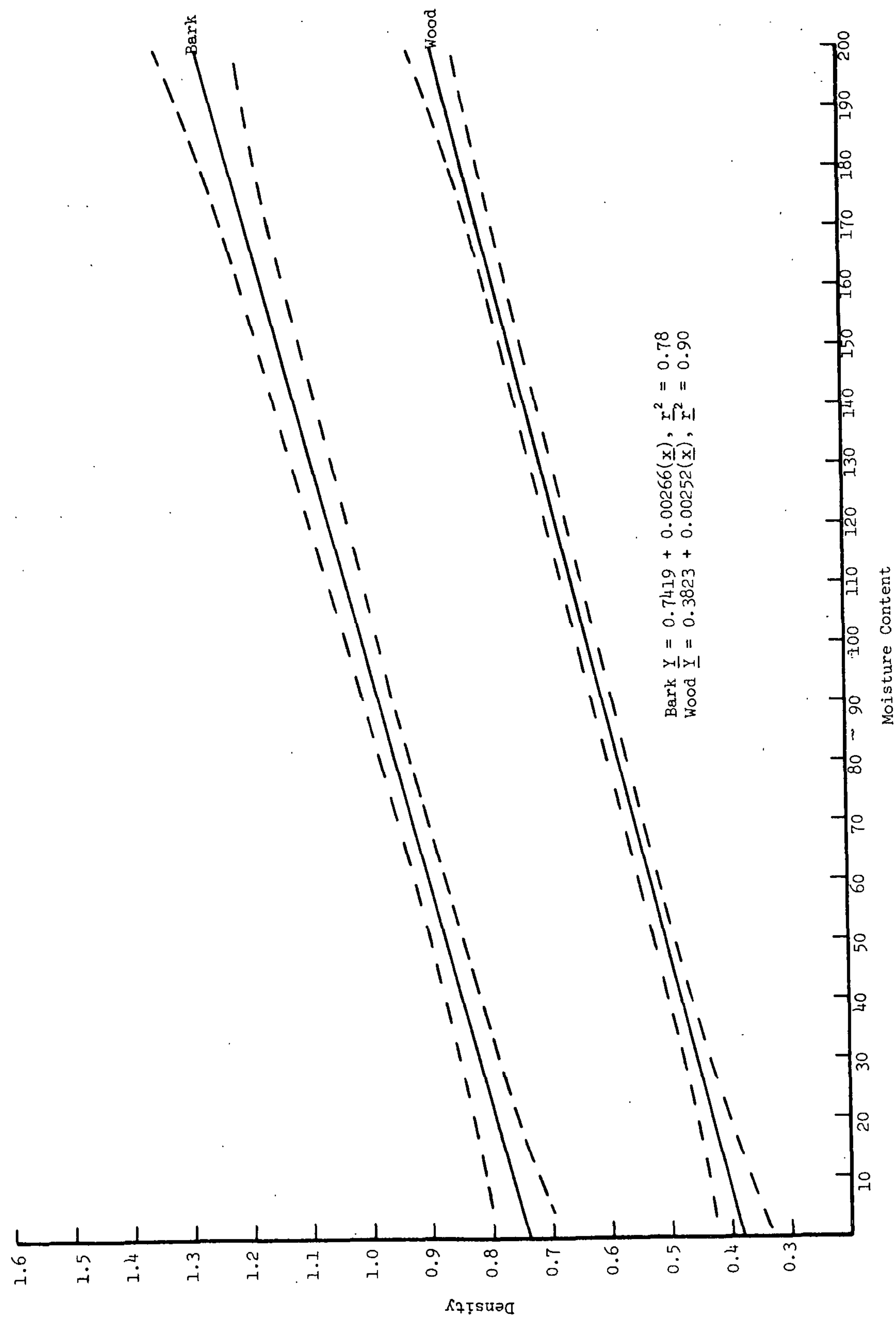


Figure 22. Illustrated is the Relationship Between Basic Density and Moisture Content for Eastern White Pine. The Dashed Lines are Two Standard Deviations Above and Below the Mean

moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XXV summarizes the results for eastern white pine. The trees behaved much as expected with the wood floating at moisture contents of approximately 87%. Part of the bark sank for both trees but the moisture contents, particularly for tree 3212-143, were close to the point where sinking should occur. The results confirm the density measurements and indicate that increasing the moisture content of wood/bark chip mixtures above 100% will give satisfactory segregation.

DATA INTERPRETATION

Eastern white pine, like most of the softwoods investigated, has no fiber in the bark. It does contain sieve cells which would act as filler in paper but probably would not contribute to paper properties. It also contains a minor amount of phellem cells, most of which would be lost during pulping. However, in high-yield pulping, clumps of phellem cells could cause problems in paper. Eastern white pine thinnings gave favorable strength properties but lower yields and greater chemical consumption (41).

Since bark extractives are relatively high in this species and there is no usable fiber, removal of at least part of the bark appears desirable. Hammermilling, the mechanical treatment investigated in this project, resulted in only a modest reduction in levels of bark. However, as mentioned before for several tree species, the screening-hammermilling-rescreening approach would be possible. Removed would be a greater proportion of outer bark.

TABLE XXV

SUMMARY OF DWELL TIME RESULTS FOR EASTERN WHITE PINE

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
3212-137 Bark	87.0	after 5	8.6	91.4
		15	8.6	91.4
		60	8.6	91.4
		240	13.7	86.3
3212-137 Exterior wood	88.8	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-137 Interior wood	86.8	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-143 Bark	89.7	after 5	32.5	67.5
		15	39.6	60.4
		60	40.4	59.6
		240	43.7	56.3
3212-143 Sapwood	85.6	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-143 Heartwood	87.5	after 5	0	100
		15	0	100
		60	0	100
		240	0	100

Segregation of wood/bark chip mixtures is possible with this species at moisture contents above 100%. This is essentially the moisture content of fresh chips and segregation should be possible if the trees were subjected to water flotation shortly after being harvested and chipped.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark mixtures. They include papers by Auchter and Horn (19), Hooper (20), Biltonen, et al. (21), Short, et al. (22), Miller (23), Vais and Vostrov (24), Arola and Erickson (25) and Arola, et al. (26). A good review on kraft pulping of rough wood chips is also given by Horn and Auchter (27). Investigated by Martin and Crist (28) were physical-mechanical properties of eastern tree barks while Martin (43) examined interim volumetric expansion values for bark.

BARK AND WOOD PROPERTIES OF EASTERN HEMLOCK

[Tsuga canadensis (L.) Carr]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

The climate preferred by eastern hemlock is predominantly cool and humid with adequate moisture in all seasons. It is native to the northeastern United States, southern Canada, the Lake States and Appalachians. Eastern hemlock may reach large size and great age at maturity but commonly is 60-70 feet tall and 2-3 feet in diameter. It is a tolerant species.

WOOD AND BARK MORPHOLOGY

Wood

The sapwood is creamy white to pale brown and usually indistinguishable from the heartwood. The wood is soft to moderately hard, medium textured, dry, brittle and uneven grained. It is odorless or sour smelling when fresh but without characteristic taste. The springwood occupies at least two-thirds of the ring and the transition to summerwood is abrupt. The summerwood frequently has a reddish-brown tinge. Resin canals are normally absent. The rays are very fine in cross section and not distinct with the naked eye. Parenchyma cells are not visible. Fiber measurements average 28-40 μm in diameter and 3.0 mm in length.

Bark

On young trees, the bark is flaky or scaly but it soon develops wide, flat ridges. The bark on old trees is deeply furrowed. The outer bark, for the three trees examined, averaged 67% of the total bark, with a range from 59 to 80%. Figure 23 illustrates a cross section of eastern hemlock wood and bark. Appendix Table XXXVI describes the trees used in this study.

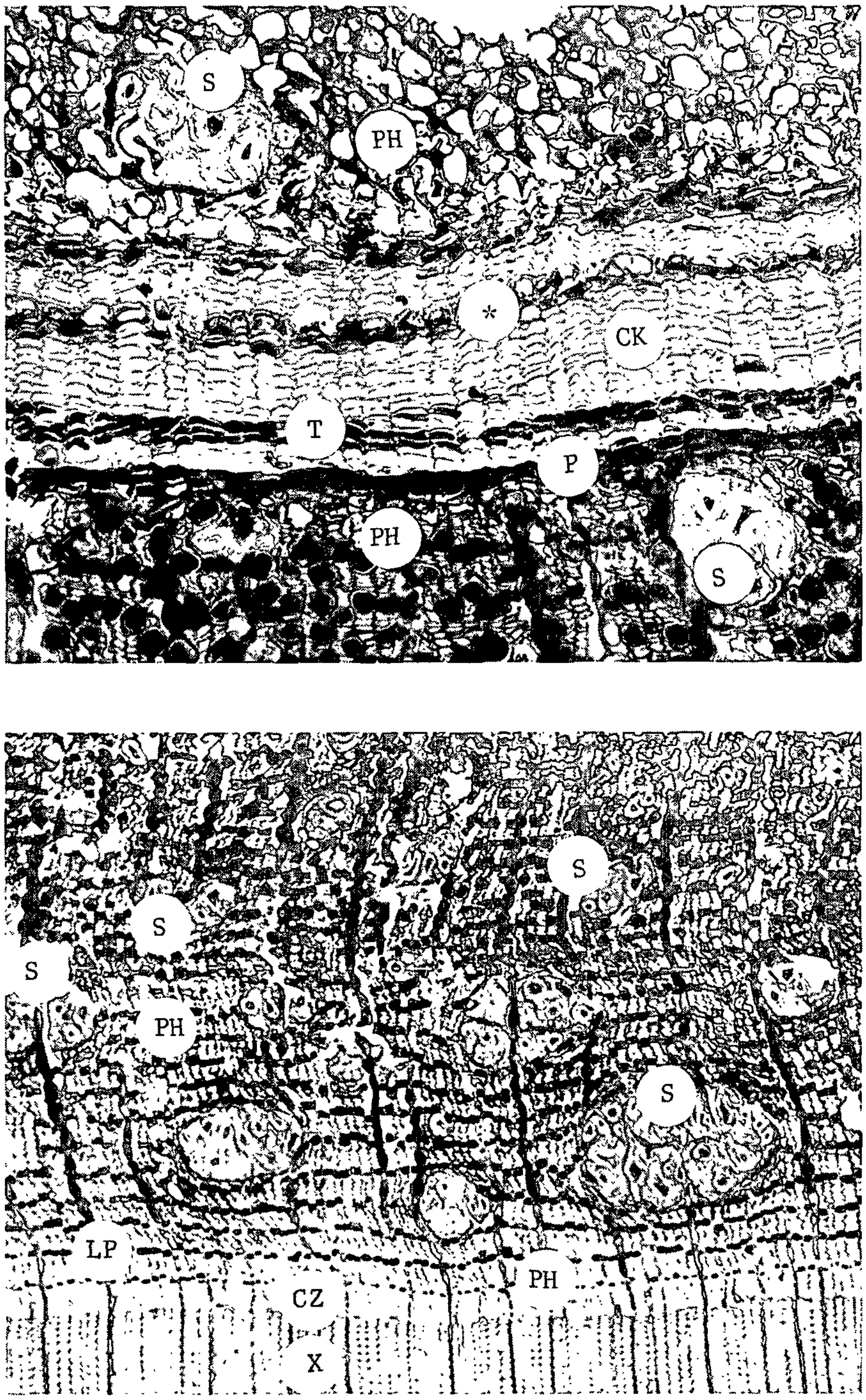


Figure 23. Cross Sections of Eastern Hemlock. Photograph on the Bottom Shows the Wood and Inner Bark with Clusters of Sclereids (S) Among Collapsing Elements of the Secondary Phloem (PH). Longitudinal Parenchyma (LP) are Evident in Tangential Bands. Also Illustrated is the Xylem (X) and Cambium Zone (CZ). The Photograph on Top Shows the Periderm System (P) with Numerous Cork Cells (CK), Isolating Regions of the Secondary Phloem (PH). Some Cork Cells are Sclerotic (*) and/or Tanniferous (T). Magnification — 75X Top, 40X Bottom

Anatomical Structure of Bark

Near the cambium zone, sieve cells occur in radial rows of 4-5 cells between uniseriate, tangential lines of tannin-filled longitudinal parenchyma. Further out, the sieve cells are compacted, the longitudinal parenchyma more abundant with no special arrangement, and rays somewhat dilated. Tannin also occurs in the ray parenchyma.

Phloem sclerenchyma occur in the form of clusters of lignified and branched sclereids. These clusters appear as close as 15-20 cells outside the cambium zone, with diameters up to about 500 μm. No resin passages were observed in the secondary phloem of the samples examined. The rhytidome here occurred outside about 3-4 mm of inner bark and was composed of relatively concentric periderms, which sometimes curved to isolate zones of secondary phloem, including sclereids. Only very few phelloderm cells per periderm were produced, but (bands of) 10-20 phellem (or cork) cells were common. Some tangential lines of phellem cells were sclerotic. Eastern hemlock has a bark structure generally like that of western hemlock.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

Specific Gravity

Table XXVI summarizes the information available on wood and bark of eastern hemlock. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of eastern hemlock at several moisture contents.

TABLE XXVI

EASTERN HEMLOCK SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

	Bark			
Wood Average	Inner	Outer	Total	References
0.40 (4.6-8.9 diam. class)				Wahlgren, et al. (37)
0.38 (9.0-12.9 diam. class)				Wahlgren, et al. (37)
0.39				Pronin (44)
0.41				Young, et al. (45)
0.38				IUFRO (8)
0.38				Isenberg (7)
			0.40	Fournier and Goulet (9)
0.42 (exterior) 0.47 (interior)	0.37	0.40	0.40	IPC 3212-136
0.40 (sapwood) 0.42 (heartwood)	0.46	0.49	0.49	IPC 3212-142
0.37 (exterior) 0.41 (interior)	0.36	0.43	0.43	IPC 3212-147
			0.51[a]	Harkin and Rowe (38)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.40 appears appropriate for the wood of eastern hemlock. Our samples were divided into sapwood and heartwood and, in one case, into exterior and interior wood. For 3212-136, the exterior wood constituted the outer 20 rings out of a total of 115 rings. Our limited data showed the sapwood and heartwood to be very close in specific gravity.

The specific gravity of the total (inner + outer) bark of eastern hemlock is close to that of the wood. The outer bark was slightly higher in specific gravity than the inner bark on all three trees examined in this project. Overall values suggested for use in species comparisons are 0.40 for wood and 0.40, 0.44 and 0.43 for inner, outer and total bark.

Interestingly, the specific gravity of western hemlock for both the wood and the bark is very close to that of eastern hemlock (0.40 for wood and 0.45, 0.46 and 0.45 for inner, outer and total bark). However, the bark structure of both species is also very similar.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of eastern hemlock wood and bark. Table XXVII summarizes existing data and includes the three IPC trees examined. Eastern hemlock wood is low in extractives and a level of 3.7% is suggested for use in between-species comparisons. Extractives work done on eastern hemlock bark in this project plus an additional value showed an average level of 25.4%. This is a high level of extractives and might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques. In comparison, bark extractives levels in western hemlock averaged 11.7%.

TABLE XXVII

EASTERN HEMLOCK EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.0	Isenberg (7)
Wood	3.3	IPC 3212-136
Wood	3.5	IPC 3212-142
Wood	3.9	IPC 3212-147
Bark	24.0	Chang and Mitchell (33)
Bark	31.8	IPC 3212-136
Bark	22.8	IPC 3212-142
Bark	23.2	IPC 3212-147

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking operations.

Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of eastern hemlock having an effect on the pulp are sieve cells and sclereids. There are no fibers in the bark of eastern hemlock.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. Using cross sections, Chang (1) estimated the percentage of sieve cells in the secondary phloem of eastern hemlock to be 60%.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. This problem might especially arise with the thick-walled, branched groups of sclereids and the larger, individual sclereid cells. Sclereids amounted to 16.5% of the secondary phloem of eastern hemlock, using cross sections (1). As a check on pulp yield and the nature of the material produced from eastern hemlock, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXVIII summarizes the results of this investigation. Micropulping of eastern hemlock bark resulted in a yield of 29 to 41% solids. When screened, the coarse screens (60- and 100-mesh) retained mainly sieve cells and some sclereids. The on 150-mesh screen retained a mixture of sieve cells and sclereids. The on 200-mesh

TABLE XXVIII

EASTERN HEMLOCK MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-136	Sample No. 3212-142	Remarks
Yield, % solids	28.7	41.2	
Fraction			
On 60 mesh, %	47.4	39.3	Fraction contained principally sieve cells (80-90%), and a smaller percentage of sclereids (10-20%). Average arithmetic length of the sieve cells was 1.9 mm.
On 100 mesh, %	12.7	19.4	Fraction contained a mixture of sieve cells (55-65%) and sclereids (35-45%). There was also a trace of parenchyma and thin-walled peridermal cells (1%).
On 150 mesh, %	6.6	3.6	Fraction contained a mixture of sieve cells (45-50%) and sclereids (45-55%). Also found was a small percentage of parenchyma and peridermal cells (3-5%).
On 200 mesh, %	4.3	2.3	Fraction contained a large percentage of thick-walled sclereids (55-60%), with smaller percentages of sieve cells (25-30%), and parenchyma and peridermal cells (10-20%).
Through 200 mesh, %	29.0	35.4	Fraction contained a large percentage of sclereids (70-80%), with smaller percentages of parenchyma and peridermal cells (20-25%), and a trace of sieve cells (2-3%).

[a]Percentages given are on a dry weight basis.

and through 200-mesh screens contained large amounts of sclereids and smaller percentages of sieve cells and parenchyma and peridermal cells. Figure 24 illustrates the type of material on the 60- and 150-mesh screens.

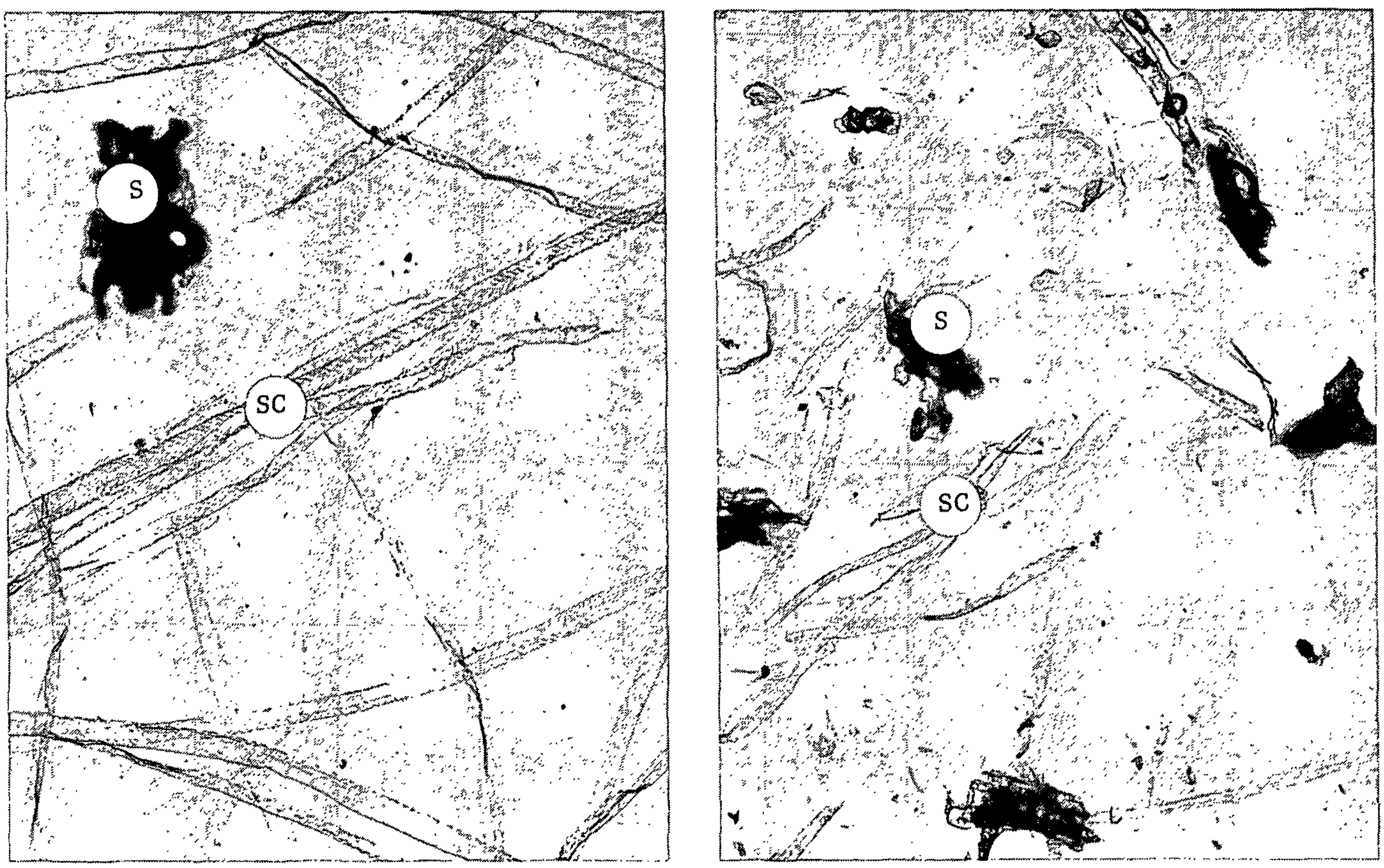


Figure 24. The 60-Mesh Screen (Left) Contained by Weight Primarily Sieve Cells (SC) and a Smaller Percentage of Sclereids (S). The 150-Mesh Screen (Right) Contained a Mixture of Sieve Cells and Sclereids. Magnification — 75X

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 35 grams of solids will result. Of this 35 grams, about 16.3 grams (16.3%) of sieve cells and 4.5 grams (4.5%) of sclereids will be produced. This assumes that only the material on the

60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. In contrast to eastern hemlock, 13% of the sieve cells and 11% of the sclereids were retained on the coarse screens for western hemlock.

Hyland (40), in pulping conifer needles, found they added little or nothing to the fibrous mass when included as a component. When needles were pulped alone, the yield for eastern hemlock was 17.8%. The fibers were very short and lighter in color than those from balsam fir. The handsheet was well formed but very weak.

Chase and Young (41), investigating the potential of softwood thinnings, concluded that pulp from softwood thinnings is not as well delignified as most commercial pulps, lower yields may be expected, chemical consumption is higher and pulp from thinnings generally compare favorably with standard pulps in strength properties.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for eastern hemlock samples collected November 9. After testing, the samples were examined to determine the location of the zone of failure. Figure 25 illustrates the zone of failure for eastern hemlock during the dormant season. The failure zone was located in the inner bark, essentially along the tangential lines of parenchyma. Most sclereids remained on the phloem side of the test sample with only a few sclereids being retained with the wood. Adhesion measurements average 14.3 kg/cm^2, a moderate value.

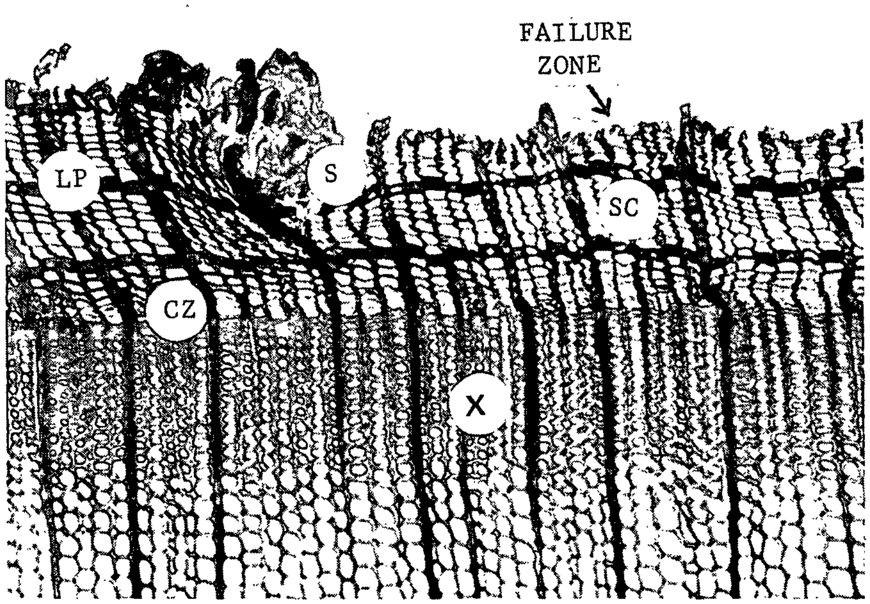


Figure 25. Illustrated is the Failure Zone for Eastern Hemlock During the Dormant Season. Failure Occurred in the Inner Bark, Essentially Along the Tangential Lines of Parenchyma. Magnification — 75X. Symbols Illustrate Xylem (X), Cambium Zone (CZ), Sieve Cells (SC), Longitudinal Parenchyma (LP) and Sclereids (S)

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Erickson (16) reported that better wood/bark separation was achieved by chipping frozen winter-cut roundwood than by chipping unfrozen roundwood although more fines resulted. Unloosened bark averaged 2.3% of the total material.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXIX summarizes the bark strength and toughness tests made on the wood and bark of eastern hemlock. (Appendix Tables XXXIX and XL compare the modulus of elasticity of eastern hemlock bark with other species examined in the project.)

TABLE XXIX

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF EASTERN HEMLOCK

Material	Strength	Toughness
Wood	--	0.60
Inner bark	5.9	0.16
Outer bark	5.8	0.10

Bark strength values for eastern hemlock inner and outer bark were moderate compared to other species tested thus far. Toughness values for the sapwood were relatively high while those for the inner and outer bark were intermediate. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the moderate specific gravity of the bark and the intermediate to high bark strength and toughness values, it appears hammermilling might not work too well on this species.

Summarized in Table XXX are the results of the hammermilling tests run on eastern hemlock wood and bark. Pure fractions of either wood or bark were

TABLE XXX

SUMMARY OF HAMMERMILLING TEST ON EASTERN HEMLOCK

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-136	Bark	31.5	31.9	12.6	5.2	5.3	13.5	Larger amount of inner bark on bigger meshes, increasing amounts of outer bark on smaller mesh screens.
	Exterior	48.0	35.1	9.9	2.6	2.2	2.2	
	Interior	51.6	34.4	7.0	2.9	1.8	2.3	
3212-142	Bark	29.9	32.3	12.4	5.0	6.8	13.6	Same as above.
	Exterior	57.9	32.8	5.5	2.0	0.8	1.0	
	Interior	50.3	40.0	6.0	1.7	1.0	1.1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a modest reduction in levels of bark. When the half-sized chips for the two trees (3212-136 and 3212-142) were hammermilled and the material on the 14-mesh screen retained, the result was a 5% wood loss and a 25% reduction in levels of bark. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (37% bark removal and 12% wood loss). In many instances, a wood loss that high would be unacceptable. Figure 26 illustrates the effect of hammermilling on wood and bark of eastern hemlock. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method or used for fuel. Most of the bark removed would be outer bark. Summary Table XXXV compares strength, toughness and reaction to hammermilling of eastern hemlock with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

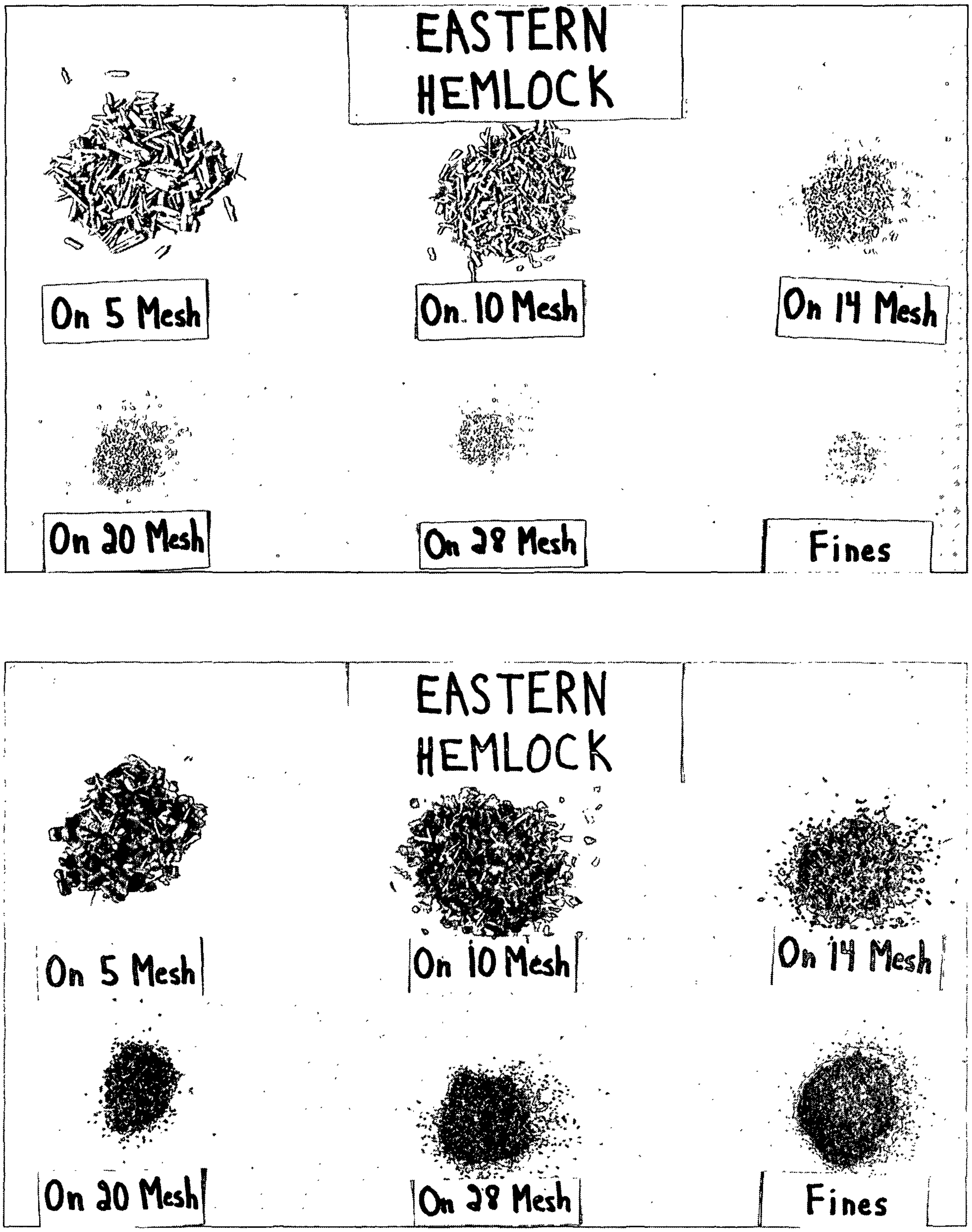


Figure 26. Illustrated is the Effect of Hammermilling on Eastern Hemlock Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two eastern hemlock trees (IPC 3212-136 and IPC 3212-142) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark appeared slightly higher than the total bark in density at various moisture contents while the outer bark was very similar in density to the total bark.

Figure 27 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

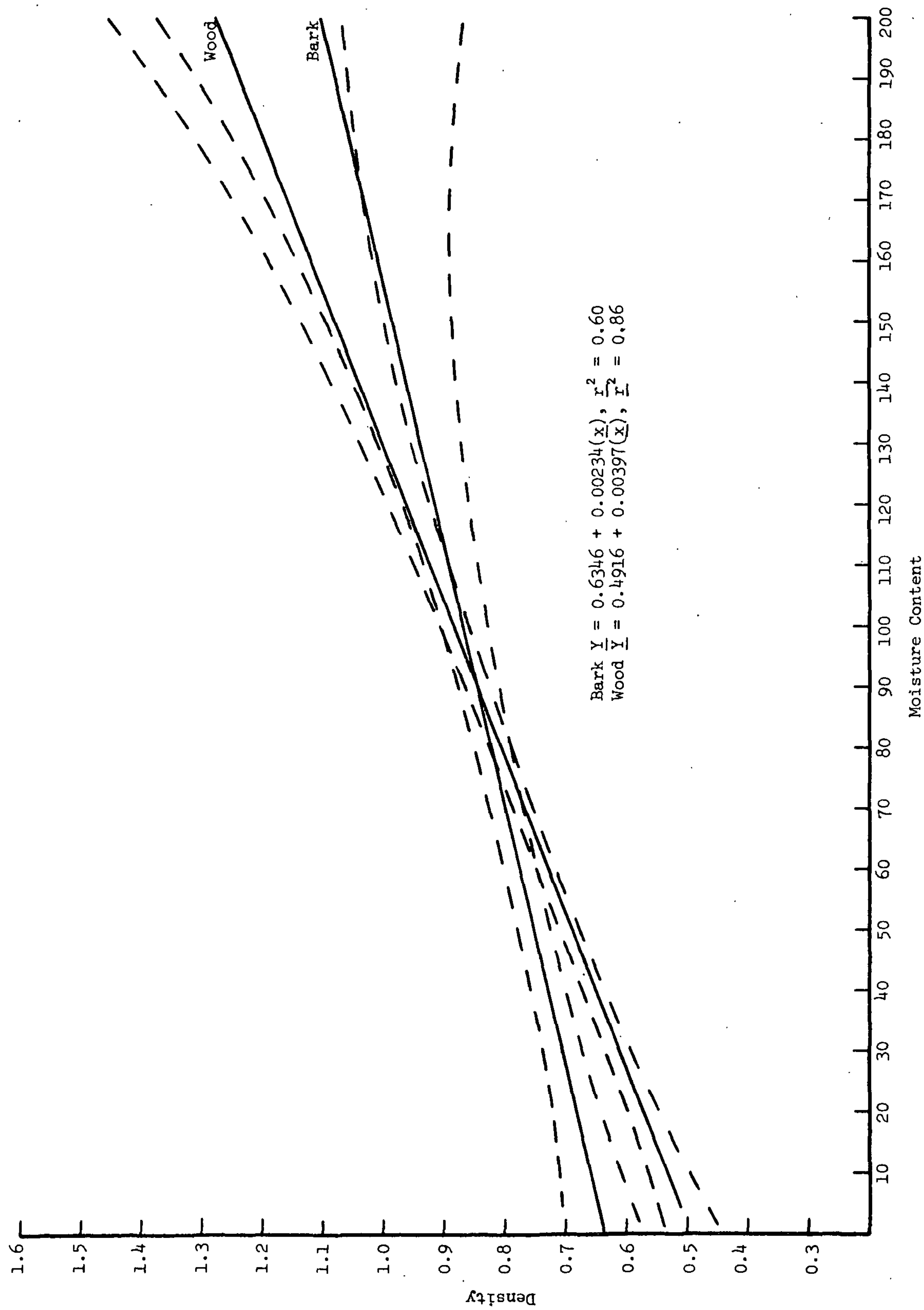


Figure 27. Illustrated is the Relationship Between Basic Density and Moisture Content for Western Hemlock. The Dashed Lines are Two Standard Deviations Above and Below the Mean

mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation of wood and bark chips through water flotation is not a feasible technique for eastern hemlock. Both fractions are too similar in density at the various moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XXXI summarizes the results for eastern hemlock. As predicted from the density-moisture content curves, both fractions floated at moisture contents from 67 to 100%.

TABLE XXXI

SUMMARY OF DWELL TIME RESULTS FOR EASTERN HEMLOCK

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
3212-136 Bark	66.6	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-136 Exterior wood	92.5	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-136 Interior wood	75.2	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-142 Bark	82.3	after 5	4.8	95.2
		15	4.8	95.2
		60	4.8	95.2
		240	4.8	95.2
3212-142 Sapwood	81.3	after 5	0	100
		15	0	100
		60	0	100
		240	0	100
3212-142 Heartwood	99.6	after 5	1.8	98.2
		15	1.8	98.2
		60	1.8	98.2
		240	1.8	98.2

DATA INTERPRETATION

The bark of eastern hemlock has no true fiber and appears to be a source of sclereid problems. Sclereids make up approximately 16.5% of the secondary phloem and are short, thick-walled, and heavily lignified. Micropulping eastern hemlock bark resulted in 16% sieve cells and 4.5% sclereids being produced. Most of the sclereid groups separate into smaller entities when pulped and would be removed in screening and washing operations. Further reductions in sclereids might be possible by beating and centricleaning procedures. Although the bark of eastern and western hemlock are similar, many more sclereids were retained in the usable fraction of western hemlock bark (11%).

Considering the lack of true fiber, the presence of large numbers of sclereids and the high extractives, removal of at least part of the bark is desirable. The possibility of segregation of chip/bark mixtures through water flotation does not look promising for this species. Density determinations at varying moisture contents indicate that both fractions are too similar in density for a simple water-flotation procedure to work.

Compression debarking trials with western hemlock suggested this approach was quite promising with wood recovery of 92% and bark contamination of 4% (46). Since the bark structure of the two species is so similar, it appears the technique might also work well with eastern hemlock. Chipping frozen wood also had merit with unloosened bark comprising only 2.3% of the total material. Hammermilling trials resulted in a 25% reduction in bark levels with a 5% wood loss and suggest that an approach worthy of consideration is the use of the "screening-hammermilling-rescreening" procedure described earlier for a number of other species.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating wood/bark mixtures. They include papers by Auchter and Horn (19), Hooper (20), Biltonen, et al. (21), Short, et al. (22), Miller (23), Vais and Vostrov (24), Arola and Erickson (25) and Arola, et al. (26). A good review on kraft pulping of rough wood chips is also given by Horn and Auchter (27).

BARK FUEL VALUE, ASH, CALCIUM, AND SILICA LEVELS

FUEL VALUE

Rising fuel prices have prompted a closer look at the use of bark as fuel. For many end products, removal of the bark is necessary and utilization of bark as fuel is a partial solution to disposal of bark waste. Arola (47) estimates that, if about 60% of the forest residues being generated were recoverable, it would amount to about 6 billion cu. ft. of solid wood annually. If the entire 6 billion cu. ft. were used as fuel to generate steam, the gross potential heat content would be about 1,700 trillion Btu.

Listed in Table XXXII are the Btu values of the species investigated thus far, both in terms of Btu's per ovendry pound and Btu's per cubic foot. Although values are quite similar when figured on the basis of Btu's per ovendry pound, the relative fuel value of the various species becomes more apparent when the specific gravity of the bark is taken into account and heating value is figured in terms of pounds per cubic foot. Also given in Table XXXII are values found in the literature. In most cases, the values found in the literature have been converted to pounds per cubic foot for comparison with IPC values.

Chang and Mitchell (33) reported that the heating value of hardwood barks was lower than that of softwood barks. They found that the barks of all eight softwood species investigated had values greater than 8500 Btu's per dry pound and nine of twelve hardwoods had lower values. However, hardwood barks, on the whole, are higher in specific gravity than softwoods and, when this is taken into account by calculating the values on a cubic foot basis, the fuel value of hardwood barks is generally greater than that of softwood barks.

TABLE XXXII

BARK FUEL VALUES

Species	Total Sp.Gr.	Weight, lb/ft.[3]	Btu/lb o.d. wt.	Btu/ft.[3]	Literature Values, Btu, lb/ft.[3a]
Quaking aspen	0.50	31.2	8,712	271,814	318,041 (48), 263,110 (33)
Sugar maple	0.54	33.7	8,426	283,956	299,572 (48), 246,044 (33)
White birch	0.56	34.9	10,332	360,587	371,160 (48), 329,247 (33)
Northern red oak	0.65	40.6	8,896	361,178	320,090 (4)
Southern red oak	0.70	43.7	8,371	365,813	349,250 (4)
Pin oak	0.71	44.3	8,883	393,517	
Black oak	0.68	42.4	8,340	353,616	
Northern white oak	0.58	36.2	7,536	272,803	
Southern white oak	0.56	34.9	8,046	280,805	256,271 (4)
Post oak	0.56	34.9	6,773	236,378	
Eastern cottonwood	0.31	19.3	8,422	162,545	
Sweetgum	0.42	26.2	7,650	200,430	188,640 (4), 195,190 (33)
Yellow poplar	0.38	23.7	8,956	212,257	
Black tupelo	0.44	27.5	8,102	222,805	
Sycamore	0.60	37.4	7,978	298,377	
White ash	0.50	31.2	8,453	263,734	
Red alder	0.58	36.2	8,760	317,112	305,383 (49), 287,681 (33)
N. black cottonwood	0.40	25.0	8,765	219,125	225,000 (49)
Silver maple	0.57	35.6	8,360	297,616	
American beech	0.67	41.9	7,993	334,906	320,116 (48)
Red maple	0.60	37.4	8,293	310,158	
Black willow	0.34	21.2	8,137	172,504	151,962 (33)
Green ash	0.45	28.1	8,367	235,113	
Shagbark hickory	0.72	44.9	8,423	378,193	
Loblolly pine	0.33	20.6	9,320	191,992	193,640 (50)
Slash pine	0.35	21.8	9,327	203,329	196,244 (33), 204,484 (50)
Douglas-fir	0.41	25.6	9,962	255,027	252,595 (51), 258,560 (49)
Western hemlock	0.45	28.1	9,297	261,246	262,735 (51)
Engelmann spruce	0.51	31.8	8,830	280,794	265,816 (33)
Lodgepole pine	0.38	23.7	9,382	222,353	241,503 (33)
Ponderosa pine	0.35	21.8	9,616	209,629	
Western larch	0.32	20.0	8,825	176,500	164,080 (33)
White spruce	0.39	24.3	8,913	216,586	241,399 (48)
Balsam fir	0.40	25.0	9,339	233,475	281,190 (48), 221,525 (33)
Jack pine	0.41	25.6	9,393	240,461	299,155 (48), 224,282 (33)
Red pine	0.27	16.8	9,070	152,376	
Shortleaf pine	0.35	21.8	9,310	202,958	208,190 (50)
Longleaf pine	0.45	28.1	9,290	261,049	256,553 (50)
Virginia pine	0.54	33.7	9,170	309,029	283,889 (49)
Black spruce	0.42	26.2	9,143	239,547	216,045 (33), 225,582 (48)
Eastern white pine	0.47	29.3	9,647	282,657	
Eastern hemlock	0.43	26.8	9,517	255,056	235,894 (33)

[a]Literature cited [Chang and Mitchell (33)] values based on airdry samples with an average moisture content of 6% (range 4.8 to 6.7%).

Fuel value is extremely sensitive to moisture content. Green wood of most species has about 60% of the heat value of well air-dried wood. For instance, a pound of oven-dried red oak wood with a calorific value of 8600 Btu's yields about 5700 Btu's when air dried and about 3400 Btu's when green (52). Figure 28, taken from data supplied by Cunningham and De Vriend (53) shows the drop in usable Btu's at increasing moisture contents.

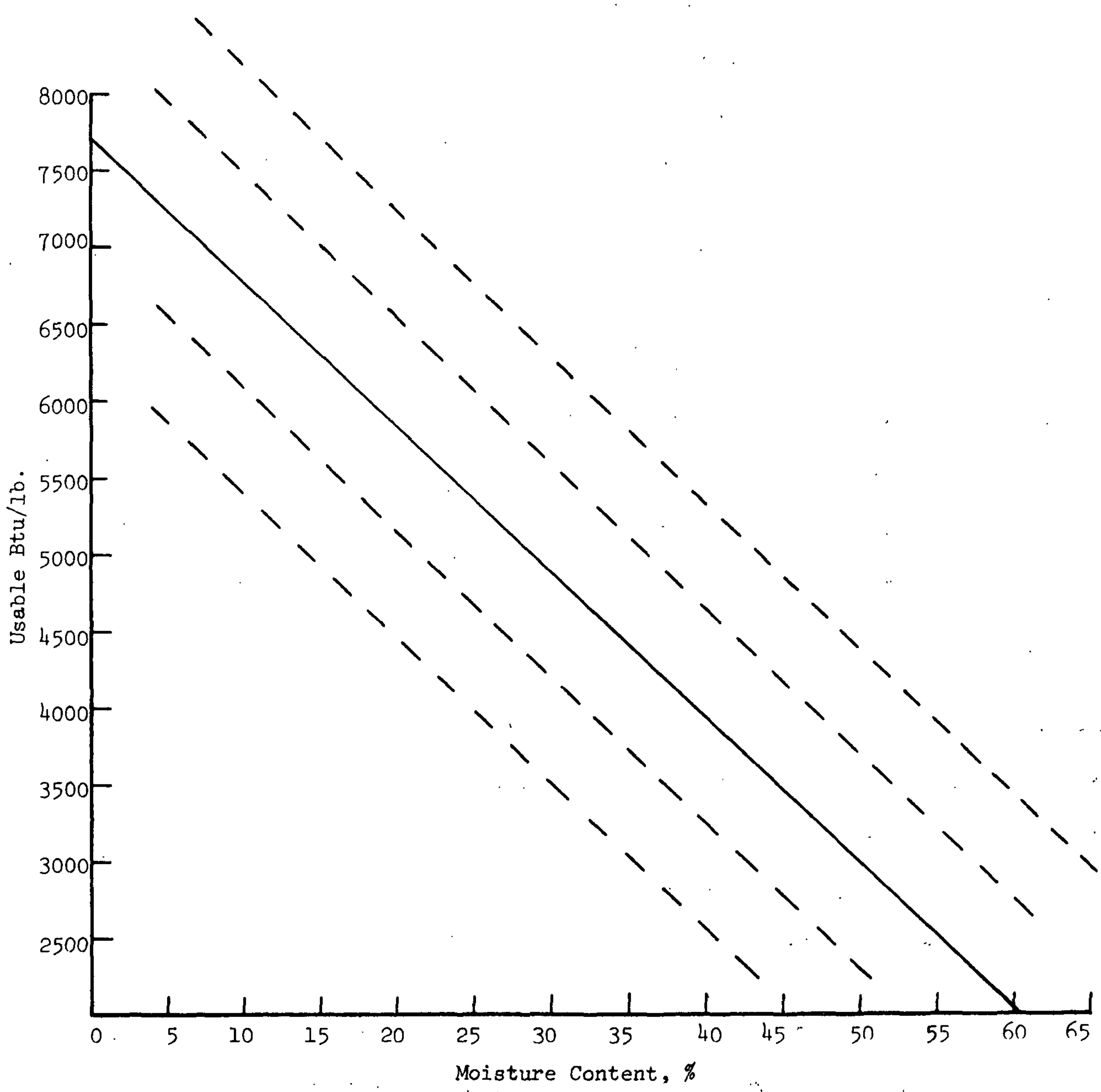


Figure 28. Illustrated is the Effect of Moisture Content on Usable Btu's per Pound

ASH, CALCIUM, AND SILICA LEVELS

Listed in Table XXXIII are percent ash, calcium and silica on an oven-dry basis. Ash is the noncombustible part of the bark and needs to be removed, at least in part, after burning. According to Chang and Mitchell (33), a high percentage of ash tends to give lower heat of combustion values. Wood has a low ash content, generally less than 1% of dry weight (51). IPC ash values for bark ranged from 0.8% for loblolly and slash pine to 12.6% for northern white oak. Softwoods generally had lower ash values than did hardwoods. Also listed in Table XXXIII are values obtained from the literature.

Calcium is one of the principal inorganic elements in bark. When bark is pulped, high levels of calcium can be expected to increase recovery system scaling problems. More rapid scaling increases evaporator down time and reduces heat transfer. Low percentages of calcium in bark are therefore desirable. Trends were the same for percent calcium with loblolly and slash pine, again the lowest of the species investigated (0.2%), and northern white oak, the highest (5.2%). Also, as with percent ash, softwoods generally had lower values than did hardwoods.

Insoluble silicates are naturally occurring minerals that are commonly found in soils. They include not only extremely hard and abrasive types of minerals but silicon as an element in clay minerals of soils. Silica (SiO_2) levels are of interest because, in the form of minerals, they represent the principal acid insoluble fraction in bark and, as such, are expected to remain as one possible abrasive contaminant in pulps.

The SiO_2 levels reported in Table XXXIII are levels from bark samples which have been carefully harvested and transported and represent SiO_2 levels in bark relatively free from contaminating soil minerals. Some measure of silica

TABLE XXXIII

PERCENT ASH, CALCIUM AND SILICA IN BARK

Ovendry Basis

Species	Ash, %[a]	Literature Values, ash, %	Calcium, %	Silica, %
Quaking aspen	5.2	2.8 (33), 3.9 (48)	1.9	0.03
Sugar maple	8.3	6.3 (33), 5.0 (48)	3.0	0.19
White birch	2.4	1.5 (33), 1.7 (48)	0.7	0.06
Northern red oak	5.4	5.4 (33)	2.2	0.12
Southern red oak	6.5		2.6	0.14
Northern white oak	12.6	10.7 (33)	5.2	0.29
Southern white oak	8.2	10.7 (33)	3.4	0.42
Eastern cottonwood	6.2		2.5	0.18
Sweetgum	10.5	5.7 (33)	3.8	1.41
Yellow poplar	2.8		1.0	0.05
Black tupelo	7.3		2.9	0.11
Sycamore	7.1		3.0	0.06
White ash	4.4		1.6	0.13
Red alder	5.9	3.1 (33), 3.1 (49)	1.4	0.05
N. black cottonwood	5.0		1.1	0.08
Silver maple	3.6		0.6	0.18
Shagbark hickory	7.3		2.5	0.08
Post oak	17.8		5.1	0.02
Pin oak	6.3		2.1	0.1
Black oak	7.5		2.8	0.06
American beech	10.5	9.4 (54)	3.4	1.1
Red maple	5.2		1.5	0.37
Black willow	6.3	6.0 (33)	1.8	0.08
Green ash	6.5		1.8	0.12
Loblolly pine	0.8	0.4 (50)	0.2	0.09
Slash pine	0.8	0.6 (33), 0.7 (50)	0.2	0.04
Douglas-fir	1.2		0.3	0.06
Western hemlock	1.7		0.3	0.04
Engelmann spruce	2.6	2.5 (33)	0.8	0.08
Lodgepole pine	2.2	2.0 (33)	0.6	0.16
Ponderosa pine	0.7		0.2	0.16
Western larch	2.4	1.6 (11)	0.6	0.26
White spruce	4.2	3.5 (49)	1.2	0.14
Balsam fir	3.4	2.3 (33), 2.6 (48)	1.0	0.10
Jack pine	1.3	1.7 (33), 2.1 (48)	0.3	0.14
Red pine	1.3		0.3	0.03
Shortleaf pine	1.6	0.7 (50)	0.4	0.10
Longleaf pine	0.6	0.7 (50)	0.2	0.004
Virginia pine	2.2		0.7	0.01
Black spruce	3.1	1.8 (48)	0.8	0.10
Eastern white pine	1.2		0.2	0.17
Eastern hemlock	2.0	1.6 (33)	0.5	0.12

[a]Ashed at 600°C.

levels (principally sand) that are added by harvesting and transporting could be obtained by comparing appropriately sampled and analyzed wood and bark samples from company operations with the relatively soil-free silica (SiO_2) levels reported in Table XXXIII.

There has been greatly increased interest in bark Btu's, calcium, ash and silica content, resulting in a number of publications in this area. Additional publications of interest include those by Corder (49,55), Junge (56,57), Howard (58), Johnson (59), Smith (60), Burnett (61) and Kowalczyk (62).

BETWEEN-SPECIES COMPARISONS

The completion of this report marks the end of the characterization of the bark of 42 pulpwood species. Covered have been 24 hardwoods and 18 conifers. A number of interesting relationships have been observed between species and also between measured parameters such as wood/bark adhesion, bark strength and toughness, and hammermilling results. The large volume of data obtained will be examined statistically and the results should prove valuable in assessing the value of the bark resource. This information will be summarized in a special report, to be issued within the next few months.

An important aspect of the characterization of the species covered in these reports is the way they relate to each other, both in terms of improving our overall understanding of bark and also determining which species can be handled in a similar manner, perhaps in a chip mixture. Tables XXXIV and XXXV provide a quick method of comparing the basic information compiled for all 42 species.

Considered in the present report were three hardwoods and two conifers. Although the project was originally scheduled to cover 32 species, the species in this report and the preceding report were added because of high company interest. Many of the comments in this section are the same as in previous reports. The final summary report will attempt to tie all the information together in a comprehensive manner.

For most species investigated, the hardwood barks were similar or higher in specific gravity than the conifer barks (Engelmann spruce, Virginia pine, eastern cottonwood, black willow, and yellow-poplar are exceptions). The specific gravity of the hardwood barks investigated showed no consistent relationship to the specific gravity of the wood. Conifer bark was generally similar or lower in specific

TABLE XXXIV

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULP SPECIES

Characteristic	Quaking Aspen	Eastern Cottonwood	Sweetgum	Sugar Maple	White Birch	Northern Red Oak	Southern Red Oak	Northern White Oak	Southern White Oak	Sycamore	Yellow Poplar	Black Tupelo
Specific gravity (o.d. wt./green vol.)												
Wood	0.38	0.38	0.44	0.59	0.49	0.56	0.60	0.64	0.67	0.45	0.39	0.52
Total bark	0.50	0.31	0.42	0.54	0.56	0.65	0.70	0.58	0.56	0.60	0.38	0.40
Inner bark	0.40	0.29	0.51	0.69	0.57	0.53	0.68	0.65	0.70	0.60	0.38	0.37
Outer bark	0.55	0.32	0.36	0.49	0.54	0.71	0.70	0.52	0.44	--	0.42	0.37
Extractives, % (airdry)												
Wood	3.0	1.4	2.6	1.0	4.0	4.5	4.8	2.4	4.6	2.2	3.9	3.0
Bark	15	7.9	10.2	6	17	11	11.6	7.2	8.6	8.1	13.8	10.6
Density at 100% moisture (green wt./green vol.)												
Wood	0.79	0.84	0.84	1.24	1.01	1.06	1.25	1.30	1.38	0.98	0.79	0.88
Bark	1.15	0.81	0.87	1.08	1.16	1.18	1.39	1.05	1.13	1.21	0.82	0.85
Pulp yield, % (bark)	33.8	35.4	34.9	33.9	36.3	28.4	30.7	35.4	36.6	31.4	32.3	31.4
Usable bark fiber, %[a]	10	9	5	3	0	5	4	3	3	0	13	1-10
Sclereids remaining, %[a]	1	<0.1	--	0.2	0.7	0.2	--	--	--	--	0	0
Fiber location[b]	IB	IB	IB	IB	--	IB	IB	IB	IB	--	IB	IB
Sclereid location[b]	IB	--	IB	IB	IB	IB	IB-OB	IB-OB	IB-OB	IB	--	IB-OB
Wood/bark adhesion, kg/cm²												
Growing season	6.4	4.4	10.2	5.8	5.1	2.5	5.4	4.8	--	--	--	--
Dormant season	11.4	13.5	15.3	10.1	12.0	8.4	8.2	7.8	7.2	14.8[e]	16.6	13.5
Bark strength, kg/cm²												
Inner bark	9.0	17.7	8.1	1.4	1.6	2.1	3.6	4.6	4.7[d]	6.1	13.4	9.6
Outer bark	4.9	4.2	5.2	4.7	9.8	4.6	3.4	3.2	--	--	10.4	10.5
Toughness												
Inner bark	0.22	0.14	0.20	0.25	0.10	0.13	0.11	0.16	0.12	0.15	0.20	0.20
Outer bark	0.10	0.11	0.11	0.10	0.10	0.18	0.14	0.10	0.09	--	0.18	--
Sapwood	0.45	0.38	0.28	1.20	0.68	0.93	0.55	0.62	0.98	0.50	0.23	0.56
Hammermilling[c]												
Bark removed, %	34	18	32	29	38	34	46	37	38	45	23	39
Wood loss, %	5	5	7	5	6	10	6	5	3	7	7	5

Characteristic	White Ash	Red Alder	Northern Black Cottonwood	Silver Maple	Post Oak	Pin Oak	Black Oak	Shagbark Hickory	American Beech	Red Maple	Black Willow	Green Ash
Specific gravity (o.d. wt./green vol.)												
Wood	0.57	0.37	0.31	0.42	0.64	0.61	0.57	0.65	0.60	0.51	0.36	0.56
Total bark	0.48	0.58	0.40	0.57	0.56	0.71	0.68	0.72	0.67	0.60	0.34	0.45
Inner bark	0.51	0.55	0.38	0.51	0.65	0.57	0.69	0.69	0.67	0.59	0.40	0.49
Outer bark	0.43	0.62	0.42	0.61	0.53	0.74	0.68	0.81	--	0.61	0.28	0.35
Extractives, % (airdry)												
Wood	4.0	2.1	2.3	3.5	4.3	4.4	5.0	3.2	1.5	1.0	2.6	4.0
Bark	12.6	6.0	20.0	6.6	8.2	14.9	15.4	14.6	10.6	6.0	6.9	12.6
Density at 100% moisture (green wt./green vol.)												
Wood	1.20	0.77	0.63	0.91	1.27	1.30	1.29	1.41	1.32	1.03	0.82	1.18
Bark	0.95	1.15	1.04	1.11	1.14	1.31	1.69	1.23	1.43	1.22	0.67	0.91
Pulp yield, % (bark)	35.7	27.0	26.0	32.0	46.2	26.5	31.4	28.3	37.0	32.0	40.0	38.0
Usable bark fiber, %[a]	16	0	12	6	4	2	5	15	0.25	12	21	12.9
Sclereids remaining, %[a]	0	0	0	2.5	--	--	--	0	--	0.9	0.3	0.8
Fiber location[b]	IB	--	IB	IB	IB	IB	IB	IB	IB	IB	IB-OB	IB-OB
Sclereid location[b]	--	IB	IB-OB	IB	IB-OB	IB-OB	IB-OB	--	IB-OB	IB	--	IB-OB
Wood/bark adhesion, kg/cm²												
Growing season	--	--	--	6.1	--	--	--	3.8	--	--	--	--
Dormant season	23.8	13.0	18.7	14.1	12.2	12.9	21.5	30.6	14.0	12.4	17.6	17.4
Bark strength, kg/cm²												
Inner bark	20.0	8.2	13.9	3.4	6.8	10.5	11.7	25.0	7.4	11.3	10.4	12.6
Outer bark	4.2	5.9	7.3	--	3.4	9.9	9.7	72.7	--	--	8.7	6.4
Toughness												
Inner bark	0.45	0.10	0.10	0.17	0.20	0.24	0.29	0.90	0.12[d]	0.41	0.32	0.36
Outer bark	0.20	0.02	0.07	0.12	0.18	0.14	0.10	0.71	--	0.18	0.12	0.22
Sapwood	0.68	0.50	0.30	0.50	0.66	0.64	0.86	1.48	1.02	0.63	0.44	0.64
Hammermilling[c]												
Bark removed, %	24	48	26	14	47	33	37	11	43	18	13	32
Wood loss, %	6	8	5	4	6	6	7	4	6	4	4	5

[a]Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens.
[b]The percentage given is the yield based on whole bark samples.
[c]Major proportion located in either the inner bark (IB) or outer bark (OB).
[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d]Test performed on total bark.
[e]Sample failed in tensile.

TABLE XXXV

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock	Lodgepole Pine	Ponderosa Pine	Engelmann Spruce	Western Larch	Red Pine	Shortleaf Pine	Longleaf Pine	Virginia Pine	Black Spruce	Eastern White Pine	Eastern Hemlock
Specific gravity (o.d. wt./green vol.)																		
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40	0.39	0.39	0.34	0.50	0.39	0.47	0.55	0.50	0.40	0.32	0.40
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45	0.38	0.35	0.51	0.33	0.27	0.35	0.45	0.54	0.42	0.47	0.43
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46	0.32	0.34	0.41	0.37	0.20	0.26	0.25	0.27	0.33	0.32	0.40
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45	0.45	0.35	0.52	0.33	0.29	0.35	0.48	0.56	0.46	0.53	0.44
Extractives, % (airdry)																		
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6	3.5	5.3	2.8	1.4	3.5	4.1	4.3	4.1	1.5	7.4	3.7
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7	15.7	15.7	24.4	14.4	5.8	7.7	8.8	8.2	14.7	15.5	25.4
Density at 100% moisture (green wt./green vol.)																		
Wood	0.70	0.75	0.79	0.88	1.10	0.815	0.80	0.89-0.92	0.96	0.80	1.43	0.74	1.10	1.20	1.08	0.84	0.63	0.88
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85	0.74-0.95	0.62	1.14	0.61	0.62	0.72	0.90	1.03	0.97	1.01	0.87
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8	27.4	29.1	24.4	27.8	33.0	20.1	26.4	23.2	26.0	30.5	35.0
Usable bark fiber, %[a]	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0
Sclereids or phellem cells remaining, %[a]	1.5	12.0	<1	1	2	2	11	<1	1	3	0	<1	<1	<1	<1	3	<1	4.5
Fiber location[b]	--	--	--	--	--	IB-OB	--	--	--	--	IB	--	--	--	--	--	--	--
Sclereid or phellem cell location[b]	IB-OB	IB	OB	OB	OB	IB-OB	IB-OB	OB	OB	OB	--	OB	OB	OB	OB	IB-OB	OB	IB-OB
Wood/bark adhesion, kg/cm^2																		
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6	2.2	5.0	3.4	1.2	--	--	--	--	--	--	--
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2	5.6	9.6	12.5	4.4	9.6	8.6	5.2	7.2	18.1	7.3	14.3
Bark strength, kg/cm^2																		
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0	--	4.6	--	4.5	--	7.4	--	4.6	10.6	5.6	5.9
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--	2.4	4.9	4.2	4.4	5.6	2.7	5.8	4.0	7.6	5.3	5.8
Toughness																		
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12	0.10	0.10	0.24	0.12	0.16	0.16	0.21	0.30	0.22	0.20	0.16
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10	0.08	0.08	0.16	0.10	0.12	0.10	0.10	0.16	0.10	0.14	0.10
Sapwood	0.34	0.42	0.34	0.54	0.54	0.58	0.28	0.28	0.26	0.26	0.28	0.60	0.94	0.89	0.61	0.45	0.36	0.60
Hammermilling[c]																		
Bark removed, %	23	44	26	34	36	28	24	31	26	25	26	26	29	35	31	26	29	25
Wood loss, %	4	6	5	6	5	4	3	4	4	4	6	5	4	6	4	6	4	5

[a] Usable bark fiber and sclereids or phellem cells remaining are the fibers and sclereids retained on the 60- and 100-mesh screens.
[b] The percentage given is the yield based on whole bark samples.
Major proportion located in either the inner bark (IB) or outer bark (OB).
[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

gravity than associated sapwood (Engelmann spruce and eastern white pine were exceptions). The lack of a consistent specific gravity relationship between bark and wood in hardwoods makes the use of a water flotation procedure for mixed hardwood chips virtually impossible except for a few associated species like red alder and northern black cottonwood, which have similar densities at the same moisture content. In addition, because of the lack of major differences in specific gravity between the bark and wood of conifers, eastern white pine, Engelmann spruce, western larch, and shortleaf and longleaf pine appeared to be the only conifer species in which bark could be segregated from the wood by water flotation with no additional preparation.

Hardwood barks, with the exception of sycamore, white birch, and red alder, have varying levels of fiberlike structures in the bark. Conifers, in contrast, with the exception of Douglas-fir and to a lesser extent western larch, contain no fiberlike elements in the bark*. These results suggest that most conifer barks, when pulped, should not be expected to produce fiber that will contribute to the strength of the paper or board being produced. There is also considerable evidence that the high amounts of thin-walled cells (sieve cells and parenchyma cells) produced when high levels of bark are pulped could result in paper machine drainage problems. Also to be considered when bark levels of 10-15% are being pulped are the economics of such factors as lower pulp yields, brightness, higher permanganate number, and greater chemical consumption. Major monetary losses have been described when daily production is reduced by 10% because the mill is "digester-limited" and pulp production is decreased as a result of pulping wood/bark mixtures [Keays and Hatton (63)]. However, the presence of some bark in the pulp furnish will be

*There is evidence from the literature (65,66) that western red cedar, along with several other species of the Cupressaceae family, also have fiberlike elements in the bark.

stimulated by the trend to greater utilization of the entire tree. The amount of bark tolerated in the pulp furnish and the efforts expended to separate and segregate bark will be determined in part by its value for fuel or its use for chemicals and board (64).

The fiber content of hardwood bark offers an interesting situation when some type of mechanical procedure is used to break up and remove the bark. The part of the bark that does not respond to this type of treatment is usually the stringy, fiber-rich bark. As a result, a procedure that removes much of the non-fibrous bark (usually outer bark) and retains for pulping the stringy bark that behaves like wood during mechanical treatment, could result in a fairly favorable situation for fiber yield. White ash, black tupelo, yellow-poplar, quaking aspen, eastern cottonwood, northern black cottonwood, shagbark hickory and, most particularly, black willow are examples of species that could be a source of modest amounts of bark fiber.

There has been no consistent pattern with regard to levels of bark extractives with the exception that the levels in the bark are from about three to eight times higher than in the wood. Browning (67) reported that mineral substances in the bark can be more than ten times higher than in the corresponding wood. Most conifer barks have higher levels of extractives than do hardwood barks. Red pine and the southern pines (slash, loblolly, shortleaf, longleaf and Virginia) are the exception with extractives levels from only 5.8 to 8.8%. Aspen, northern black cottonwood, white birch, shagbark hickory, pin and black oak are hardwood species with high levels of extractives and Engelmann spruce, balsam fir and eastern hemlock are the three conifers with the highest levels of extractives. Even with these latter species, pitch problems are not expected to be serious unless, as the result of concentrating large amounts of bark from screening procedures, high levels of bark are pulped. It is also important to remember that seasoning can diminish the content of extractives in bark and our values are based on airdry samples in most cases, rather than fresh samples.

Wood/bark adhesion during the growing season was low and very similar for all species investigated (except sweetgum). Quite consistently, the zone of failure occurred in the cambium zone or the newly-formed, unlignified wood fibers adjacent to the cambium zone. Dormant season adhesion was, as expected, higher than growing season adhesion, and the failure zone usually occurred in the partially mature sieve and parenchyma cells of the inner bark, just outside the cambium zone. Dormant season wood/bark adhesion tends to be slightly higher for hardwoods than for conifers and, in certain instances, seems to be associated with the presence of large numbers of phloem fibers in the inner bark. Medium-high dormant season adhesion was associated with intermediate levels of inner bark fibers in aspen, cottonwood, and black tupelo. High wood/bark adhesion was associated with high levels of inner bark fibers in yellow-poplar, northern black cottonwood, white ash and shagbark hickory. Moderate levels of wood/bark adhesion in white birch, red alder and sycamore appear to be exceptions to the rule.

Mechanical treatment of bark continues to look promising as a method of upgrading low-quality chips possessing high levels of bark. The approach attempts to take advantage of the lower strength and toughness of bark with the result that there will be a reduction in the size of the bark particles sufficient to allow removal by screening. For hardwoods, when a hammermilling type action is employed, good bark removal seems to be best correlated with high specific gravity. For conifers, correlations between bark removal and strength properties are quite low. The most effective reduction in bark levels, particularly with hardwoods, results when bark and wood specific gravity is high, bark strength and toughness is low, and the bark is relatively thick. When inner bark strength is high because of high levels of bark fibers, the stringy inner bark reacts like wood and is retained with the wood. Although such inner bark is classified as bark contamination, modest levels should have no adverse influence on paper properties.

Bark ash content, and calcium in particular, is of importance because of its apparent influence on recovery system scaling problems. Levels of ash (and calcium) in the barks of conifers are quite consistently less than in hardwood barks. White spruce, yellow-poplar, and white birch are exceptions. Calcium levels range from 0.2% in longleaf, slash, loblolly, Ponderosa and eastern white pine to 5.2% in northern white oak. Since the levels in the bark are about 10-15 times higher than in the wood of most hardwood pulp species, pulping of whole-tree chips can be expected to worsen recovery system scaling problems.

The fuel values of the bark of all pulpwood species investigated are summarized in this report. The ovendry Btu values for hardwoods vary more than for conifers. Our data for hardwood barks confirms Chang and Mitchell's (33) observations and indicate that there is a negative correlation between ash content and ovendry Btu values. This relationship is less evident for the conifers investigated. Both hardwood and conifer barks, when the Btu values are converted to a cubic foot basis, demonstrate fairly major differences. These differences are due to bark specific gravity differences. Values range from 152,780 for red pine and 162,500 for cottonwood to 365,800 Btu/cubic foot for southern red oak. Western larch also had a relatively low value for a conifer (176,500 Btu/cubic foot) while Virginia pine had the highest value (309,000 Btu/cubic foot). The potential of bark and other forest residue as fuel was estimated by Arola (47) and covered in the section on Fuel Value. Briefly, he estimated a gross potential heat content of 1,700 trillion Btu if 60% of the forest residuals being generated were recoverable.

PLANS

The barks of 42 pulpwood species have been characterized in this project, including quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); white spruce, balsam fir, jack pine, eastern cottonwood (Report Three); southern white oak, northern white oak, southern red oak, sweetgum (Report Four); lodgepole pine, ponderosa pine, Engelmann spruce, western larch (Report Five); red pine, shortleaf pine, longleaf pine and Virginia pine (Report Six); sycamore, yellow-poplar, black tupelo and white ash (Report Seven); black spruce, red alder, northern black cottonwood and silver maple (Report Eight); and shagbark hickory, post oak, pin oak, black oak and American beech (Report Nine). Covered in this final characterization report were red maple, black willow, green ash, eastern white pine and eastern hemlock. In addition, we plan to summarize, in a special report, the overall findings of the bark characterization research. The summary report is expected to be issued in the spring of 1978 and should be particularly useful because it will not only compare the specific gravity, extractives, fuel value, ash content, etc., of conifers and hardwoods but will examine bark morphological factors that influence strength, wood/bark adhesion and segregation procedures and, in turn, contribute to pulping difficulties. This overview information will also be useful in extending the results to species that have not been characterized.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The cambium in the stem and root gives rise to xylem and phloem.

Dbh. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which appears in the light microscope to be more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark; the rhytidome.

Paratracheal. Said of xylem parenchyma in hardwoods which occurs in association with the vessels but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex; the zone from the innermost periderm outward; the outer bark.

Scalariform. Like a ladder.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Sclerotic. Hard, thick-walled, and often lignified.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve cell. A characteristic cell of softwood phloem. It translocates food materials synthesized in the plant. Sieve cells are elongated, tapering in shape and lack sieve plates.

Sieve tube element. A characteristic cell of hardwood phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled, and in longitudinal rows. They are connected by perforations (sieve plates) in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylosis. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal; forming a sheath (around vessels).

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers, and some parenchyma.

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Marianne L. Harder

Marianne L. Harder
Research Fellow

R. A. Parham

R. A. Parham
Research Associate

Dean W. Einspahr

Dean W. Einspahr
Director
Forest Biology Section

APPENDIX

TABLE XXXVI

SAMPLE TREE INFORMATION

Species	Tree No.	Age, yr	Height, ft.	dbh, inch	Location
Red maple	3212-135	41	55.5	8.0	Crandon, WI
	3212-141	66	55.5	8.5	Raleigh, NC
	3212-146	46	48.0	6.4	Rhinelander, WI
Black willow	3212-140	22	44.5	7.4	Greenville, WI
	3212-144	35	49.0	10.6	Virginia
	3212-149	13	52.0	8.5	Mississippi
Green ash	3212-138	40	46.5	7.2	Greenville, WI
	3212-139	55	69.0	10.1	Greenville, WI
	3212-145	38	65.0	9.6	Virginia
Eastern white pine	3212-137	26	38.5	7.5	Crandon, WI
	3212-143	23	25.0	9.0	Lower Michigan
	3212-148	38	41.0	8.2	Argonne, WI
Eastern hemlock	3212-136	115	39.0	7.0	Crandon, WI
	3212-142	40	30.0	6.0	Lower Michigan
	3212-147	121	48.0	9.1	Argonne, WI

TABLE XXXVII

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm² Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Eastern hemlock	--[a]	14.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Lodgepole pine	2.2	5.6
Ponderosa pine	5.0	9.6
Engelmann spruce	3.4	12.5
Western larch	1.2	4.4
Red pine	--[a]	9.6
Shortleaf pine	--[a]	8.6
Longleaf pine	--[a]	22.0
Virginia pine	--[a]	7.2
Eastern white pine	--[a]	7.3
Black spruce	--[a]	18.1
Shagbark hickory	3.8	30.6
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4
Southern red oak	5.4	8.2
Northern white oak	4.8	7.8
Southern white oak	--[a]	7.2
Sweetgum	10.2	15.3
Sycamore	--[a]	14.8[b]
		30.6
Yellow-poplar	--[a]	16.6
Black tupelo	--[a]	13.5
White ash	--[a]	23.8
Red alder	--[a]	13.0
Northern black cottonwood	--[a]	18.7
Silver maple	6.1	14.1
Shagbark hickory	3.8	
Post oak	--[a]	12.2
Pin oak	--[a]	12.9
Black oak	--[a]	21.5
American beech	--[a]	9.3
Red maple	--[a]	12.4
Black willow	--[a]	17.6
Green ash	--[a]	17.4

[a]Growing season adhesion not measured.
[b]Samples failed in tensile.

TABLE XXXVIII

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2 Inner Bark	Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	--	7.4
Eastern hemlock	5.9	5.8
Jack pine	2.3	2.3
Balsam fir	1.7	1.4
Lodgepole pine	--	2.4
Ponderosa pine	4.6	4.9
Engelmann spruce	--	4.2
Western larch	4.5	4.4
Red pine	--	5.6
Shortleaf pine	7.4	2.7
Longleaf pine	--	5.8
Virginia pine	4.6	4.0
Eastern white pine	5.6	5.3
Black spruce	10.6	7.6
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6
Southern red oak	3.6	3.4
Northern white oak	4.6	3.2
Southern white oak	4.7[a]	--
Sweetgum	8.1	5.2
Sycamore	6.1	--
Yellow-poplar	13.4	10.4
Black tupelo	9.6	10.5
White ash	20.0	4.2
Red alder	8.2	5.9
Northern black cottonwood	13.9	7.3
Silver maple	3.4	--
Shagbark hickory	25.0	72.7
Post oak	6.8	3.4
Pin oak	9.1	9.9
Black oak	11.7	9.7
American beech	7.4	--
Red maple	11.3	--
Black willow	10.4	8.7
Green ash	12.6	6.4

[a]Bark strength measured on total bark rather than inner and outer bark.

TABLE XXXIX

MODULUS OF ELASTICITY VALUES[a]
HARDWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
Northern white oak	1	19100	10400	6700
	2	42800	6700	2700
Sugar maple	1	31600	14000	3500
	2	43600	15900	3300
Quaking aspen	1	17000	14000	6500
	2	24400	8200	--
Northern red oak	1	23700	13500	10900
	2	34100	6800	7800
White birch	1	34200	6900	1900
	2	33400	8400	2200
Eastern cottonwood	1	33900	23200	4300
	2	48700	17900	7200
Silver maple	1	31500	32000	13900
	2	32600	25000	11500
Sweetgum	1	23400	21300	--
	2	32700	23400	13400
Southern red oak	1	45500	10700	8600
	2	36500	7400	5900
Southern white oak	1	52000	6900	4700
	2	41000	9700	5500
Black tupelo	1	39000	9400	--
	2	41300	15700	--
Sycamore	1	43300	9600	--
	2	30000	12100	--
Yellow-poplar	1	35800	11000	7400
	2	22800	8800	7500
White ash	1	47600	15500	7100
	2	50400	19500	8200
Red alder	1	36200	12900	4400
	2	17500	11500	5300
Northern black cottonwood	1	15100	20100	6700
	2	19400	19200	10900
Silver maple	1	18700	28800	9800
	2	36400	37100	17100
Pin oak	1	26000	7200	3600
	2	28000	6800	2600
Black oak	1	33200	6400	4400
	2	24800	7600	2600
Post oak	1	25600	7600	4800
	2	32800	6400	2700
Shagbark hickory	1	34800	24000	19200
	2	37200	24400	14800
American beech	1	42000	6400[b]	--
	2	29200	7600[b]	--
Red maple	1	56200	17500	9500
	2	49500	11400	11500
Black willow	1	30100	21500	4600
	2	25600	12700	8600
Green ash	1	33000	18800	6300
	2	43600	5900	3300

[a]Values based upon 4-6 determinations. Dashes indicate bark was unable to be tested for various reasons.
[b]Test done on total bark.

TABLE XL

MODULUS OF ELASTICITY VALUES[a]
SOFTWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
White spruce	1	20600	--	12200
	2	29600	--	17300
Jack pine	1	25700	--	4400
	2	24600	--	3800
Loblolly pine	1	25200	6700	3800
	2	21200	6500	2100
Western hemlock	1	43300	12600	7000
	2	34900	13200	4400
Douglas-fir	1	42400	28200	--
	2	43100	21700	1000
Slash pine	1	33100	3400	1900
	2	29800	3300	1900
Balsam fir	1	35200	6200	--
	2	21600	7000	--
Engelmann spruce	1	21600	24500	--
	2	30000	25500	6700
Ponderosa pine	1	15200	6500	2000
	2	34800	5100	3700
Lodgepole pine	1	30100	6700	1900
	2	24700	25900	5300
Western larch	1	40900	10900	5300
	2	40800	31600	8100
Red pine	1	18600	25800	1800
	2	20000	28900	3100
Shortleaf pine	1	35900	14300	3100
	2	41800	25000	3800
Virginia pine	1	48100	37100	3700
	2	23000	30700	7800
Longleaf pine	1	49500	33900	3800
	2	42000	26200	5900
Black spruce	1	31400	30900	7000
	2	25100	25000	5900
Eastern white pine	1	25400	23400	6400
	2	28200	20400	4100
Eastern hemlock	1	26000	16200	7200
	2	40600	6600	4400

[a]Values based upon 4-6 determinations except the outer bark for western hemlock tree #2 which is one determination. Dashes indicate bark was unable to be tested for various reasons.