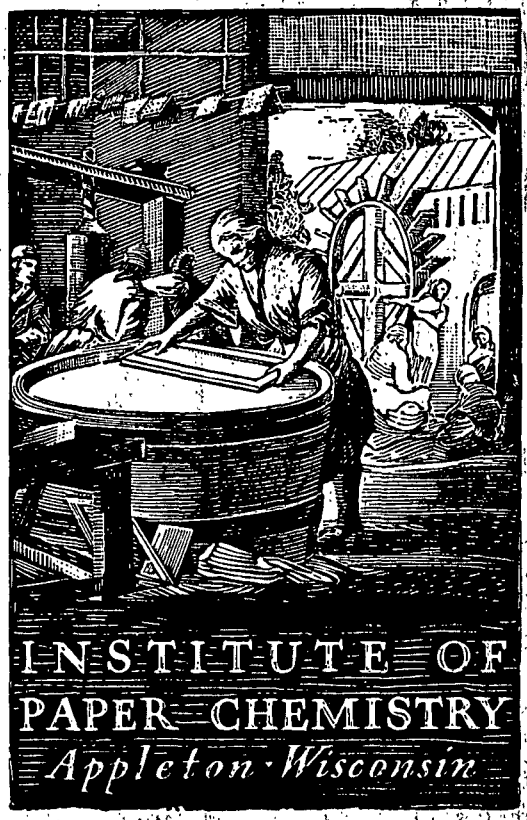

WOOD/BARK ADHESION AND METHODS OF REDUCING ADHESION IN HARDWOOD SPECIES

Project 2929

Report One

A Progress Report

to

MEMBERS OF GROUP PROJECT 2929

December 21, 1970

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Blandin Paper Company

Cox Newsprint, Inc.

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The Institute of Paper Chemistry

Appleton, Wisconsin

WOOD/BARK ADHESION AND METHODS OF REDUCING ADHESION IN HARDWOOD SPECIES

SUMMARY

Research on the measurement of wood/bark adhesion and methods of reducing adhesion was initiated on March 15, 1970. The first order of business was to develop a field collection method that would provide an undisturbed sample which could be stored for one to three days and provide suitable test specimens for making 8 to 10 adhesion measurements. Use of a small chain saw for cutting wedge-shaped samples turned out to be the best all-around solution to the problem. A procedure for measuring wood/bark adhesion was developed using the Instron tester. The method measures shear parallel to the grain in the "cambium zone." A small specially prepared tab is employed in the test that, because of its size and shape, will be useful in checking the effectiveness of the methods employed to reduce adhesion.

Seasonal variation in wood/bark adhesion was measured for Lake States grown sugar maple, bur oak, quaking aspen, and white birch. The length of the peeling season and differences between species in wood/bark adhesion were not as great as anticipated. Morphological examination of the wood and bark and the seasonal changes in the zone of failure were completed for quaking aspen and white birch. These observations pointed out the limitations of the testing procedure and disclosed a similarity in zones of weakness in the inner bark of aspen and birch.

Plans for the program during the next six months include: (1) completion of the morphological observations on bur oak and sugar maple, (2) preliminary trials on ways of reducing dormant season wood/bark adhesion in quaking aspen,

sugar maple, white birch and bur oak, (3) the measurement of the seasonal variation in wood/bark adhesion for loblolly pine, white spruce, shagbark hickory and a southern source of eastern cottonwood.

INTRODUCTION

Background information presented to cooperating companies when Project 2929 was being established stressed that "recent predictions of increases in raw material requirements, woods labor problems, and increased pressure by the public to create less disturbance to man's environment has made it increasingly evident that the pulp and paper industry must develop radically new and more efficient raw material harvesting systems." Basically, the approach that appears to offer the most promise is one being pursued by the American Pulpwood Association which involves developing a procedure that allows chipping at the stump and the bulk handling of the chips from the woods to the mill. Such a procedure would make possible the utilization of small-sized trees and the use of a greater proportion of the total tree. In addition, it has been predicted that greatly reduced harvesting and transportation costs would result and shorter rotations would be possible.

Techniques that need to be mastered before the several benefits associated with "chipping at the stump" can be realized include: (1) mobile harvester-chippers need to be perfected, (2) ways of reducing wood/bark adhesion on chip samples during the dormant season need to be worked out, (3) methods of separating chip/bark mixtures need to be developed.

Numerous studies have been made into the separation of wood and bark prior to utilization. Chemical debarking of trees was intensively investigated

by McIntosh (1) and Wilcox, et al. (2) and described in a review by Schutt (3). The anatomy of common North American pulpwood barks has been described by Chang (4). Several investigators [Wilcox, et al. (5), Wilcox, et al. (2), Schutt (3), Fobes (6)] have discussed the influence of cambium activity and the number of newly formed xylem and phloem cells on ease of peeling. Little has been done to critically examine morphologically what structures are destroyed in separating wood and bark, either during the "peeling season" or at times when wood/bark adhesion is high. Similarly, little attempt has been made to explain the reasons for differences between species in wood/bark adhesion during either the active growing season or the dormant season.

The objectives of Project 2929 are to: (1) measure accurately seasonal changes in wood/bark adhesion for sugar maple, white birch, quaking aspen, white oak, shagbark hickory, white spruce, southern cottonwood, and loblolly pine; (2) examine between-species and seasonal morphological differences in an attempt to correlate morphological differences with measured wood/bark adhesion; (3) develop suitable methods of reducing wood/bark adhesion based upon information obtained regarding the causes of adhesion.

The testing procedures and treatment methods being developed have been based upon the premise that the treatments will be applied to chips having attached bark as contrasted to the treatment of pulpwood bolts or standing trees. The report that follows describes the progress made toward the above-listed objectives during the first eight months of the program.

EXPERIMENTAL METHODS AND MATERIALS

TREE SPECIES SAMPLED

The research proposal instrumental in establishing Project 2929 suggested that the research be restricted to hardwood species. Cooperating companies, as part of the original proposal, were asked to indicate what tree species were of most interest. A tabulation of the suggested tree species revealed a total of 13 species were of interest with four conifers (softwoods) included on the list. With cooperating company interests in mind, the following species were selected as test trees for intensive study. Included in the final list are two ring porous hardwoods, four diffuse porous hardwoods, and two species of conifer.

(1) sugar maple (Acer saccharum Marsh.)

(2) white birch (Betula papyrifera Marsh.)

(3) quaking aspen (Populus tremuloides Michx.)

(4) bur oak (Quercus macrocarpa Michx.)*

(5) shagbark hickory [Carya ovata (Mill.) K. Koch]

(6) southern source of cottonwood (Populus deltoides Bartr.)

(7) white spruce [Picea glauca (Moench) Voss]

(8) loblolly pine (Pinus taeda L.)

Lake State's grown sugar maple, white birch, quaking aspen and bur oak were selected for the first series of experiments. All four species were available in native stands near Appleton, Wisconsin. The sampling and testing procedures employed are described in the paragraphs that follow.

*Bur oak is a member of the white oak group.

FIELD SAMPLING PROCEDURES

Field sampling procedures employed by other researchers were reviewed and several sampling techniques were tried including the use of a leather punch, a plug cutter in a gasoline-powered drill, and the use of a small chain saw. The objective of the sampling was to obtain a minimum of nine undisturbed bark/wood test specimens. Of primary importance was the use of a procedure that was simple and provided an undisturbed sample that could be stored for 48 to 72 hours without drying or deterioration. Use of a small chain saw provided the most useful sample that, even during the peeling season, could be prepared and tested satisfactorily. The sampling procedure consisted of: (1) making a series of four parallel horizontal cuts about four inches apart with the end of the chain saw, (2) making two parallel vertical cuts, connecting the horizontal cuts, and on an angle that produced a wedge-shaped sample (see Fig. 1), (3) gently lifting out the sample with a hammer, (4) labeling and immediately storing in plastic bags at 40°F., (5) trimming each wedge-shaped sample in the laboratory into test specimens for use in the Instron tester.

A review of the wood/bark adhesion work of Berlyn (7) suggested that sample location within the tree had a very minor influence on test results. However, just to be on the safe side, the decision was made to take all sample wedges at a height of from 48 to 60 inches. Each tree was sampled three times on three successive sampling dates. The first sample was taken from the northwest quadrant, the second from the north and the third from the northeast. Sampling was initiated early in the spring prior to cambial activity and continued until adhesion measurements indicated cambial activity had stopped and failure in the test specimens was occurring in the bark.

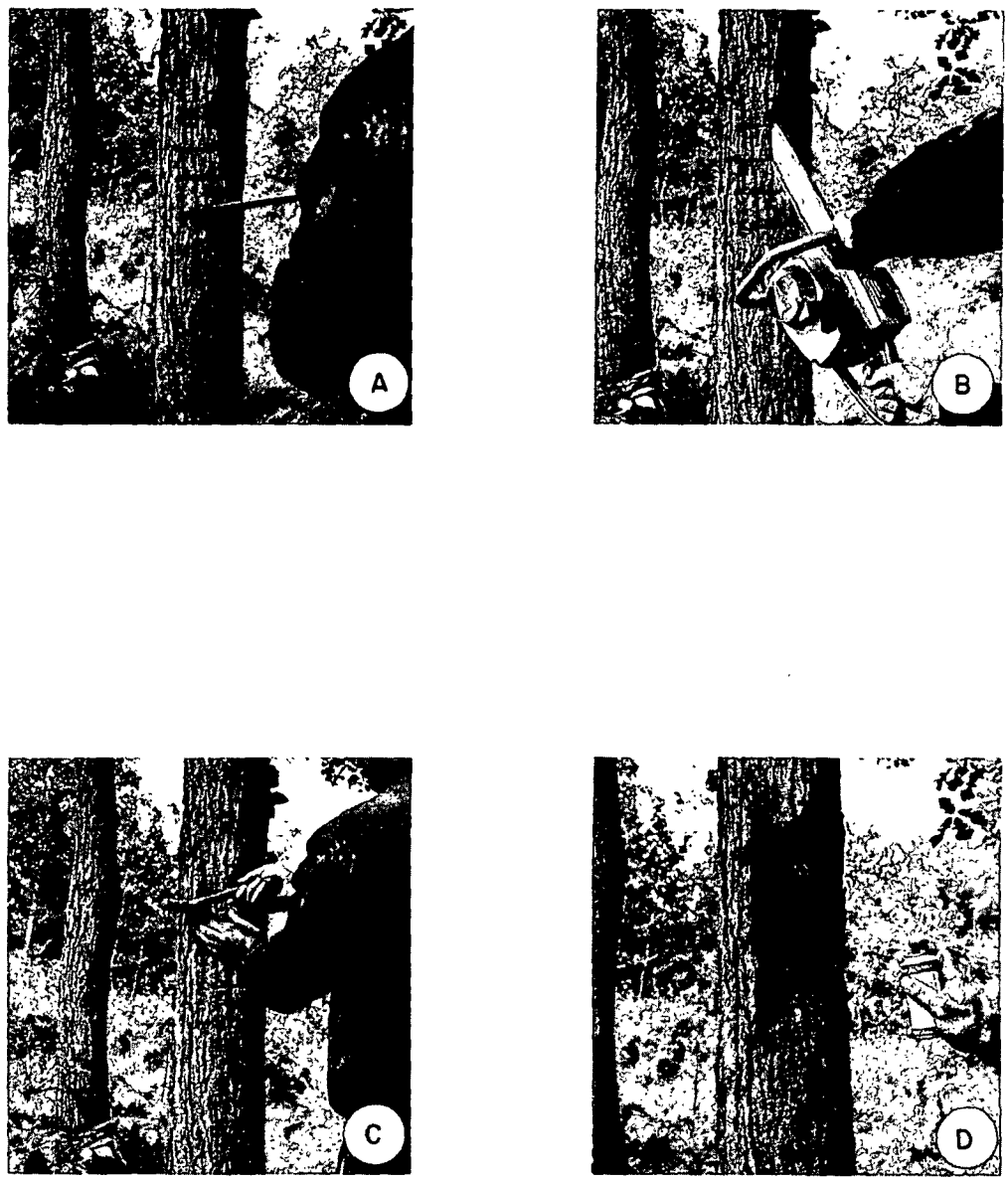

Figure 1. Satisfactory Test Samples Were Obtained from Standing Trees Using a Small Chain Saw. Illustrated are the Steps Involved, Including: (A) Making the Horizontal Cuts, (B) Making the Vertical Cuts, (C) Lifting Out the Wedge-Shaped Sample, (D) Painting with Tree Wound Paint so a Second Sample Could be Taken

As a check on the influence of storage time on test results, 15 aspen samples were taken and tested at storage times of 6, 24, 72, 144, and 341 hours. These results are reported in the section on aspen and indicated it was feasible to store the wedge-shaped sections in plastic bags at 40°F. for up to 72 hours without appreciable change in adhesion.

MICROTECHNIQUES

The anatomical observations performed on the samples collected throughout the spring, summer, and fall were made by John D. Hankey of the Division of Natural Materials and Systems. Standard microtechnique, microscopy, and photomicrography methods were employed in preparing and examining the specimens of hardwood species involved in this study.

The objective of this phase of study was to examine the anatomical structure of the hardwood species and determine what cell types, structure, and degree of cell differentiation are important in wood/bark adhesion. It was decided that the use of absolute ethyl alcohol as the killing and fixing reagent would be satisfactory and would preserve the cell chemistry and cell structure of the specimens in as nearly the natural living condition as possible. The celloidin method was used to embed the test specimens (transferring the specimens through six solutions of celloidin) and cross and radial sections 10 to 30 μm.* thick were cut from the embedded material. Permanent slides for reference were prepared by staining the sections with Heidenhain's hematoxylin and safranin and then mounting the stained sections in Canada balsam.

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*1 micrometer = 1 micron = 1/25,400 inch.

In addition to the permanent slides, sections of the material were examined for cell contents, lignification (phloroglucinol test) of cell walls, amount and location of starch (weak solution of I-KI), etc.

MEASUREMENT OF WOOD/BARK ADHESION

Adhesion between wood and bark has been the subject of research for many years. A number of apparently satisfactory but relatively crude techniques have been developed for measuring adhesion (5, 7, 8). A major portion of the wood/bark adhesion research was initiated during a period in the 1950's, when there was considerable interest in the chemical debarking of standing trees. Most of these early tests were designed for use on bolts or standing trees and were judged to be unsatisfactory for examining adhesion changes in chip or simulated chip samples that were expected to result from planned treatments.

Willmer Wink and Roger Van Eperen*, with the goal of developing a "parallel to grain" shear test that could be used on small wood/bark samples, developed the Instron test method described in the following paragraphs.

The shear strength of the wood/bark interface was measured on specimens as shown in Fig. 2. Except for the time required to cut the specimens to the desired dimensions, the samples were stored over ice (approximately 40°F.) until tested. The specimens were first cut on a band saw to an approximate size of 1/4 by 1/4 by 1-1/4 inches long. The wood and bark surfaces were then trimmed with a razor blade to make them as nearly parallel to the interface as possible. These two surfaces were clamped in the jig shown in Fig. 2A, the specimen was aligned so that the grain direction was parallel with the long dimension of the jig, and

*Paper Evaluation Section, Division of Materials Engineering and Processes of The Institute of Paper Chemistry.

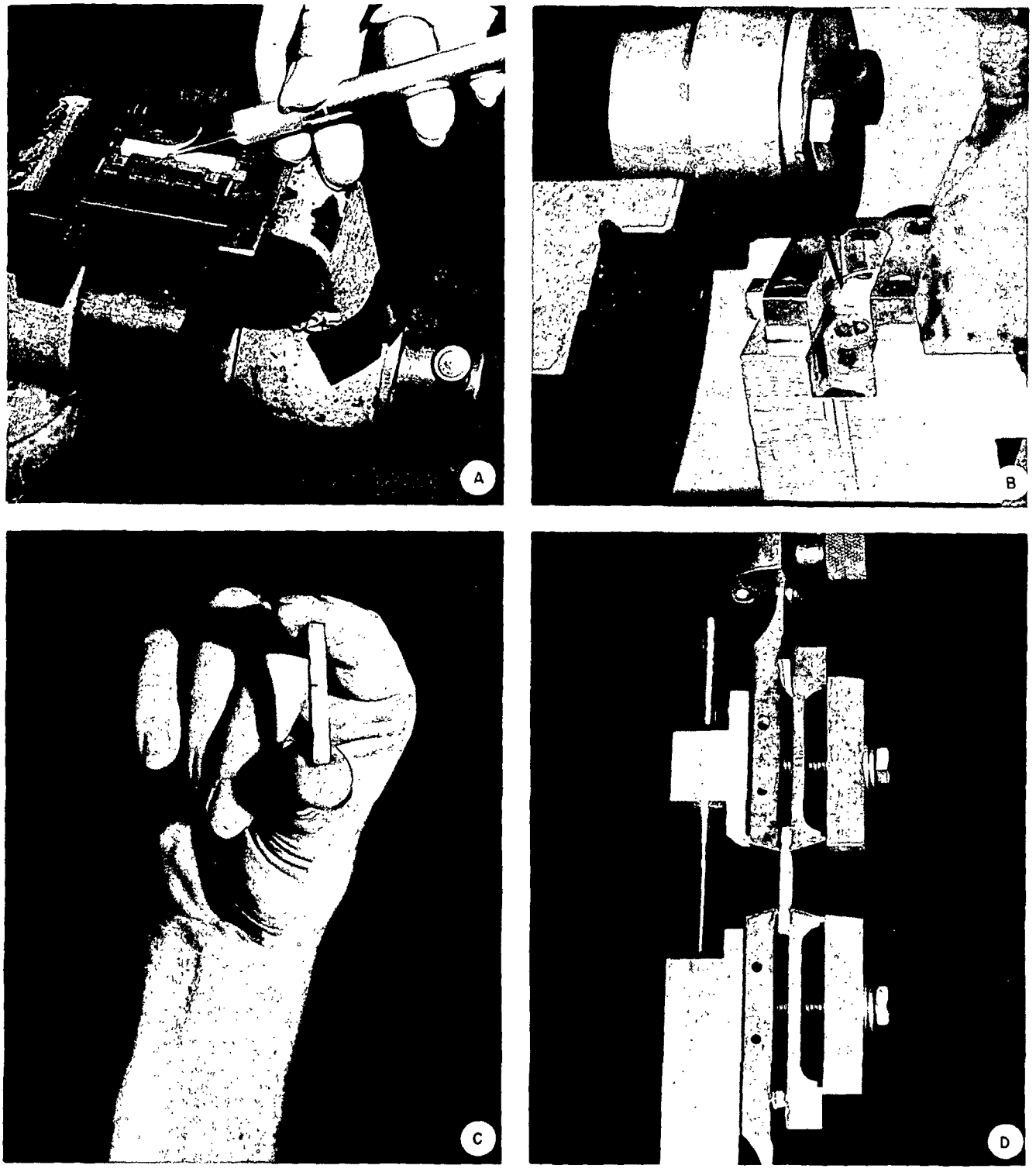

Figure 2. Small Test Samples Suitable for Use in the Instron Tester Were Prepared by Cutting the Sample to Approximate Size on the Band Saw. The Samples Were Then: (A) Shaved to the Exact Dimensions, (B) Cuts Made Through the Bark and Wood to Cambium, (C) Removed from the Jig Used in Holding the Sample During Cutting, (D) Tested for Adhesion (Shear Parallel to Grain) in the Instron Tester

the two exposed surfaces were trimmed flush with the 3/16-inch dimension of the jig. The specimen was turned in the jig and aligned so that the wood/bark interface corresponded with the bottom of the 3/32-inch cutout of the jig, and the wood and bark surfaces were trimmed flush with the surface of the jig. The resulting specimen was 3/16 by 3/16 inch and 1-1/4 inches long, with the wood/bark interface centered with respect to the thickness of the specimen.

To facilitate making the final two cuts in the specimen, the apparatus shown in Fig. 2B was used together with the shaper attachment on a machine lathe. The specimen was held in a U-shaped jig and supported on the bottom during cutting. The cutting tool was an X-acto No. 23 two-sided blade which was held in the chuck of the lathe. The specimen was positioned just behind the blade with the latter displaced 1/16 inch with respect to the center of the U-shaped jig. The specimen was raised until the tip of the blade coincided with the wood/bark interface and the setting of the depth index was noted. The specimen was then lowered to a position where the blade would just cut the surface and a cutting pass was made by moving the shaper forward. The specimen was raised 0.010 inch and a second cutting pass was made by moving the shaper backward. Similarly, additional cutting passes were made until the depth of cut was 0.005 inch below the wood/bark interface. The specimen was then inverted and a cut was made in the same manner from the opposite side, again with the blade positioned 1/16 inch off center of the U-shaped jig. Hence, the distance between the two cuts was 1/8 inch, the bottom of the two cuts overlapped 0.010 inch and the surface area of the wood/bark interface being tested was 0.0234 sq. in. or 0.151 sq. cm. Figure 3 illustrates the size and shape of the test specimens.

For testing, the specimens were mounted in an Instron tensile testing machine, as shown in Fig. 2D. The clamping jaws were 0.02 inch wide and were

separated by a distance of 0.75 inch. The specimens were strained at a rate of 0.2 inch per minute. Nine specimens were tested for each species of tree on each testing date. Each specimen, after testing, was examined and the type of failure noted. Two specimens of each species were immersed in ethyl alcohol immediately after testing for later morphological examination. Two additional specimens of each species were loaded to about 3/4 of the average breaking load of the first nine specimens and immediately unloaded. These were also immersed in ethanol for examination. The results of the seasonal measurements for quaking aspen, white birch, sugar maple, and bur oak are reported in the sections that follow.

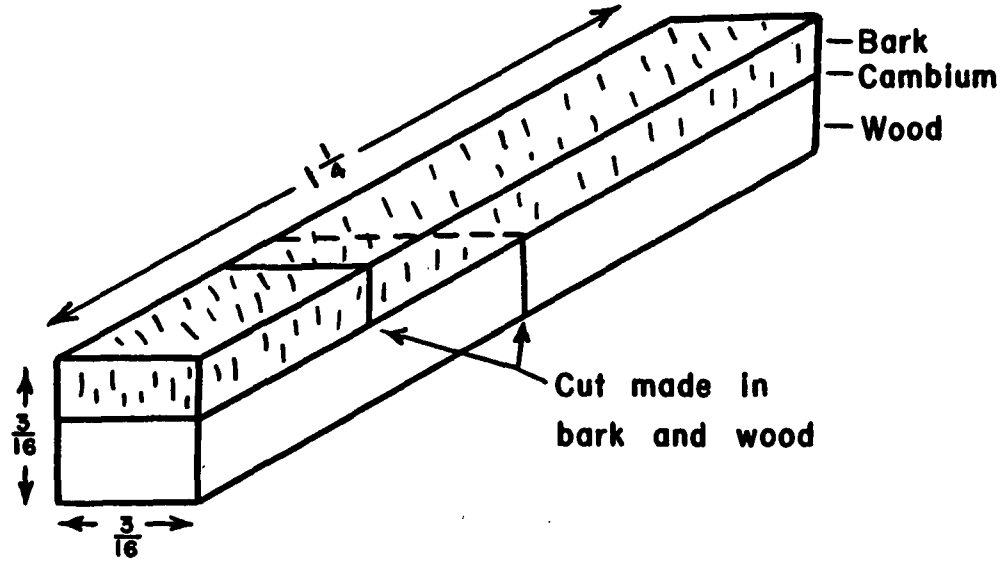

Figure 3. Diagram of the Wood/Bark Adhesion Test Sample. The Dimensions of the Test Tab are 3/16 x 3/16 x 1-1/4 and the Area Between the Two Cuts Tested for Adhesion is 0.0234 Square Inches (0.151 Square Centimeters)

One important limitation of the IPC procedure for measuring wood/bark adhesion (and a limitation for all procedures presently being employed) is that, during the dormant season, when failure occurs in the bark, the magnitude of the test value is dependent upon the strength of the inner bark of the species involved. All that can be said about the values obtained during this period is that "adhesion in the cambium zone and in the bark and wood elements immediately adjacent to the cambium zone is in excess of the values obtained." The principal limitation of the test is that it does not provide a suitable value that can be used to compare wood/bark adhesion differences between species during that part of the year when adhesion is extremely high. Within species comparisons, between species comparisons during the growing season and the evaluation of methods of reducing adhesion can be adequately measured by the testing procedure.

SEASONAL VARIATION IN WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in ease of debarking pulpwood species. Periodic sampling from early spring until fall was the approach used to obtain information on: (1) magnitude of wood/bark adhesion, (2) seasonal changes in wood/bark adhesion, (3) morphological structures associated with wood/bark adhesion, (4) importance of cell differentiation in seasonal variation in wood/bark adhesion, and (5) reasons for differences between species in wood/bark adhesion. Using the sampling and testing procedures described in the preceding sections, seasonal variation in wood/bark adhesion was measured and morphological changes associated with changing adhesion were studied. The results of these observations are described in the following section.

QUAKING ASPEN

Anatomical Structure of Wood and Bark

The wood (xylem) of quaking aspen is made up of fibers, vessels, and ray cells. Quaking aspen is classified as a semiring porous wood because the transition from springwood to summerwood vessels is more or less gradual. As viewed in cross section, the early springwood vessels are solitary or in clusters of six or more. They are approximately 95-100 μm. in diameter. These large vessels are immediately adjacent to the terminal band and are separated by 1-3 rows of fibers. The vessels in the latewood are smaller and average approximately 60-70 μm. in diameter. They appear in smaller clusters and are separated by as many as 8-10 rows of fibers. There are between 85 and 180 vessels per sq. mm. in this species of wood.

The fibers in the xylem of quaking aspen average approximately 20-25 μm. in diameter and 1.0 mm. in length. They have a cell wall thickness of 2-3 μm. Gelatinous fibers, which have a cell wall thickness more than double that of normal fibers, are quite common in this wood species. Figure 4 illustrates the appearance of the major elements that make up the bark and wood of quaking aspen.

The inner bark (secondary phloem) of quaking aspen is made up of sieve tubes, companion cells, parenchyma cells, sclerenchyma (phloem fibers and sclereids), and ray cells. The sieve tubes are large diameter (40-50 μm.), thin-walled cells whose individual sieve tube elements are approximately 800 μm. in length. They are normally surrounded by small diameter, thin-walled companion cells and parenchyma cells. The inner bark of quaking aspen is characterized by tangential bands, 2-10 cells in width, of phloem fibers. The bands may be discontinuous near the "cambium zone."* The fibers are approximately 18-20 μm. in diameter. They have a cell wall thickness of 8-10 μm. and narrow lumen of 2-4 μm. These fibers have an average length of approximately 1 mm. The homogeneous, uniseriate phloem rays are distributed uniformly throughout the inner bark. The rays appear more narrow in width near the cambium zone than in the outer region of the inner bark. The rays average 15-20 cells and approximately 400 μm. in height.

Storage of Test Samples

The early preliminary use of the Instron testing method was developed using quaking aspen samples. In May (5/11/70) when wood/bark adhesion was low and maximum biological changes could be expected as a result of storing the test samples,

*Cambium zone – the true cambium consists of a single layer of dividing cells from which the xylem (wood) and secondary phloem (inner bark) arise. In this study the term "cambium zone" has been used to designate the true cambium plus all undifferentiated xylem and phloem cells immediately adjacent to the cambium.

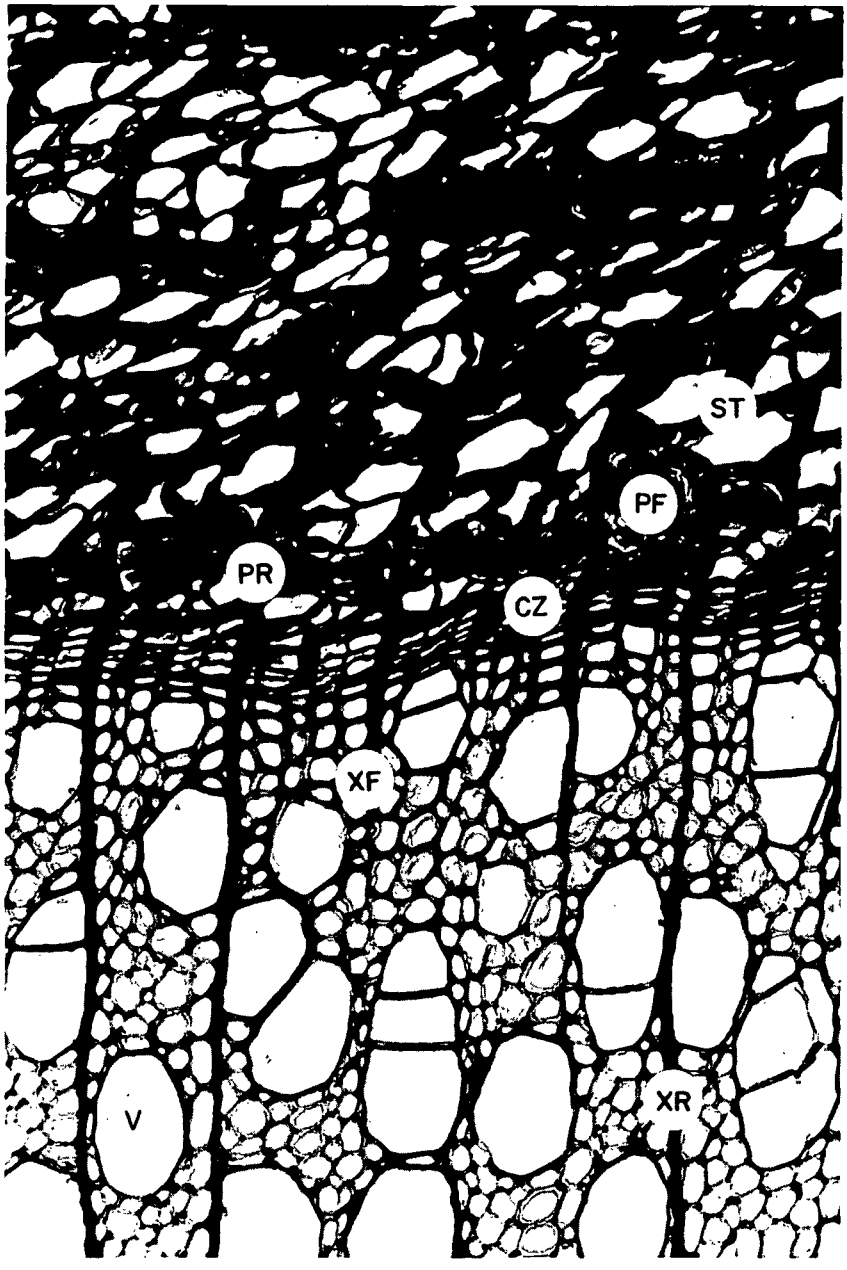

Figure 4. Cross Section of Quaking Aspenwood and Bark Sampled When the Cambium was Dormant. Illustrated are Phloem Fibers (PF), Xylem Fibers (XF), Vessels (V), Sieve Tubes (ST), Xylem Rays (XR), Phloem Rays (PR), and Cambium Zone (CZ)

five samples were taken and evaluated for the influence of storage prior to testing. The procedure used was to store freshly cut, wedge-shaped samples in polyethylene bags at about 40°F. and test the samples at 6, 24, 72, 144, and 341 hours after field collection.

Table I summarizes the results and illustrates the change obtained with storage. Measured wood/bark adhesion increased with increasing storage time. Analysis of variance calculations indicated that the differences obtained were statistically significant. Further evaluation of the data using Duncan's multiple range test makes it appear that samples could be stored for up to 72 hours without a significant change in test results. Based upon this preliminary comparison, it is recommended that locally collected samples be tested at from 24-48 hours after sampling and that samples being shipped be maintained at approximately 40°F. and tested 48-72 hours after collection.

TABLE I

EFFECT OF TEST SAMPLE STORAGE ON WOOD/BARK ADHESION

Storage Time, hours	Adhesion, kg./cm.^{2} Range	Average[a]
6	3.6-8.2	6.3
24	4.8-7.3	6.3
72	5.4-8.8	7.0
144	8.5-11.5	9.9
340	9.7-13.6	11.6

[a]Duncan's multiple range test (9) was used to compare averages. Values connected by a common line are not statistically different at the 5% level of probability.

Seasonal Testing of Aspen

Seasonal sampling of aspen wood/bark adhesion was initiated on March 2. Adhesion measurements were continued throughout the growing season and measurements were discontinued after the September 14 samples were tested. Table II summarizes the morphological observations made on test specimens and the results of the measurements taken using the previously described Instron testing procedure. Figure 5 graphically presents the seasonal variation in quaking aspen wood/bark adhesion measurements as measured by shear parallel to the grain. Figure 6 shows some of the seasonal changes that occurred in the cambium zone and Fig. 7 illustrate the changes that were found in the location of the zone of failure. Briefly described below are observations on seasonal morphological changes that were associated with changes in wood/bark adhesion.

March 2 – Cambium dormant; cambium zone 3-5 cells in width; failure occurred in inner bark (in sieve tube area between the last two tangential bands of phloem fibers nearest the cambium); adhesion values are higher and more variable than normal because of problems in making cuts into the cambium area. Estimated adhesion in cambium zone was in excess of 17.8 kg./cm.^{2}.

April 6 – Cambium dormant; cambium zone 3-5 cells in width; failure occurred in inner bark (in sieve tube area between the last two tangential bands of phloem fibers nearest the cambium); adhesion in cambium zone in excess of 13.0 kg./cm.^{2}.

May 4 – Cambium active; cambium zone 5-7 cells in width (Fig. 6); no new xylem cells deposited as yet; failure occurred in cambium zone (Fig. 7); adhesion in cambium zone was 4.1 kg./cm.^{2}. Low values apparently due to physiological changes in cambium zone.

TABLE II

SUMMARY OF OBSERVATIONS ON SEASONAL VARIATION
QUAKING ASPEN – APPLETON, WISCONSIN

Date	Adhesion, kg./cm.^{2} Average	Adhesion, kg./cm.^{2} Standard Deviation	Cambium[a] Activity	Width Cambium Zone	New Xylem Cells Total No.	New Xylem Cells No. Non-lignified	No. Immature Phloem Cells	Location of Zone of Failure	Additional Zone of Apparent Weakness
3/2/70	17.8	1.70	D	3-5	0	0	2	Sieve tubes between last two tangential bands of phloem fibers nearest cambium	Undifferentiated cambium; phloem immature
4/6/70	13.0	0.94	D	3-5	0	0	2-3	Sieve tubes between last two tangential bands of phloem fibers nearest cambium	Undifferentiated cambium
5/4/70	4.1	0.42	A	5-7	0	0	2-3	Cambium zone	Sieve tubes between last two bands of phloem fibers
5/18/70	7.2	0.63	VA	8-10	2-3	2-3	2-3	Cambium zone	Immature xylem cells
6/1/70	7.7	0.58	A	12-14	12-14	8-10	3-4	Immature & non-lignified xylem cells 6-8 cells in from cambium zone	Cambium zone
6/29/70	6.5	0.42	A	4-6	18-20	3-4	5-6	Between cambium & last formed 2 to 3 rows of xylem cells	Immature phloem
7/22/70	12.0	0.78	D	4-6	20	0	4-6	Last formed phloem fibers & sieve tubes	Cambium zone
8/10/70	7.6	0.91	D	3-4	18	0	2-3	Some failure like 7/22 and some in cambium zone	Immature phloem
8/24/70	8.7	0.77	D	3-4	20	0	2-3	Sieve tubes between last two bands of phloem fibers nearest cambium	Undifferentiated cambium
9/14/70	8.4	0.84	D	3-4	20-25	0	2-3	Sieve tubes between last two bands of phloem fibers nearest cambium	Undifferentiated cambium

[a] A = active, D = dormant, VA = very active.

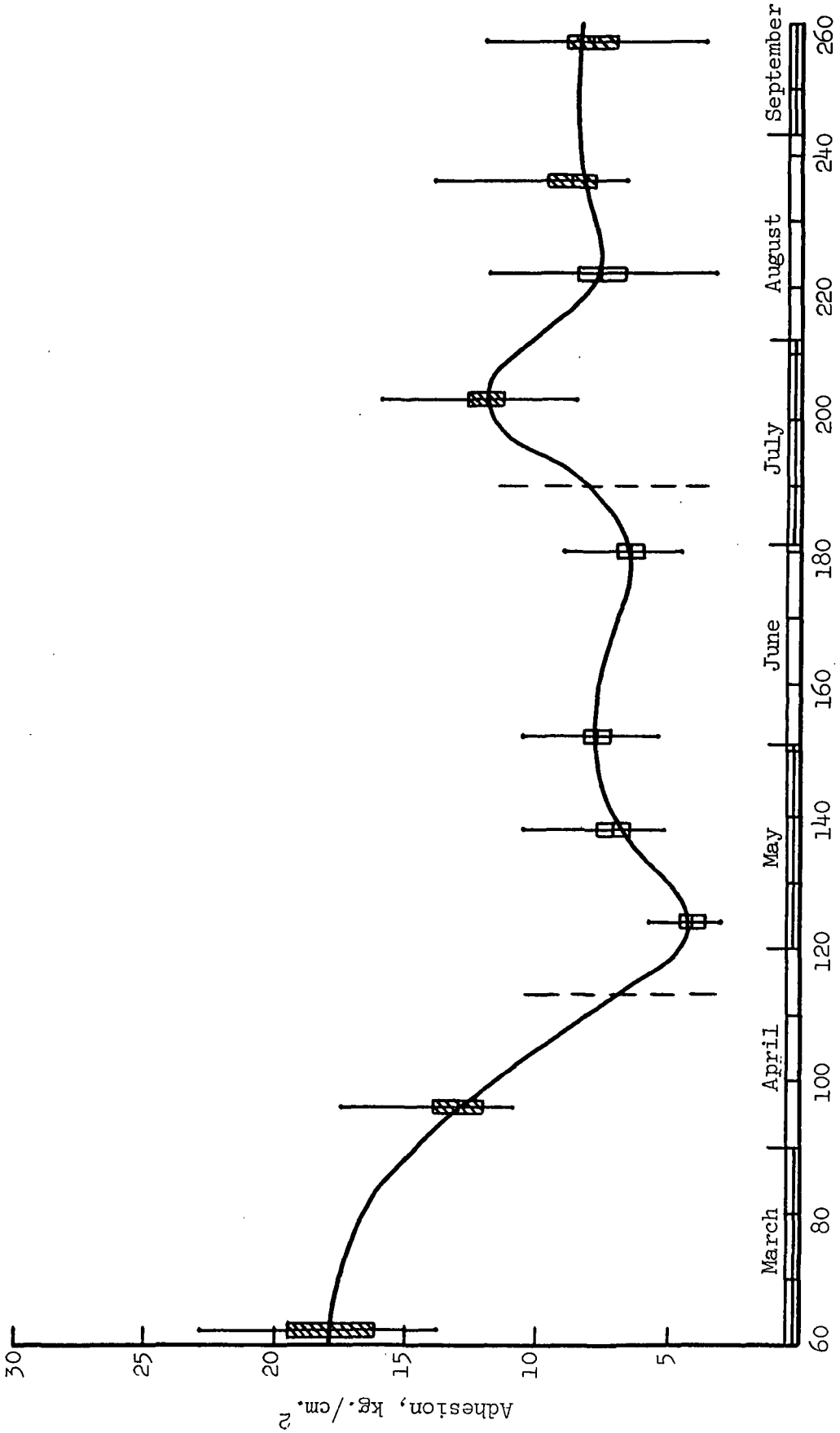

Figure 5. Seasonal Variation in Wood/Bark Adhesion for Quaking Aspen. Shown for Each Sampling Date is the Range, the Mean and One Standard Deviation Each Side of the Mean. When the Small Standard Deviation Rectangle is Shaded, Failure Occurred in the Bark. The Nonshaded Rectangles Designate Failure in the "Cambium Zone." The Vertical Dashed Lines Indicate the Estimated Start and End of the Peeling Season

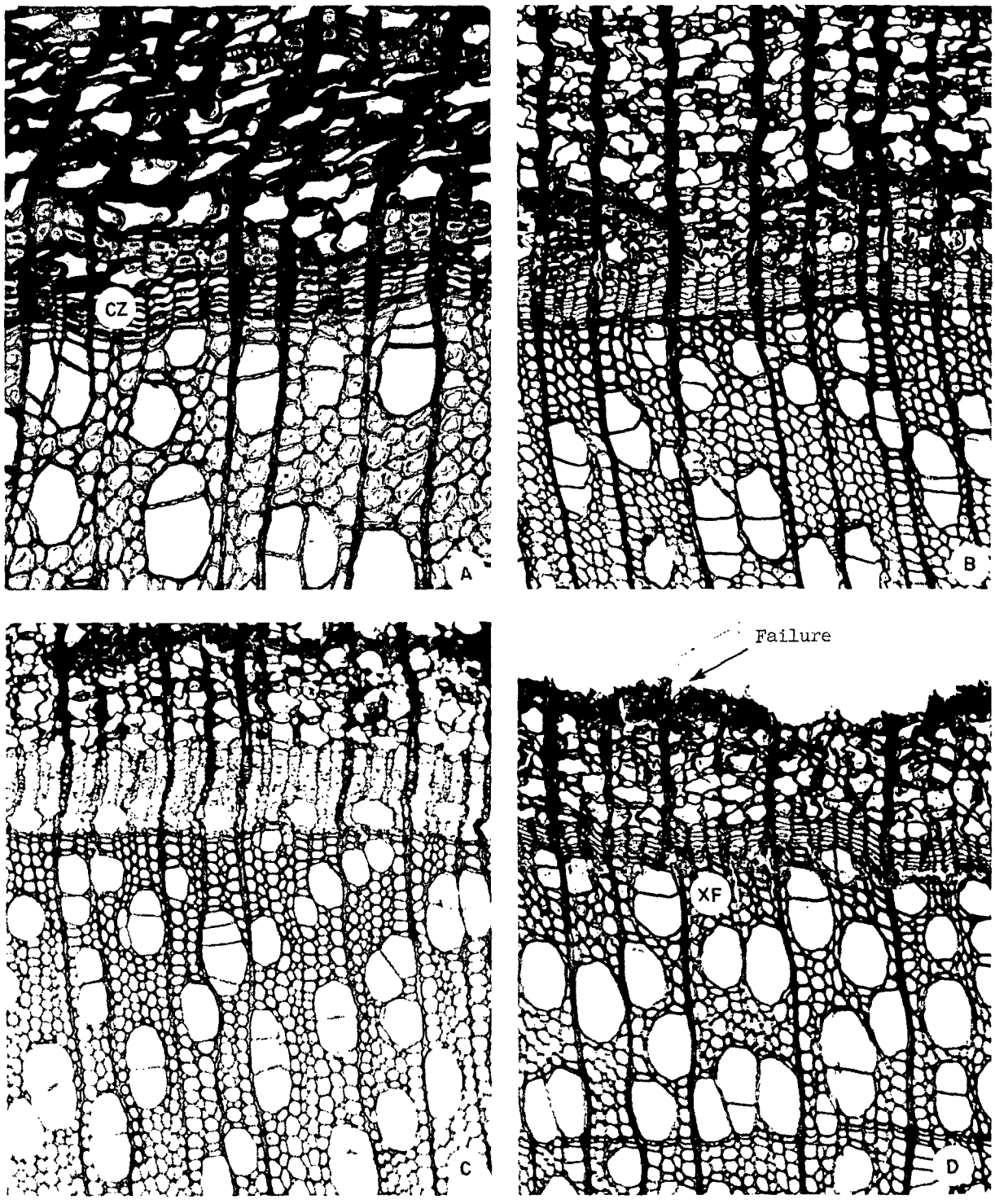

Figure 6. Illustrated are Cross Sections of Aspen Showing the Bark (Phloem), Wood (Xylem) and the Seasonal Changes that Occurred in the Cambium Zone Between the Bark and Wood. A – March 23 Collection Showing Inactive Cambium (CZ); B – May 4 Collection, Cambium Activity Just Starting and Adhesion Low; C – May 18 Collection, Cambium Very Active and Adhesion Low; D – July 22 Collection, Cambium Inactive, Xylem Fibers (XF) Lignified, Failure Occurred in Inner Bark

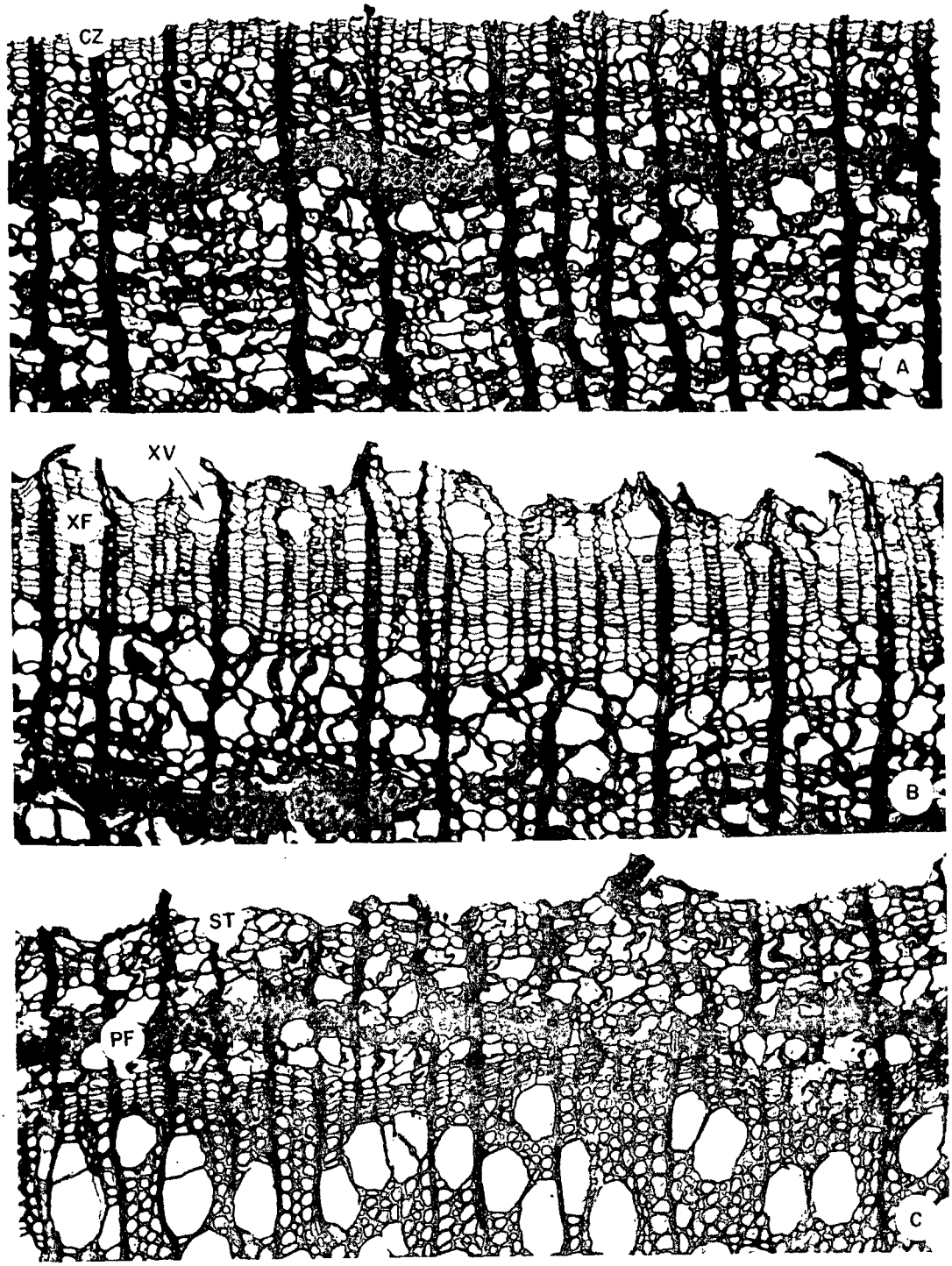

Figure 7. Illustrated are the Seasonal Changes in the Location of the Zone of Failure in Quaking Aspen. A – May 4 Collection, Failure Along Cambium (CZ); B – June 1 Collection, Failure in Newly Differentiated Non-lignified Xylem Fibers (XF) and Xylem Vessels (XV) and C – September 14 Collection, Failure in Phloem Sieve Tube (ST) Area Outside of Band of Phloem Fibers (PF). The Bark Appears in the Lower Area of Cross Sections A and B and in the Upper Area in Cross Section C

May 18 – Cambium very active; cambium zone 8-10 cells in width (Fig. 6); two to three immature xylem and two to three immature phloem cells present. Failure occurred in cambium zone, adhesion in cambium zone was 7.2 kg./cm.^{2}.

June 1 – Cambium active; cambium zone 12-14 cells in width; 12-14 xylem cells have been laid down with the first-formed cells showing lignification. Failure occurred in the last formed two to three xylem cells adjacent to the cambium zone and outside of the lignified xylem cells (Fig. 7). Adhesion in the cambium zone and newly-formed xylem cells was 7.7 kg./cm.^{2}.

June 29 – Cambium is active; cambium zone is 4-6 cells in width; 18-20 xylem fibers have formed. The earliest-formed xylem is well lignified and all xylem cells, even the most recently formed, show some lignification. Shear failure occurred in a zone between the cambium and last-formed immature and partially lignified xylem cells. Adhesion in the cambium zone and newly-formed xylem cells was 6.5 kg./cm.^{2}.

July 22 – Cambium appears dormant; cambium zone is 4-6 cells in width (Fig. 6); all xylem cells (20 cells in width), including the last-formed cells, are heavily lignified. Failure occurred in the inner bark area beyond the last-formed phloem fibers, and in the adjacent sieve tubes and parenchyma cells (Fig. 6). Adhesion in the cambium zone exceeded 12.0 kg./cm.^{2}.

August 10 – Cambium is dormant; cambium zone is 3-4 cells wide; lignification and secondary thickening of all cells in this year's growth ring has been completed. Parenchyma cells terminating this year's growth are apparent in the cross section. Failure in part of the samples

occurred in the inner bark and for part of the samples in the cambium zone. Cool moist weather apparently resulted in some reactivation of the inner bark zone. Adhesion in the zone dropped below the July reading and was only 7.6 kg./cm.^{2}.

August 24 – Cambium is dormant; cambium zone is 3-4 cells wide; lignification and secondary thickening of all xylem cells has been completed. This year's growth consists of 20 fibers and is 500 μm. in width. Failure occurred in the inner bark, in the sieve tube area between the last two bands of phloem fibers nearest the cambium. Adhesion in the cambium zone as measured by the shear parallel to the grain exceeded 8.7 kg./cm.^{2}.

September 14 – Cambium is dormant; and the condition of the other cells in the test specimen, as viewed in the cross section, is the same as described for August 24. Failure again occurred in the inner bark sieve tube area between the last two bands of phloem fibers nearest the cambium. Adhesion in the cambium zone exceeded 8.4 kg./cm.^{2}.

The time of year when wood/bark adhesion is at a minimum and failure occurs in the cambium zone is often termed the "bark peeling season." There is evidence in the literature that the length of this season and the ease with which the bark can be removed is influenced by the vigor and growth rate of the tree involved, site quality, and such climatic factors as temperature and rainfall. The aspen sampled in this study were slow growing and were growing on a below average site during a season that was hot and dry during July and early August. The 1970 bark peeling season for quaking aspen near Appleton, Wisconsin was estimated to extend from April 23 to July 9. Adhesion during this period was 7.7 kg./cm.^{2} or less and averaged 6.4 kg./cm.^{2}.

The test method used was designed to measure shear parallel to the grain in the cambium zone and the wood and bark elements immediately adjacent to the cambium zone. When failure occurred in the bark out beyond the innermost band of phloem sclerenchyma fibers, adhesion in the cambium zone and the area adjacent was interpreted as being equal to or exceeding the measured value. Failure in the cambium zone or nonlignified cells near the cambium was interpreted as giving a true measure of adhesion. This interpretation of the measured values accounts in part for the relatively small differences obtained between wood/bark adhesion during the so-called "peeling season" and the period during late summer and early fall when the bark peels with some difficulty.

The zone of failure, during the season when the cambium activity was at a minimum (Fig. 6), quite consistently was located in the inner bark sieve tube area between the two most recently formed bands of phloem sclerenchyma fibers. This consistent zone of failure appears for aspen to result because of the structure of the inner bark and because of the way the shear test was designed. Results from a closely related project in which unbarked aspen logs were cut and chipped in November demonstrated that the action of the chipper knives caused the bark and the wood to separate either in the inner bark zone described above or in the inactive cambium zone.

Preliminary examination of the failure zone revealed failure apparently occurred as the result of both breaking of cell walls and from the pulling apart of adjacent cells. Separation in the intercellular region appeared to be less prevalent than failure of the cell walls and occurred most often when the wood and bark elements were heavily lignified. However, confirmation of these observations would require additional studies with a scanning and/or transmission electron microscope.

Zones of weakness where separation of wood and bark might be affected during the dormant season include: (1) cambium zone, (2) newly-formed and only partially differentiated phloem sieve tube area outside the cambium, and (3) sieve tube area between the last two bands of phloem sclerenchyma fibers. Chemical, mechanical, thermal, and electrical approaches are being considered as ways of reducing wood/bark adhesion on chip samples on which bark remains attached.

WHITE BIRCH

Anatomical Structure of Wood and Bark

The wood (xylem) of white birch is made up of fibers, longitudinal parenchyma cells, vessels and ray cells and is classified as a diffuse porous wood. As viewed on cross sections, the vessels are solitary or in clusters of 3-6. The largest vessels are 60-100 μm. in diameter and there are 50-100 vessels per square millimeter. The rays are unstoried, 1-5 seriate and homogeneous. The fibers of white birch average approximately 25-30 μm. in diameter and are 1.5-2.0 mm. in length. The fibers have a cell wall thickness of 3-4 μm. Figure 8, a cross section of the cambium region made during September, illustrates the described elements that make up the wood and bark.

The phloem (bark) of white birch is made up of sieve tubes, parenchyma cells, ray cells, and thick-walled sclerenchyma cells arranged in groups called sclereids. There are no bands of sclerenchyma fibers that were so prevalent in quaking aspen. The sieve tubes are arranged in several tangential rows, and vary in diameter from 20-60 μm. depending upon the direction of measurement (radial or tangential). The individual sieve tube elements are 800 μm. in length. The phloem parenchyma cells are more or less circular in cross section, have an average

diameter of 20 μm. and are approximately 100-150 μm. in length. Phloem rays are homogeneous and generally 3-seriate. They are conspicuously broader than the rays in the xylem. The rays near the cambium average 15-20 cells and are approximately 300 μm. in height. The groups of thick-walled sclereid cells generally are separated from the cambium by 5-6 rows of sieve tubes and are not necessarily arranged in tangential bands as is common with the sclerenchyma fibers present in quaking aspen.

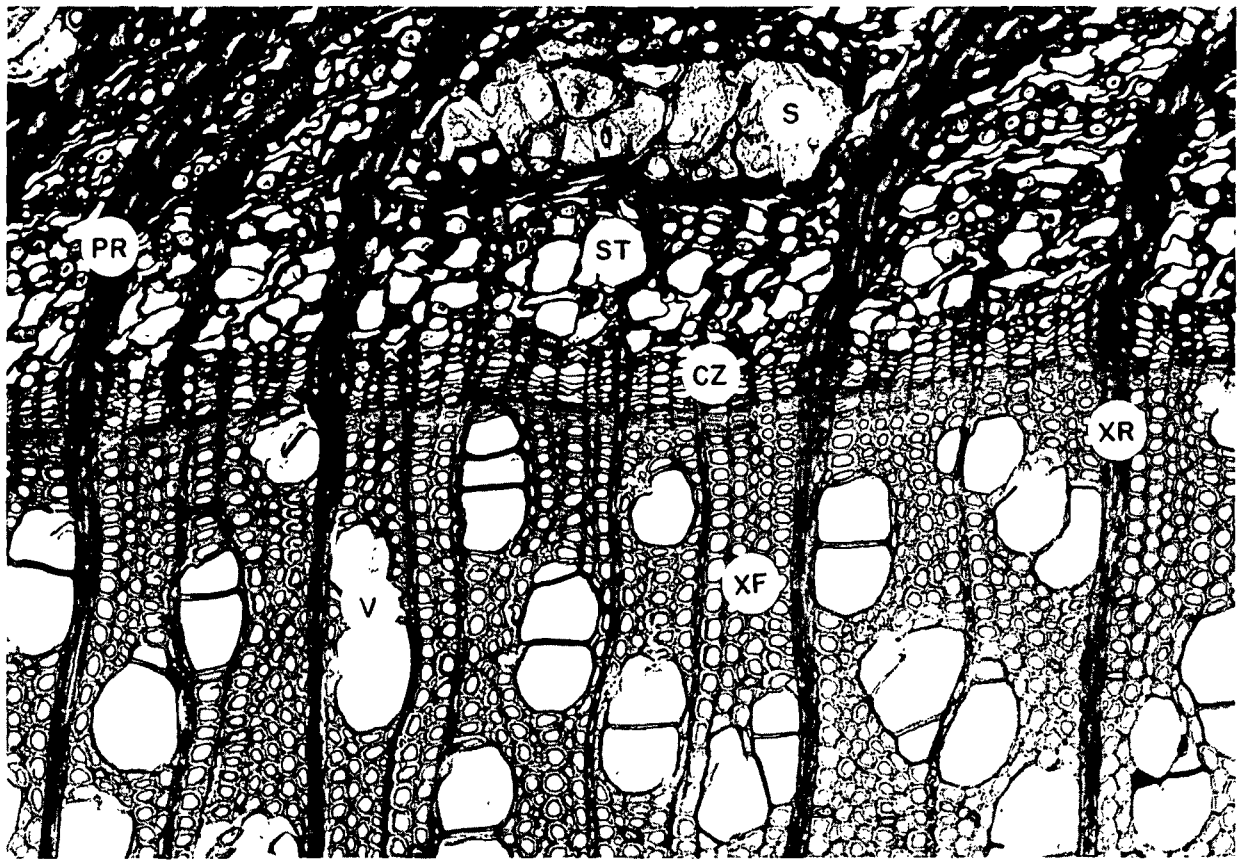

Figure 8. A Cross Section of White Birch Showing a Dormant Cambium Zone (CZ), Xylem Fibers (XF), Xylem Rays (XR), Vessels (V), Immature Sieve Tubes (ST), Phloem Rays (PR) and Thick-Walled Sclerenchyma Cells Arranged in a Group Called Sclereids (S)

Seasonal Variation in Wood/Bark Adhesion

Seasonal sampling of white birch wood/bark adhesion was initiated on March 23. Adhesion measurements were continued throughout the growing season and measurements were discontinued after the September 14 samples were tested. Table III summarizes the morphological observations made on the test specimens and the results of the measurements taken using the previously described Instron testing procedure. Figure 9 graphically presents the seasonal variation in white birch wood/bark adhesion as measured by the shear parallel to the grain. The following are observations on seasonal morphological changes that were associated with changes in wood/bark adhesion. Figures 10 and 11 illustrate these seasonal changes.

March 23 – Cambium dormant; cambium zone* 4-6 cells in width; no new xylem cells have been formed. Failure occurred in the inner bark in an irregular break starting on one edge in the sieve tubes near the cambium. Upon encountering wide well-developed rays and/or sclereids, the failure zone jumped out into weaker sieve tube areas. Adhesion of the cambium zone was in excess of 10.2 kg./cm.^{2}.

April 6 – Cambium dormant; cambium zone 4-6 cells in width; no new xylem cells have been formed. Failure occurred in the inner bark in an irregular break much like that for March 23. Adhesion of the cambium zone was in excess of 10.9 kg./cm.^{2}.

May 4 – Cambium appears dormant but physiological activity is apparently just starting. Cambium zone is 4-6 cells in width. No new xylem cells have been formed. Failure occurred in the cambium and adhesion was only 2.4 kg./cm.^{2} (Fig. 11).

*Cambium zone – The true cambium consists of a single layer of dividing cells from which the xylem (wood) and secondary phloem (inner bark) arise. In this study the term "cambium zone" has been used to designate the true cambium plus all undifferentiated xylem and phloem cells immediately adjacent to the cambium.

TABLE III

SUMMARY OF OBSERVATIONS ON SEASONAL VARIATION
WHITE BIRCH – APPLETON, WISCONSIN

Date	Adhesion, kg./cm.^{2} Average	Adhesion, kg./cm.^{2} Standard Deviation	Cambium[a] Activity	Width Cambium Zone	New Xylem Cells Total No.	New Xylem Cells No. Non-lignified	No. Immature Phloem Cells	Location of Zone of Failure	Additional Zone of Apparent Weakness
3/23/70	10.2	1.49	D	4-6	0	0	2-3	Inner bark region; irregular break along newly formed sieve tube area and then diagonally out after encountering sclereid cells and ending up in previous years' sieve tube region	Sieve tube cells of previous year's phloem
4/6/70	10.9	0.69	D	4-6	0	0	2-3	Irregular break in inner bark. Problem appears related to cutting and sclereids as described in 3/23 failure	Sieve tube cells of previous year's phloem
5/4/70	2.4	0.30	A	4-6	0	0	2-3	Cambium	Sieve tube cells of previous year's phloem
5/18/70	4.8	0.19	VA	11-13	4	4	3-4	In cambium zone and immature xylem cells	Cambium zone
6/1/70	6.9	0.29	VA	14-16	14-16	12-14	4-5	In cambium zone and immature xylem cells	Cambium zone
6/29/70	6.5	0.50	A	7-8	30	10-12	2-3	Outside the cambium zone in immature xylem cells	Cambium zone
7/22/70	12.3	0.32	D	5-6	30-34	0	2-3	Cambium zone	Immature phloem zone
8/10/70	14.7	0.78	D	4-6	32-38	0	2-3	Cambium zone	Immature phloem zone
8/24/70	13.6	0.47	D	3-4	34-38	0	2-3	Cambium zone	Immature phloem zone
9/14/70	10.0	0.60	D	5-6	38-42	0	2-3	Same as for 3/23/70 sample	Sieve tube area just outside dormant cambium

[a] A = active, D = dormant, VA = very active.

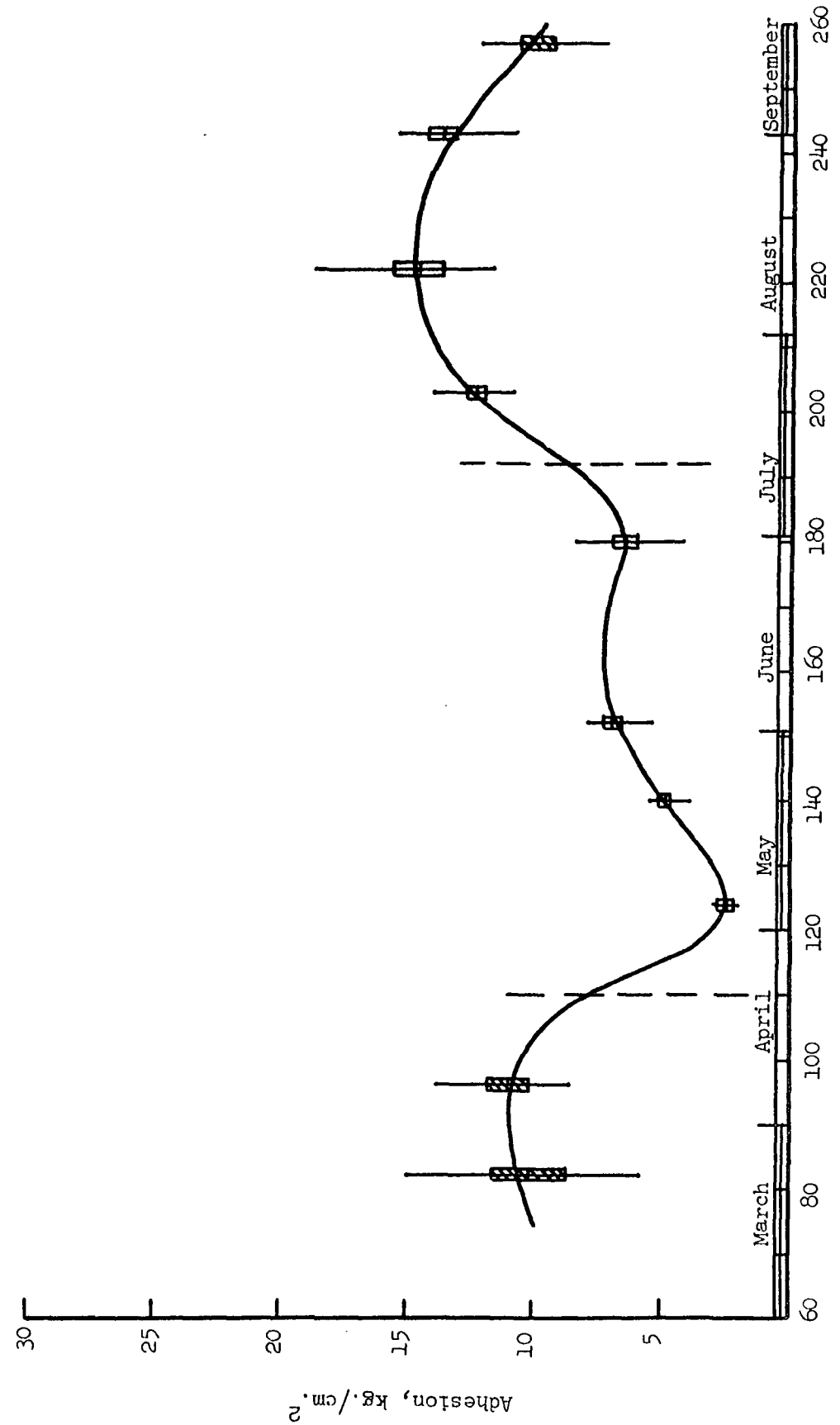

Figure 9. Seasonal Variation in Wood/Bark Adhesion for White Birch. Shown for Each Sampling Date is the Range, the Mean and One Standard Deviation Each Side of the Mean. When the Small Standard Deviation Rectangle is Shaded, Failure Occurred in the Bark. The Nonshaded Rectangles Designate Failure in the "Cambium Zone." The Vertical Dashed Lines Indicate the Estimated Start and End of the Peeling Season

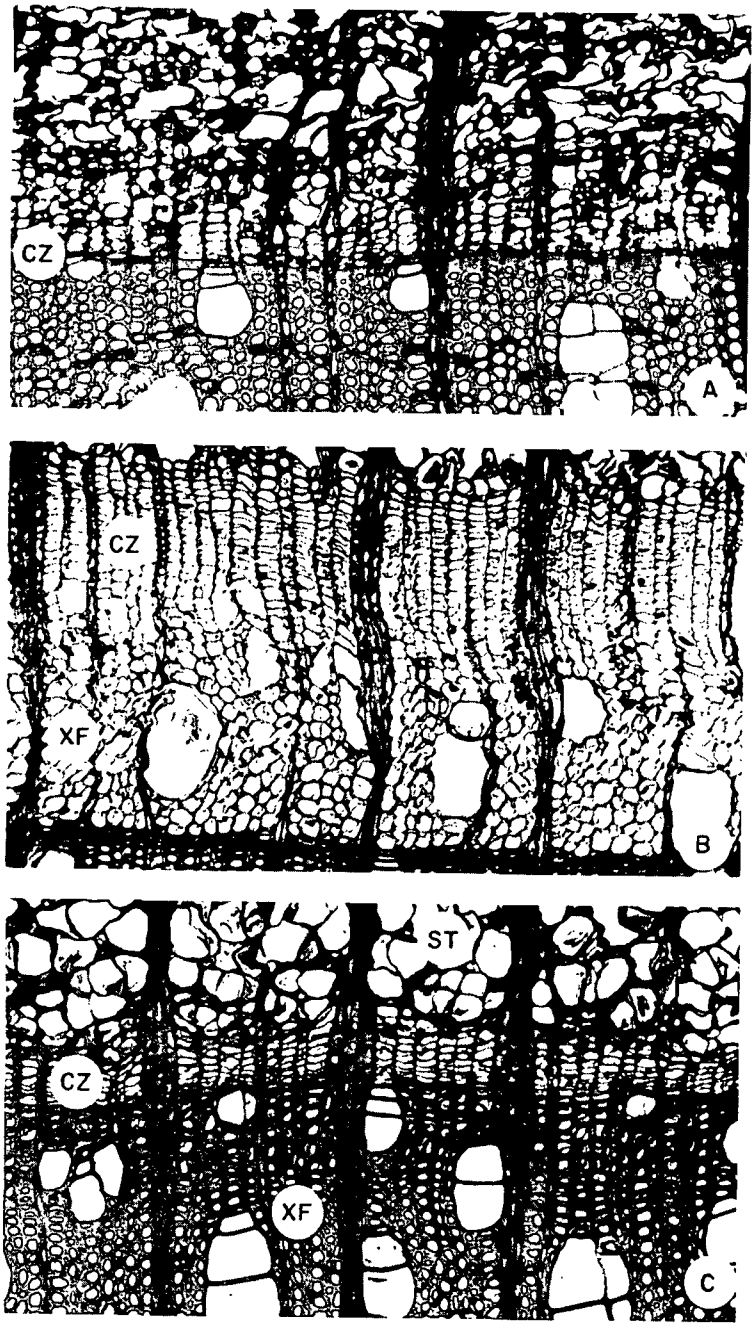

Figure 10. Illustrated are the Seasonal Changes That Occur in the Cambium Zone (CZ) of White Birch. A – May 4 Collection, Cambium Activity Just Beginning, Wood Formed During the Previous Year in Lower Part of Photograph; B – June 1 Collection, Cambium Very Active, Cambium Zone 14-16 Cells in Width, 14-16 Rows of Newly Formed Xylem Fibers (XF) Evident; C – July 22 Collection, Cambium Dormant and Cambium Zone (CZ) 5 to 6 Cells in Width, Most of the Xylem Fibers (XF) Lignified, Zone of Immature Phloem Sieve Tubes (ST) a Prominent Weak Area in the Inner Bark

May 18 – Cambium very active; cambium zone 11-13 cells in width; 4 rows of immature xylem cells and 3-4 phloem cells present near the cambium zone. Failure occurred in the outer cambium zone and the immature xylem cells. Adhesion in the cambium zone was 4.8 kg./cm.^{2}.

June 1 – Cambium very active; cambium zone 14-16 cells in width; 14-16 new xylem cells have been deposited; 3-4 rows of xylem cells are immature and none are lignified; 4-5 newly formed phloem cells are evident outside the cambium zone. Failure occurred in the cambium zone and in the immature xylem cells. Some evidence exists that the ray cells were breaking back in the zone of newly formed xylem cells and pulling out, resulting in "ray stubs" attached to the bark portion of the tested sample (see Fig. 11). Adhesion in the cambium zone was 6.9 kg./cm.^{2}.

June 29 – Cambium active; cambium zone 7-8 cells in width. A total of 30 rows of new xylem cells have been formed; all except the last formed 12-14 rows are lignified. There are 2-3 immature phloem cells present outside the cambium zone. Failure occurred outside the cambium zone and in the immature xylem cells. Ray cells in the phloem are wider and apparently stronger and the ray failure, as described in the June 1 sample, occurred in the immature xylem zone leaving "ray stubs" attached to the bark portion of the test specimen. Adhesion in the cambium zone was 6.5 kg./cm.^{2}.

July 22 – Cambium dormant; cambium zone 5-6 cells in width; a total of 30-34 rows of new xylem fibers have been formed; all have differentiated and all except the last 2-3 rows of fibers adjacent to the cambium are heavily lignified (Fig. 10). A layer of immature phloem sieve tubes 3-5 cells in width is present just outside the cambium region.

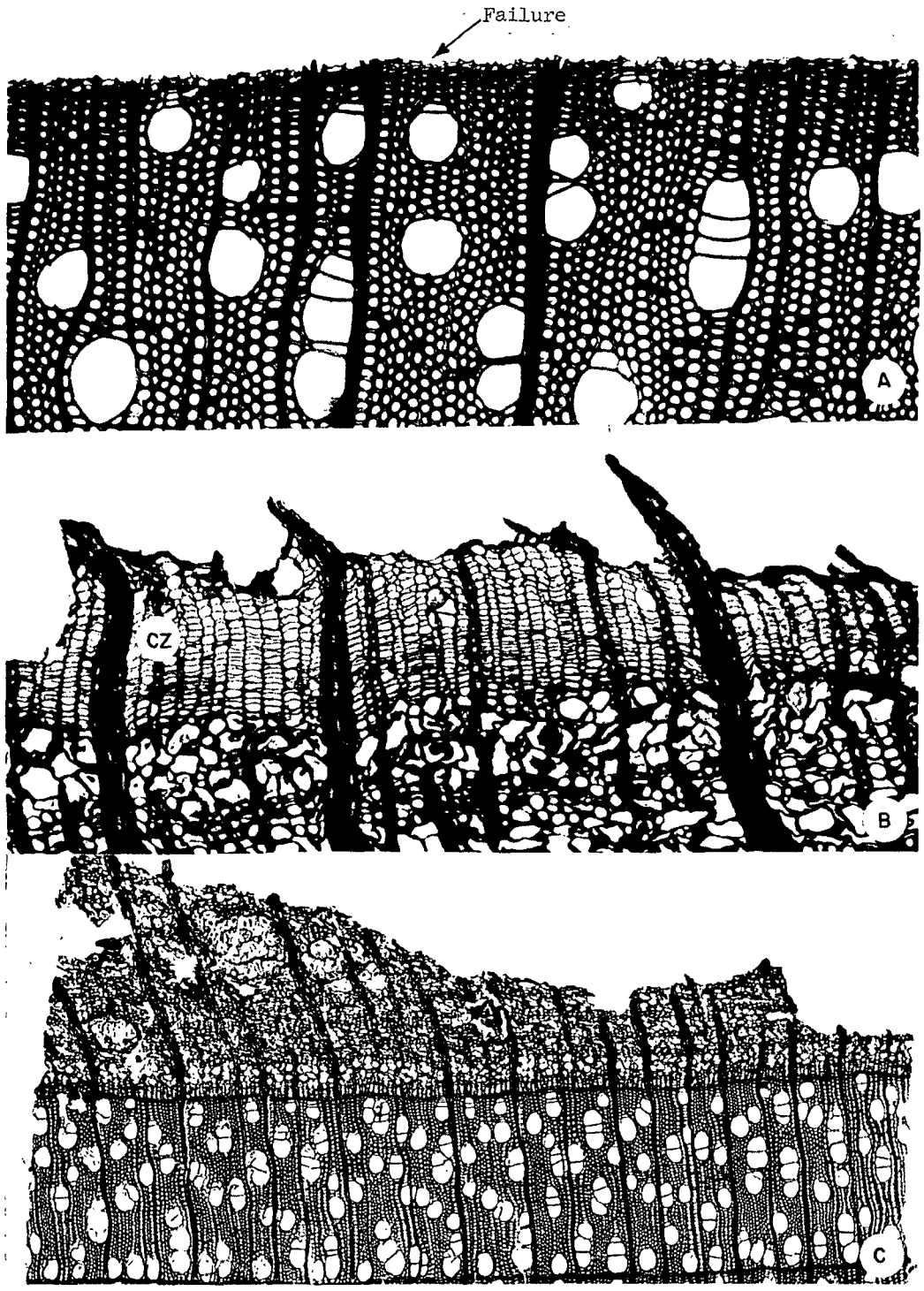

Figure 11. Zones of Failure in White Birch are Illustrated for: A – May 4 Collection, Failure Along Newly Active Cambium; B – June 1 Collection, Failure Just Outside Very Active Cambium Zone (CZ) in Newly Formed Nonlignified Xylem, Ray Stubs Prominent; C – September 14 Collection, Failure Started in Inner Bark Area Near Cambium (Right) and Progressed Diagonally Across Older Sieve Tube Areas of Inner Bark. The Wood is in the Lower Area of Cross Sections A and C and in the Upper Area in Cross Section B

Wood/bark adhesion in the cambium zone was 12.3 kg./cm.^{2}, and failure occurred in the cambium zone.

August 10 – Cambium dormant; cambium zone 4-6 cells in width. A total of 32-38 rows of new xylem cells have been deposited. All xylem cells in this year's growth ring are heavily lignified and secondary thickening is complete. Wood/bark adhesion in the cambium zone was 14.7 kg./cm.^{2}, and failure occurred primarily in the cambium zone. On at least one test specimen, part of the failure zone extended out into the inner bark and in addition to the usual phloem elements being present, several prominent rays extended into the area of attached inner bark.

August 24 – Cambium dormant; cambium zone 3-4 rows of cells in width; lignification and secondary thickening of all xylem cells in the last year's growth increment complete. There are 2-3 rows of immature, thin-walled phloem sieve tubes present outside the cambium zone. Failure occurred in the cambium zone and wood/bark adhesion averaged 13.6 kg./cm.^{2}.

September 14 – Cambium dormant; cambium zone 5-6 rows in width; the walls of all cells in the current xylem growth ring are fully mature and lignified. There are 2-3 rows of immature, thin-walled phloem sieve tubes present outside the cambium zone. Failure occurred in the inner bark but was irregular, starting along newly-formed immature sieve tube area and then moving diagonally out further into the inner bark after encountering prominent rays and/or sclereid cells and usually ending up in the sieve tube area deposited during previous years.

The length in time of the bark peeling season for birch was almost identical to that for quaking aspen and was estimated to extend from April 20 to July 9 (adhesion values less than 8 kg./cm.^{2}). Wood/bark adhesion values for the peeling season averaged 5.1 kg./cm.^{2} for birch as compared to 6.4 kg./cm.^{2} for quaking aspen during this same period.

Failure in the test specimens during the "peeling season" started in the cambium zone (April) and then moved to the zone of newly formed immature xylem cells immediately adjacent to the cambium zone. During the late summer (July 22 to August 24), when wood/bark adhesion was high, failure occurred in the cambium zone at adhesion levels higher than experienced with the other species tested (average – 13.5 kg./cm.^{2}). Failure of the September 14 sample occurred in the inner bark region in an irregular pattern similar to that observed for samples tested in the spring prior to cambial activity. The presence of well-developed, 1-5 seriate rays and groups of thick-walled sclereids are the apparent cause for the failure zone to vary in its location within the inner bark.

Observations made on cross sections during the dormant season suggest the primary zones of weakness are the undifferentiated cells of the cambium zone and the nonlignified, partially mature sieve tubes just outside the cambium. Interestingly enough, observations made on birch pulpwood cut and chipped in November without prior debarking, produced bark-free chips in which separation had occurred primarily in the immature phloem sieve tubes just outside the cambium. Treatments aimed at reducing adhesion during the season when the cambium is dormant will be concentrated on this zone of apparent weakness.

SUGAR MAPLE

The time required to fix, section, examine and relate the morphological observations to adhesion test results has turned out to be greater than anticipated. The seasonal adhesion measurements were completed for all four tree species in October but the morphological observations are still in progress for oak and maple. The seasonal morphological observations along with the wood/bark adhesion measurements described below will be included in the next progress report.

Seasonal Variation in Wood/Bark Adhesion

Seasonal sampling of sugar maple wood/bark adhesion was initiated on April 14. Measurements were continued throughout the growing season and were discontinued after the October 5 samples were tested. Figure 12 graphically presents the seasonal variation in sugar maple wood/bark adhesion as measured by the previously described IPC Instron testing method.

Adhesion varied from 5.4 kg./cm.^{2} on June 1 to 13.2 kg./cm.^{2} on September 21. Tentative estimates, based upon wood/bark adhesion measurements only, indicate that the peeling season for maple extends from about May 25 to July 17 (wood/bark adhesion less than 7.5 kg./cm.^{2}). The morphological observations, when completed, will more reliably establish the "peeling season" for maple in 1970 and will provide information on zones of failure and wood/bark elements associated with seasonal variation in adhesion.

BUR OAK*

As previously reviewed in the discussion on sugar maple, the time required to fix, section, examine, and relate the morphological observations to adhesion test

*Bur oak is a member of the white oak group.

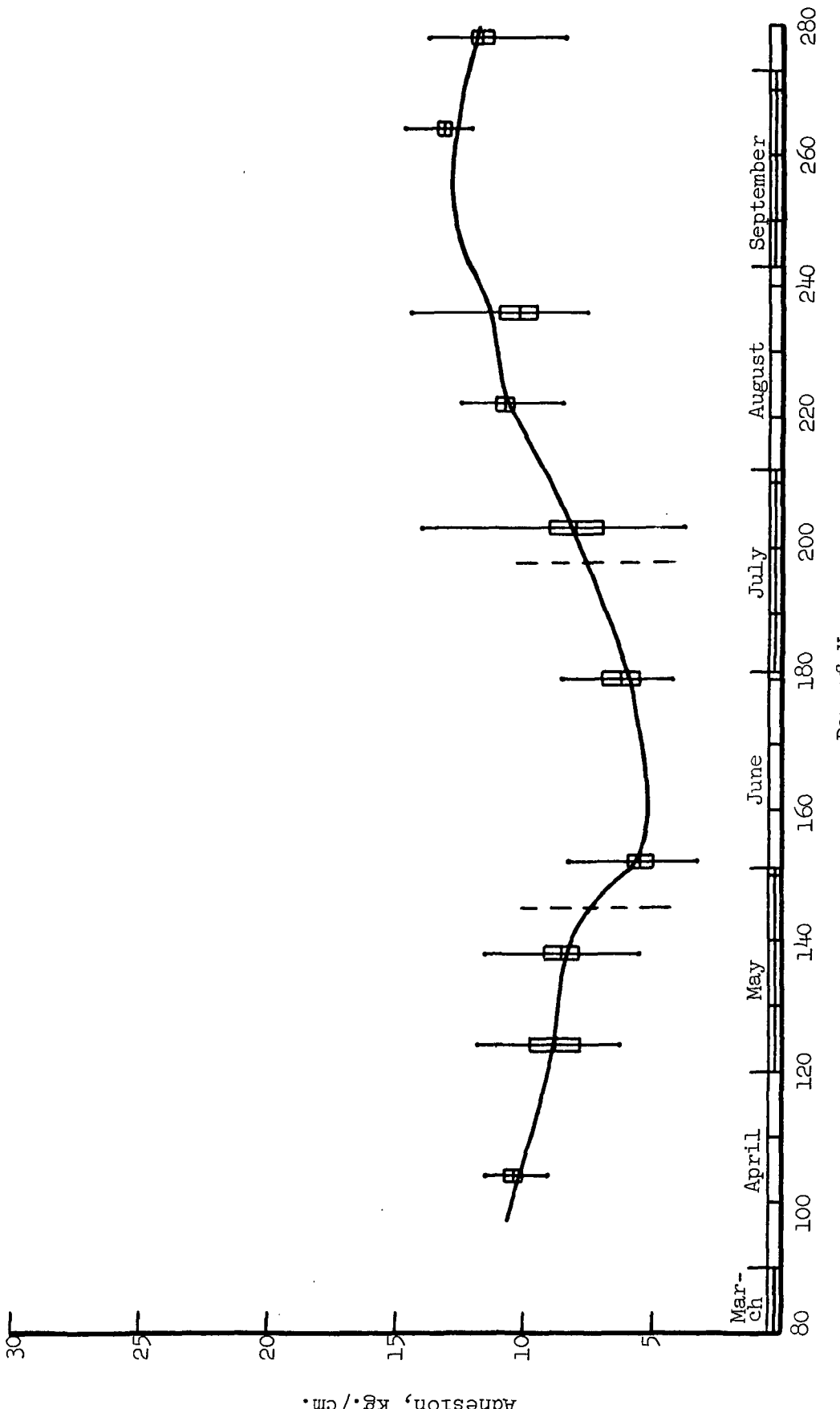

Figure 12. Seasonal Variation in Wood/Bark Adhesion for Sugar Maple. Shown for Each Sampling Date is the Range, the Mean and One Standard Deviation Each Side of the Mean. The Vertical Dashed Lines Indicate the Estimated Start and End of the Peeling Season

results has turned out to be greater than anticipated. The bur oak seasonal adhesion measurements were completed in October but the morphological observations are still in progress. The seasonal morphological observations along with the wood/bark adhesion measurements described below will be included in the next progress report.

Seasonal Variation in Wood/Bark Adhesion

Seasonal sampling of bur oak wood/bark adhesion was started on April 6 and measurements were continued on an every two- or three-week basis throughout the growing season. Measurements were discontinued after the October 5 samples were tested. Figure 13 illustrates the seasonal variation encountered in wood/bark adhesion as measured by the previously described IPC Instron testing method. Month-to-month differences in adhesion were less for the oak samples than for the other species tested. The peeling season, based on adhesion measurements only, was estimated to extend from May 25 to August 17 (wood/bark adhesion values less than 7.5 kg./cm.^{2}). Wood/bark adhesion during the peeling season averaged about 5.0 kg./cm.^{2}, while in the dormant season monthly values ranged from 7.0 to 10.6 kg./cm.^{2} with an average wood/bark adhesion during the dormant season of 8.8 kg./cm.^{2}. The morphological observations, when completed, will more reliably establish the "peeling season" for oak in 1970 and will provide information on the zone of failure and wood/bark elements associated with variations in adhesion.

BETWEEN SPECIES COMPARISONS

Little can be said regarding differences between species until the morphological observations on oak and maple are completed. The nature of the wood/bark adhesion testing procedure, as discussed earlier in the methods section, limits the comparisons that can be made when failure occurs in the inner bark at

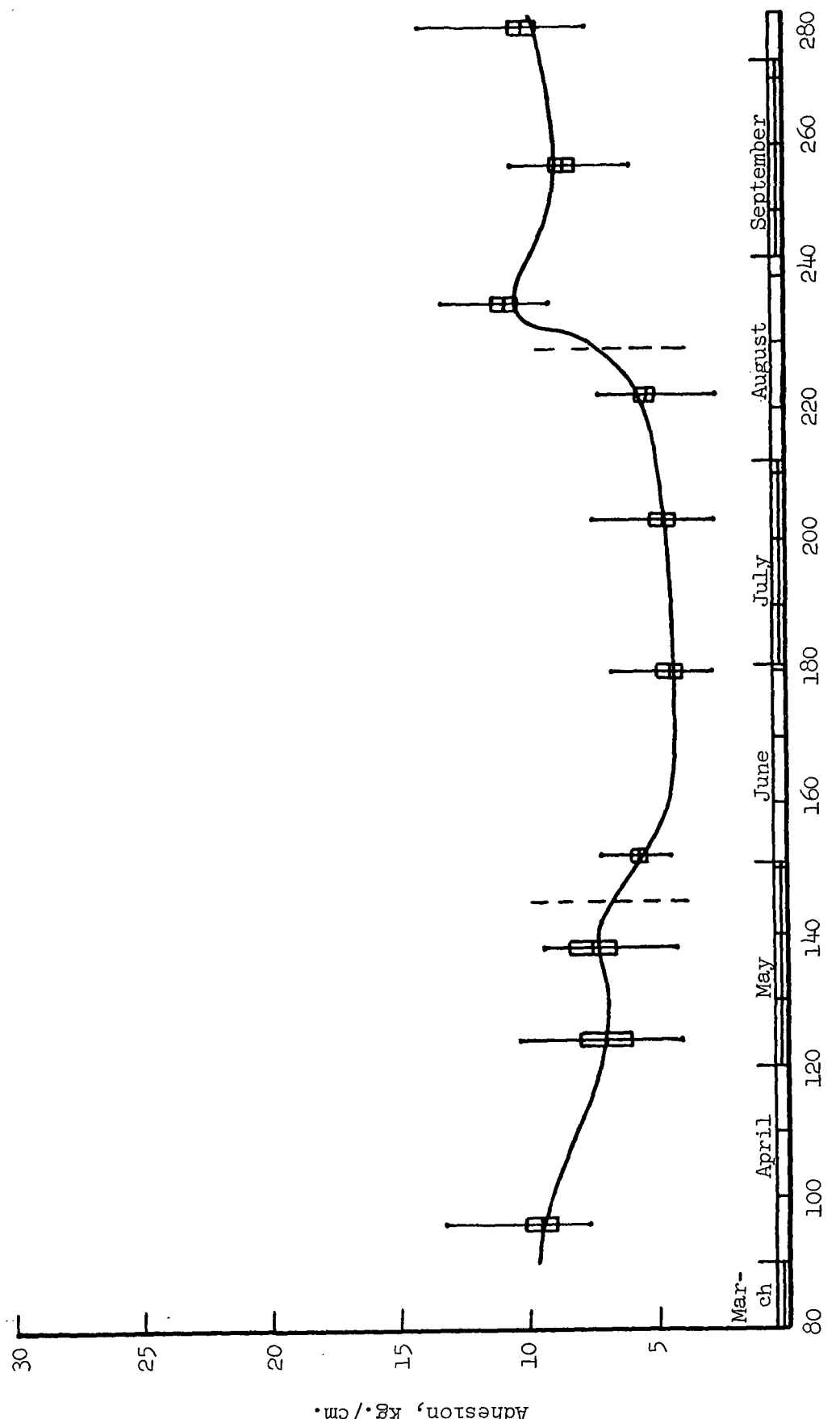

Figure 13. Seasonal Variation in Wood/Bark Adhesion for Bur Oak. Shown for Each Sampling Date is the Range, the Mean and One Standard Deviation Each Side of the Mean. The Vertical Dashed Lines Indicate the Estimated Start and End of the Peeling Season

distances of more than 300-500 μm. outside the cambium. Test values resulting from such failures must be interpreted as indicating that adhesion in the "cambium zone" and between wood and bark elements immediately adjacent to the cambium zone is "in excess of test values obtained by the testing procedure." The strength of the inner bark influences the magnitude of the values obtained. Bur oak, for example, appears to have the weakest inner bark of the species tested. One could speculate that difficulties will be encountered in debarking oak chips by mechanical forces alone (or in debarking in a drum debarker) because of this inner bark weakness. Factors affecting drum debarking and similar mechanical methods [Berlyn (7)], include wood/bark adhesion, inner bark strength, bark thickness and temperature.

Table IV summarizes the information on the length of peeling season and gives wood/bark adhesion values for the growing and dormant seasons. The peeling season information serves to emphasize the relatively short period when bark can be removed with ease and, more importantly, emphasizes the much longer period (281-312 days) in which bark removal is a problem. The morphology of the wood and inner bark of birch and aspen, which was described in considerable detail in previous sections, was similar and it is expected that methods successful on aspen would be equally useful for birch. A method which will reduce adhesion in the dormant cambium or the immature phloem sieve tube area just outside the cambium appears to be the most appropriate approach for use with birch and aspen.

TABLE IV

BETWEEN SPECIES COMPARISON OF PEELING SEASON AND WOOD/BARK ADHESION MEASUREMENT

Species	Peeling Season			Average Wood/Bark Adhesion, kg./cm.^{2}	
	Start	Stop	Length, days	Peeling Season	Dormant Season
Oak	May 25	August 17	84	5.0	8.9
Birch	April 20	July 9	80	5.1	12.0
Maple	May 25	July 17	53	5.8	10.1
Aspen	April 23	July 9	77	6.4	11.4

PLANS

The seasonal nature of the study makes the plans for the coming six to eight months very well defined. The first order of business will be to complete the morphological observations on the seasonal changes that occur in the cambium zone of oak and maple. Preliminary investigations will be undertaken in December, January, and February on the methods of reducing dormant season wood/bark adhesion in oak, maple, aspen, and birch. Again staying with the original concept of "chipping in the woods," the approach to be used will involve reducing wood/bark adhesion on chip samples. There are many possible ways that the problem could be solved including chemical, mechanical, thermal, and electrical. Budget limitations make it necessary to investigate in a very preliminary way only those methods which are very rapid and compatible with the major pulping processes.

Measurements on seasonal variation in wood/bark adhesion will be initiated for loblolly pine and a southern source of eastern cottonwood on about February 1. Wood/bark adhesion measurements will also be started for shagbark hickory and white spruce in late March. Morphological observations on the seasonal changes in the

"cambium zone" and the zone of failure will be an important part of the above study. Investigation into ways of reducing dormant season wood/bark adhesion for loblolly pine, southern cottonwood, shagbark hickory, and white spruce will be considered this coming fall and winter upon completion of the seasonal variation measurements.

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