"BLACK STREAK" IN WESTERN HEMLOCK:

ITS CHARACTERISTICS AND INFLUENCE ON STRENGTH

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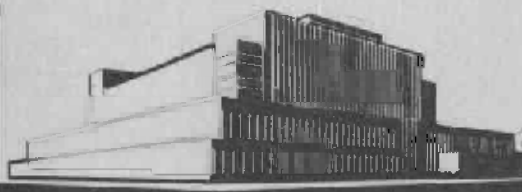

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

"BLACK STREAK" IN WESTERN HEMLOCK:

ITS CHARACTERISTICS AND INFLUENCE ON STRENGTH[1]

By

R. F. LUXFORD, Senior Engineer
L. W. WOOD, Associate Engineer
and
ELOISE GERRY, Senior Microscopist

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Summary

Black streaks in western hemlock, which often may be several feet long, are caused by the developing maggots of a small fly that live under the bark and feed at the surface of the newly forming wood. The maggot chamber, as seen on edge-grained material, appears as a relatively short distinctly wider portion of the black streak. It may exist as an actual opening or may be closed to a greater or less extent by healing growth.

Microscopical examination shows that the wound-induced tissues in the black streak are made up of many short, moderately thick-walled cells with numerous cross walls that are in sharp contrast with the long, slender fibers of the normal wood. Minute short openings or resin passages, arranged in tangential rows, frequently occur within the black streaks. Near the larger included opening, or maggot chamber, the horizontal wood-ray tissues are markedly increased, indicating further cellular reinforcement at the black streak.

Mechanical tests were made on 20 edge-grained boards, containing black streaks, that came from a carload of western hemlock aircraft

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[1]This report is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available. Original report dated December 1943.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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stock considered representative of material sold under the current Army-Navy Specification. The effect of the black streaks was studied by testing specimens that were so proportioned as to be under high stress in longitudinal shear when subjected to flexure. Resistance to shear was also measured in standard block-shear tests using specimens so cut as to place the shearing plane along the most pronounced part of the black streaks and of their included maggot chambers.

The results show that the black streak tissue is not deficient in shearing strength and indicate that, within reasonable limitation, the maggot chambers cause no significant deficiency in shear.

Introduction

In western hemlock lumber destined for use in aircraft, the presence of black or dark streaks, which often include openings, has caused considerable concern among those responsible for passing upon the acceptability of the wood. This report discusses the cause of the black streaks, their characteristics and detailed structure, and the results of tests made to determine their influence on strength.

The Cause and Characteristics of Black Streak

The Cause

A small black fly (Chilosia alaskensis, Hunter) utilizes the resinous galleries, made in western hemlock bark by beetles, as a place to lay its eggs. As a result of its activities during the maggot stage, the formation of black streak, or black check, is of frequent occurrence in western hemlock.[3,4] Western hemlock trees growing at altitudes above 1,800 feet are said to be practically free from attack by this fly. The developing maggot of the fly lives under the bark, feeding at the surface of the newly forming wood, for 1 to 5 years. It destroys or damages the cambium in its immediate vicinity producing a chamber which may remain as an opening although it may be reduced in size more or less by healing growth.

[3] "Black Check in Western Hemlock," by H. E. Burke, U. S. Dept. Agr. Bur. Entomology Circular No. 61, 10 pp., 1905.

[4] "Forest Insects," by B. W. Doane, E. C. van Dyke, W. J. Chamberlain and H. E. Burke. 1st ed., New York, 1936, pp. 396-397.

This chamber as seen without magnification on a radial surface is often no more than a slight fissure accompanied by but little distrubance of growth-ring formation (fig. 1, A), but sometimes its radial dimension is much larger and several succeeding growth rings are considerably affected and distorted (fig. 1, B). On radial surfaces a narrow black streak, resembling a pencil line, extends longitudinally above and below the chamber from several inches to as much as 3 feet, gradually decreasing in width until it disappears. As seen on a tangential, or circumferential surface, the chamber is irregular in shape. Surrounding it and extending longitudinally in both directions is black tissue that usually is entirely within the single year's growth in which the injury originated. The circumferential measurement likewise narrows as the distance from the chamber increases.

Abnormal Cellular Structure of Black Streak

Western hemlock woody tissue, as it is being formed at the cambium, readily responds to wound stimuli, such as are produced by the *Chilosia* maggot, and forms short, thick-walled cells (wound parenchyma) usually containing dark resinous material. Included within the black streaks are numerous, minute, vertical wound-resin passages or relatively short cystlike openings in a tangential row, as shown in figure 2, A and B. Mechanical or physiological injuries of all sorts, including those produced by sapsuckers, borers, unseasonable frosts, lightning, and other damage affecting the cambium are reputed also to produce such reactions. Similar abnormalities of growth have been found in noble fir and Sitka spruce. The principal difference between these and the black streak here discussed is usually the color. It may, however, often be difficult to determine whether wound tissue in hemlock was induced by the *Chilosia* maggot or by some other cause, especially if the chamber which served as the shelter of the maggot is not present in the wood being examined.

The chambers or openings included in black streaks are not bark pockets, for they do not contain bark, but are more nearly allied to pitch pockets. Floccosoids[5] or white deposits frequently occur in the vicinity of black streaks.

Appearance on radial or edge-grained surface. -- As viewed without magnification, the black streak appears on edge-grained surfaces as

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[5] Forest Products Laboratory Report No. 1392, "Western Hemlock Floccosoids," 1943.

a narrow dark line. Whenever the chamber that served as the dwelling of the maggot is present, the adjacent dark area is wider and definite separation of varying length and width between growth rings may be apparent (figs. 1 and 2, D).

The structure of the black streaks on the edge-grained surface, as seen under the microscope, is shown in figure 2, C and D. An actual separation between annual rings near the chamber, which in this case appears to be limited to one annual ring, is shown in figure 2, D, at "X." The narrowing of the affected area is apparent as the longitudinal distance from the chamber increases (from top to bottom). The short, rectangular type of parenchyma cell induced by the cambial injury (dark area) and the increase in ray tissue development following the injury are also shown in figure 2, D, at "R." In figure 2, C, parts of two black streaks produced separately in successive years are shown, but in neither is the maggot chamber present.

One of the chief characteristics of the cells constituting the black streak is their short longitudinal dimension. This is shown in figure 2, C, at "P" where it can be compared with the longitudinal dimensions of the normal cells (tracheids or fibers). Such dimensions are even more clearly shown in the tangential views of figure 3, A and B. Many cross walls together with the well-thickened character of all the walls also characterize the wound-induced cells.

Appearance on end grain. -- In figure 2, A and B, the characteristic cell formation as viewed under about 30 diameters magnification in a cross section of the wood is shown; the maggot chamber is illustrated in B at "X." As seen without magnification this would be visible as an actual opening, but would appear rather small. To the left of the center, extending along the growth ring, microscopical openings or resin passages "MO" are shown. In figure 2, A, at "MO," a similar condition, showing minute openings or separations along the ring, is also illustrated, the wound tissues being at the beginning of successive annual rings. Sometimes the abnormality may start at the beginning of the year's growth but at first during the year's wood formation more remote parts of the annual ring do not respond, so that in portions of the ring the wound tissue appears near the center rather than at the beginning of the year's growth. The photomicrographs show the dark content in the cell cavities which causes the streak to appear black. In these end-grain views, the similarity in dimensions of many of the wound cells to the normal tracheids is apparent. This is in sharp contrast with the marked decrease in the length, seen in the wound cells as viewed on radial and tangential surfaces.

Appearance on the tangential, or flat-grained surface.--When a black streak is split open, the abnormal growth induced by the insect is particularly apparent. The extent of the area on the tangential surface is frequently an inch or more in width and the entire area covered by the cavity in which the maggot developed may become visible, showing the extent of the ring separation or opening which existed. Such split specimens are shown in figure 6.

When examined with the microscope, the detail of the repair work performed by Nature in its effort to counteract the damage done by the insect is shown in an even more striking manner in tangential than in radial or cross-sectional views. In figure 3, A and B, typical areas of wound-cell tissue from the vicinity of the maggot chamber, but not bordering it, (as at "MO" in figure 2, B), show their moderately thick-walled cells and the frequent transverse end walls resulting from the development of short cells in place of long ones. The length of the wound-induced cells gradually increases with distance away from the point of injury (fig. 3, A). Although tangential rows of resin passages, which form actual minute openings, exist, the structure of the surrounding tissues appears to prevent undue weakening as a consequence of openings of these dimensions.

Influence of Black Streak on Strength

The effect of black streak on the strength of western hemlock was studied by testing specimens so proportioned as to be under high stress in longitudinal shear when subjected to flexure. Resistance to shear was also measured in standard block-shear tests using specimens so cut as to place the shearing plane along the most pronounced part of the black streaks and maggot chambers.

Test Materials

The test material consisted of 20 boards, 1 by 6 inches by about 4 feet, containing black streaks, as selected by an Army-Air Force inspector from a carload of airplane lumber consigned to a manufacturer at St. Paul, Minnesota. Presumably some culling for black streaks had previously been done, since the boards did not include the worst conditions known to exist in some lumber. The boards selected were believed to be representative of material with black streaks furnished under the present Army-Navy specification.[6] The size of actual openings,

[6] Army-Navy Aeronautical Specification AN-H-4a, October 13, 1942.

included in the black streaks, as seen on the edge-grained surface, ranged from those visible only under the microscope, termed "minute" (fig. 2, A, B, and C), to 1/50 inch in width and 3-1/4 inches in length. The boards were predominantly edge grained and free of defects except for the black streaks and a few zones of compression wood. The lengths of visible streaks ranged from a few inches to 3 feet, and many of the boards contained more than one streak.

Strength Tests

Inasmuch as reduction in strength would most likely be in shear, this property was given special consideration in the tests. Tests included static bending of I-beams in which the western hemlock boards containing the black streaks formed the webs; static bending of small specimens cut from the webs of the I-beams after test; and block-shear of specimens with black streaks, likewise cut from the webs of the previously tested I-beams. Corresponding block-shear-test controls were also cut from the webs of the I-beams after test.

Static Bending Tests

Tests of I-beams.--The most pronounced black streak in each board was selected, and when necessary a piece from one edge of the board was ripped off and reglued to the other edge so as to place the streak at the center of the width. Originally about 1 by 6 by 48 inches in size, the boards were dressed to a uniform width of 5-1/2 inches and flanges were glued to them, thus making the original western hemlock board the web of an I-beam designed to fail by shear rather than by flexure. Previous to test, the specimens were conditioned at 62 percent relative humidity at a temperature of 71° F. until the weight became constant and the moisture uniformly distributed.

The I-beams were tested with center loading on either a 42-inch or a 39-inch span, depending upon their length. The method of test is illustrated in figure 4, A. Although the black streak and included maggot chamber or opening were located at or near the center of the height, where the shear stress is presumably a maximum, none of the beams failed at the streak or opening. This is taken as evidence that the streaks and chambers did not appreciably affect shear strength.

Table 1 gives the computed shearing stress for the 20 I-beams, all of which failed in shear. Failure was at or near the junction of web and flange and extended from half to full length of the specimen (fig. 4, B).

Tests of small specimens.--The smaller static-bending specimens (approximately 1 by 1 by 8 inches) were cut from the webs of the broken I-beams and were tested with center loading on a 7-inch span, orientation the same as in the original I-beam test. Like the I-beam, they had the black streak at midheight and contained the full length of its included maggot chamber opening which occupied a much larger proportion of the shear-resisting plane than was true of the I-beams. Although 6 of the 10 specimens tested failed in shear, none of the shear failures coincided with the black streak or its included chamber. In several tests, the failure in the normal wood was very near to a black streak.

Table 2 gives the shear stresses developed in static-bending tests of these 1- by 1- by 8-inch specimens. Both bending and shear failures occurred in these specimens, as indicated in the last columns of table 2, and illustrated in figure 5.

Block Shear Test

The resistance to shear of the wood in the annual rings containing black streaks and their included maggot chambers was further investigated by means of block shear tests. The shear blocks were made in skewed form to obtain from the available material as large an area as possible in the plane of the black streak and its included chamber. Shear blocks were tested in the standard manner of the American Society for Testing Materials.

The results of these shear-parallel-to-grain tests (table 3) show that, although the specimens were cut so as to encourage failure in the black streak area, only 11 of 45 specimens failed along the black streak or opening. Of the nine specimens having maggot chambers only five failed in shear through these openings. Figure 6 shows the chamber on the edge-grained face before test and the plane of shear failure after test. Of five specimens, three had shear values higher than average of the control specimens from the same board. The average shear value of 45 specimens with black streaks (some with included chambers) was the same as for the 35 control specimens.

Other Strength Considerations

No tension nor compression-parallel-to-grain tests were made. Except in the immediate vicinity of the maggot chamber, the cross section of an individual black streak is so small, and streaks are ordinarily so

distributed, and occupy so small a proportion of the cross section of a member, that any significant adverse effect on strength in compression or tension improbable whether the stress is due to axial loading or to flexure.

The growth layers of abnormal appearance that are found adjacent to the more pronounced chambers are likely to have marked deviation of grain and deficiency in tensile strength, and hence should not be permitted at points where high tensile stress will exist. Deviations of grain adjacent to maggot chambers should be judged or evaluated the same as other local deviations of grain.

Recommendations

Based on the data presented and a consideration of the possible effects of black streaks that may include maggot chambers, the following are suggested as limitations applicable to aircraft lumber and aircraft parts.

(1) Black streaks, except for maggot chambers, are admissible, but maggot chambers are limited to the same extent as pitch or bark pockets.[7] The length of a maggot chamber should be considered only as that of the definitely wider or thicker portion of the black streak as seen on an edge-grained surface.

(2) Irregular grain or deviations of grain associated with maggot chambers should be limited in the same manner as other deviations of grain.

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[7] Army-Navy Aeronautical Specifications AN-11-4a, AN-S-6a, and AN-F-6a, and ANC-19, "Wood Aircraft Inspection and Fabrication."

Table 1.--Results of static bending tests[1] on I-beams with webs of western hemlock containing black streak

I-beam	Moisture content of web	Specific gravity of web based on ovendry weight: And volume at test	Specific gravity of web based on ovendry weight: And volume ovendry	Maximum horizontal shear along neutral axis[2]
No.	Percent			Lb. per sq. in.
		Beams with rectangular flanges[3]		
1	11.7	0.44	0.46	910
2	11.8	.43	.46	1,130
3	11.8	.44	.47	960
5	11.8	.43	.46	1,020
		Beams with trapezoidal flanges[3]		
4	12.0	.42	.45	800
6	11.9	.45	.48	970
7	11.7	.42	.44	730
8	11.9	.45	.49	970
9	12.0	.44	.47	940
10	13.4	.40	.42	820
11	12.1	.44	.46	1,130
12	12.8	.44	.47	860
13	12.6	.40	.44	680
14	12.2	.42	.46	770
15	12.5	.40	.43	710
16	12.2	.39	.43	850
17	12.0	.38	.41	830
18	11.7	.39	.42	880
19	11.8	.42	.45	910
20	11.8	.42	.44	910
Average	12.0	.42	.45	890

[1]Center loading. Span was 42 inches except for I-beams 4, 7, 18, 19, and 20, for which the span was 39 inches.

[2]Computed from formula $S_s = \frac{VQ}{It}$, where S_s is shear stress, V is total vertical shear, Q is the summation of statical moment of the half-section, I is the moment of inertia of the full section, and t is the thickness of section at the neutral axis. All specimens failed in horizontal shear, but in none did the failure coincide with the black streak or the included maggot chamber.

[3]I-beams 1, 2, 3, and 5 had rectangular flanges with height equal to one-third of total height of beam. In others, the flanges were trapezoidal and had at their outer edges a height equal to one-sixth the height of the beam and tapered to double that height at their junction with the web.

Table 2.--Results of static bending tests of small rectangular specimens[1] of western hemlock containing black streak

Specimen from I-beam	Moisture content	Specific gravity[2]	Dimensions[3] of opening as seen on edge-grained face: Length	Dimensions[3] of opening as seen on edge-grained face: Width	Maximum horizontal shear along neutral axis	Failure by Shear[4]	Failure by Bending
No.	Percent		In.	In.	Lb. per sq. in.		
2	11.2	0.45	2.0+	0.01	980	x	.....
4	11.6	.43	.3	.01	1,010	.....	x
5	11.6	.43	.8	.01	1,010	x	.....
7	10.6	.41	.4	.01	880	x	.....
14	11.5	.42	2.0+	.02	620	x	.....
16	10.5	.42	.3	.01	880	x	.....
17	10.5	.36	1.6	.01	650	.....	x
18	10.9	.41	.2	.01	890	.....	x
19	11.7	.41	.6	.01	860	.....	x
20	11.6	.41	1.5	.01	780	x	.....
Average	11.2	.42	.....	.....	860	.....	.....

[1]Specimens 1 by 1 by 8 inches tested over 7-inch span, center loading.

[2]Based on ovendry weight and volume at test.

[3]Openings were not sufficiently wide to permit depth measurement.

[4]In no specimen did shear failure pass through black streak or included maggot chamber.

Table 3.--Results of shear-parallel-to-grain tests on western hemlock containing black streak

I-beam	Control specimens					Specimens containing black streak							
	Specimen	Moisture content	Maximum shearing strength			Specimen	Moisture content	Dimensions[1] of maggot chamber when present as seen on edge-grained face		Maximum shearing strength		Failure with respect to black streak	
			Individual specimen	Board average				Length	Width	Individual specimen	Board average	Along	Away
No.	No.	Percent	Lb. per sq. in.	Lb. per sq. in.		No.	Percent	In.	In.	Lb. per sq. in.	Lb. per sq. in.		
1	1	11.2	1040			1	10.8	---	---	1050			x
	2	11.0	1060			2	10.9	---	---	[2]1120			x
	3	11.9	830	980		3	11.0	0.5	0.01	[2]790	990	x	
3	1	10.6	1170			1	10.4	---	---	1150			x
	2	10.7	1050			2	10.2	---	---	[2]1390			x
	3	10.7	930	1050		3	10.4	1.3	.02	[2]1100		x	
						4	10.3	---	---	1380			x
						5	10.5	---	---	1150	1230		x
6	1	10.7	1260			1	10.8	---	---	[2]1170			x
	2	10.6	1190			2	11.1	.9	.01	[2]750			x
	3	10.8	1150	1200		3	11.1	---	---	1030			x
						4	10.9	---	---	1200	1040		x
8	1	10.9	1300			1	10.6	---	---	[2]1290			x
	2	11.0	920	1110		2	10.9	---	---	[2]1190			x
						3	11.3	---	---	1040	1170	x	
9	1	10.6	690			1	11.1	---	---	[2]1170			x
	2	10.6	790			2	10.8	2.0	.01	[2]1070		x	
	3	10.7	880	790		3	10.7	---	---	1610			x
						4	10.7	---	---	1110	1240		x
10	1	9.1	780			1	11.8	---	---	[2]1000		x	
	2	12.4	550			2	11.6	.1	.01	[2]1050			x
	3	11.5	920			4	11.9	---	---	550			x
	4	9.6	910	790		5	12.0	---	---	480	770		x
11	1	11.6	1670			1	11.9	---	---	[2]590			x
	2	11.6	1640			3	11.3	.6	.01	[2]1040			x
	3	11.4	1660	1650		4	11.4	---	---	1740			x
						5	11.5	---	---	940	1080		x
12	1	12.1	1180			1	11.9	---	---	[2]990			x
	2	12.1	1090			2	11.9	---	---	[2]1080			x
	3	9.9	1220	1160		3	11.7	---	---	850			x
						4	11.8	---	---	1000	980		x
13	1	11.6	1000			1	11.3	---	---	[2]980			x
	2	11.3	910			2	11.3	.7	.01	[2]1110		x	
	3	11.3	1000	970		3	11.2	---	---	1100	1060	x	
15	1	11.0	940			1	12.0	---	---	880			x
	2	11.1	1060			2	11.6	---	---	970		x	
	3	11.1	910	970		3	11.3	.4	.01	[2]930		x	
						4	11.1	---	---	1020			x
						5	11.2	---	---	920	1180		x
17	1	11.2	1080			1	11.6	---	---	[2]1160			x
	2	11.2	1100	1090		2	11.6	1.5±	.01	[2]1340			x
						3	11.4	---	---	1310	1270		x
19	1	12.0	1060			1	12.4	---	---	[2]1050		x	
	2	12.1	1140			2	12.2	.6	.01	[2]1130			x
	3	12.2	970	1060		3	12.2	---	---	1010	1060	x	
Average		11.1	1050				11.3			1070			

[1] Chambers were not sufficiently wide to permit depth measurements.

[2] Specimen includes initial injury associated with black streak.

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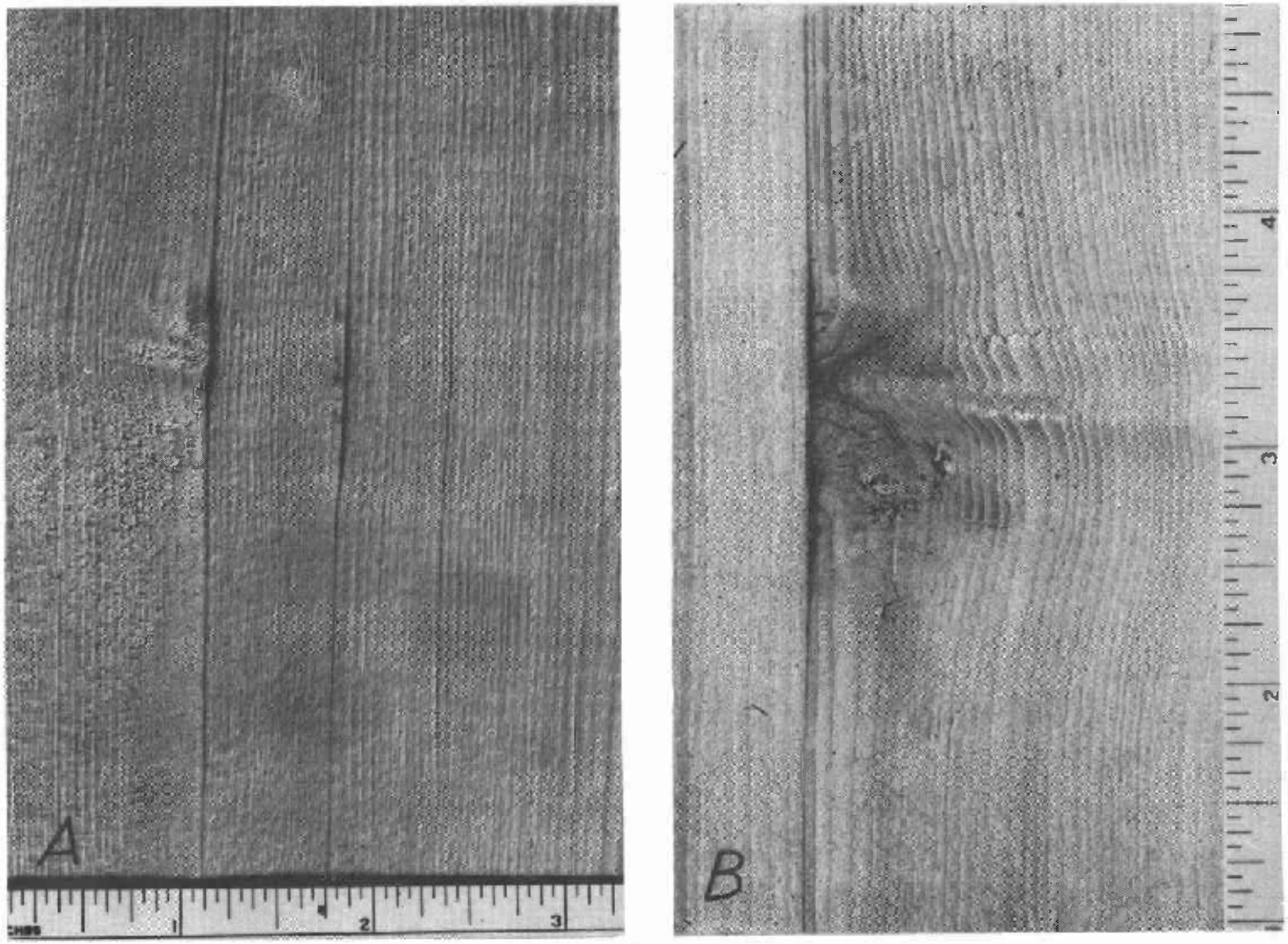

Figure 1.--Black streaks in edge-grained western hemlock boards. A, two black streaks with their maggot chambers (wider portions or included openings). B, a black streak showing greater disturbance of wood formation resulting from longer occupation by the maggot.

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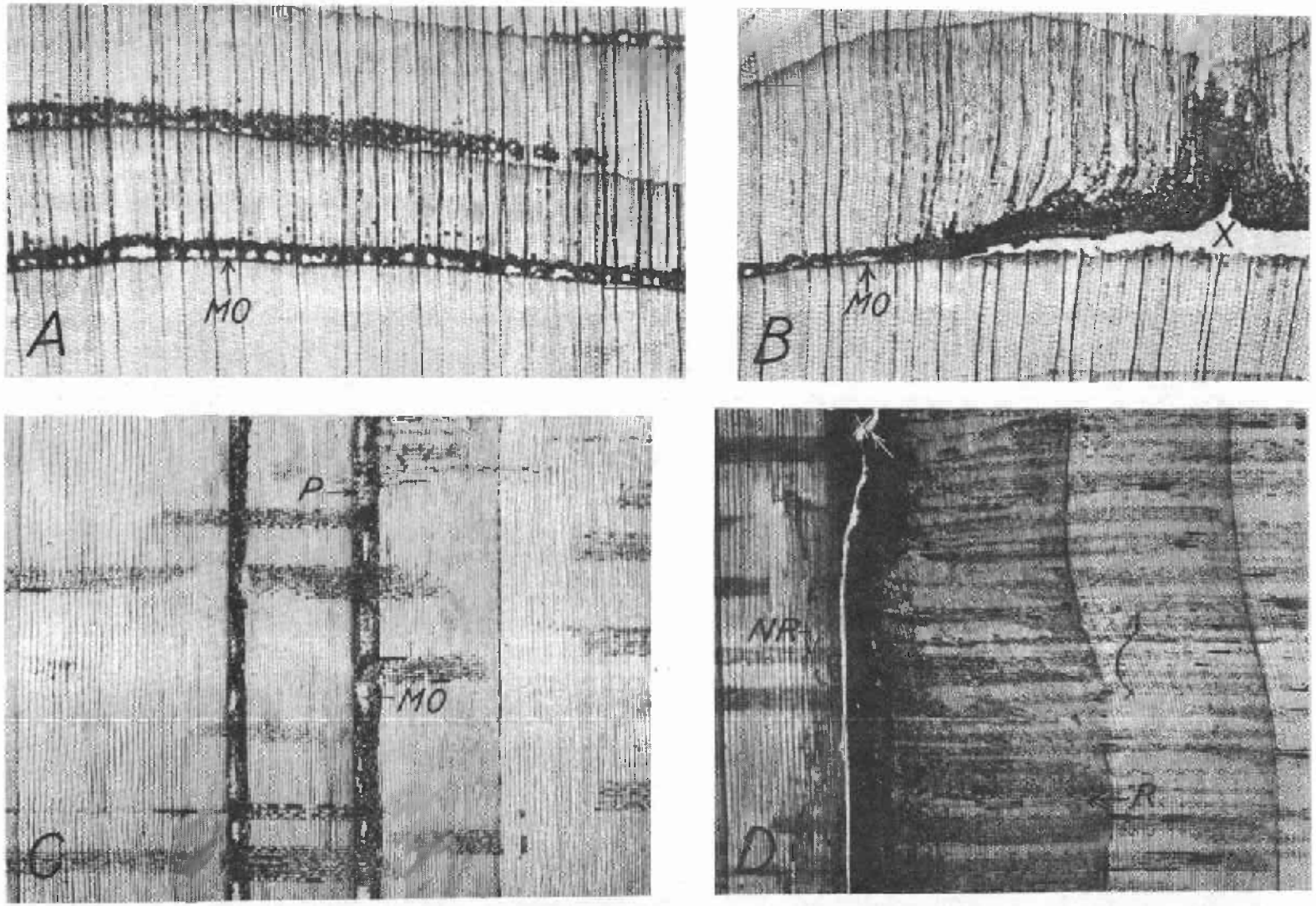

Figure 2.--Black streaks at a magnification of about 30 diameters. A, appearance, on end-grained surface, of three black streaks containing minute openings "MO" but no maggot chambers. Dimensions of the black-streak cells are practically the same as those of normal cells in this view. B, appearance, on end grain, of maggot chamber "X" and black streak at left with minute openings "MO." C, appearance, on edge-grained surface, of two black streaks with minute openings or resin cysts "MO." Short longitudinal dimension of black-streak cells is shown at "P". D, edge-grained surface with maggot chamber "X" in a black streak. At "R" is shown the increase in ray tissue as compared with normal ray tissue at "NR" before insect occupation.

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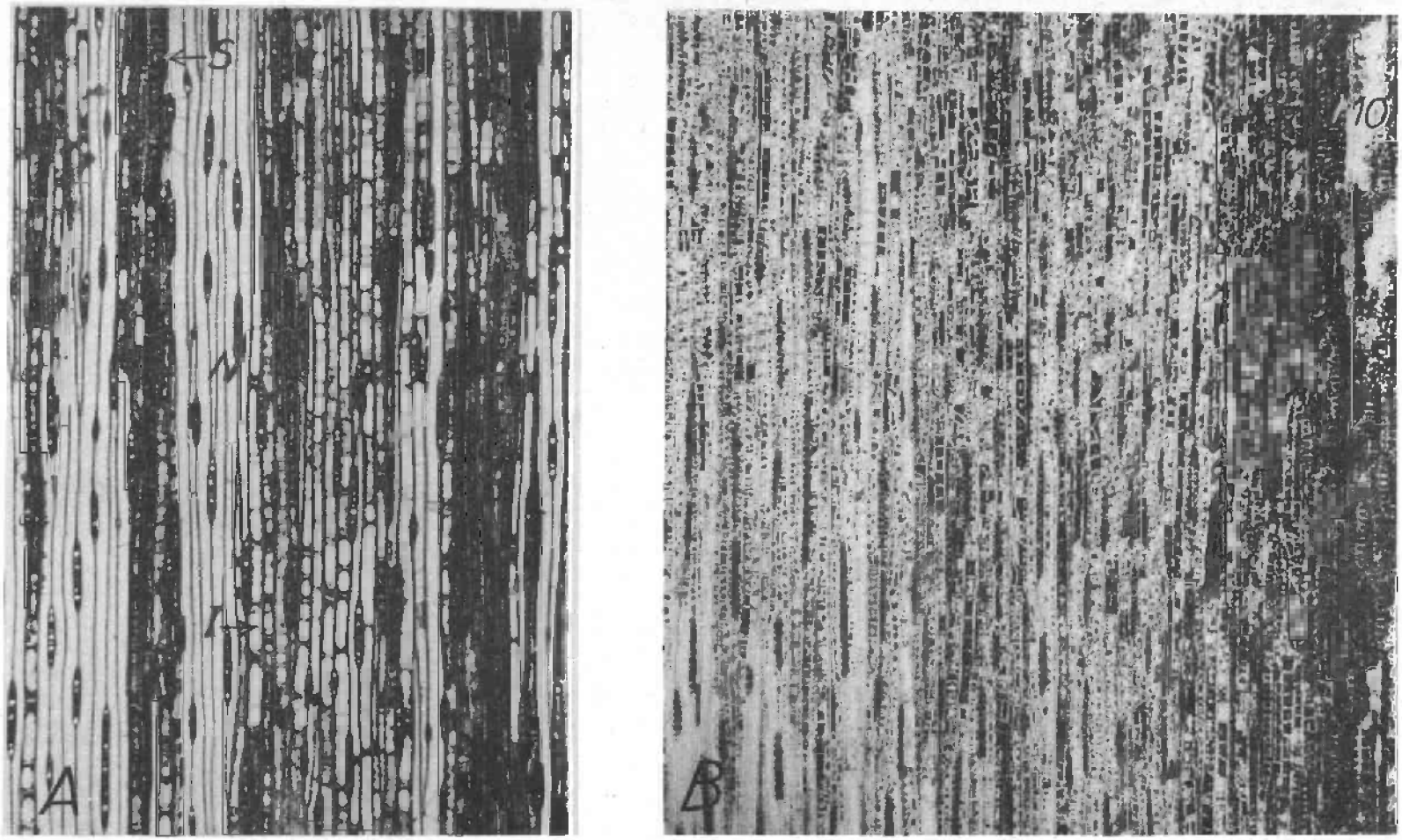

Figure 3.--Appearance of black streak tissues on a flat-grained or tangential surface in the vicinity of a maggot chamber (as at "MO", Figure 2, B) but not bordering it, magnification about 70 diameters. A, transition from black streak to normal wood showing "S," short cells of black streak tissue; "I," intermediate-length cells, and "N," normal long tracheids or wood fibers. B, cells in the midst of a black streak showing their short length, well-thickened walls and noticeable cross bracing of many end walls. "MO," minute opening or resin cyst.

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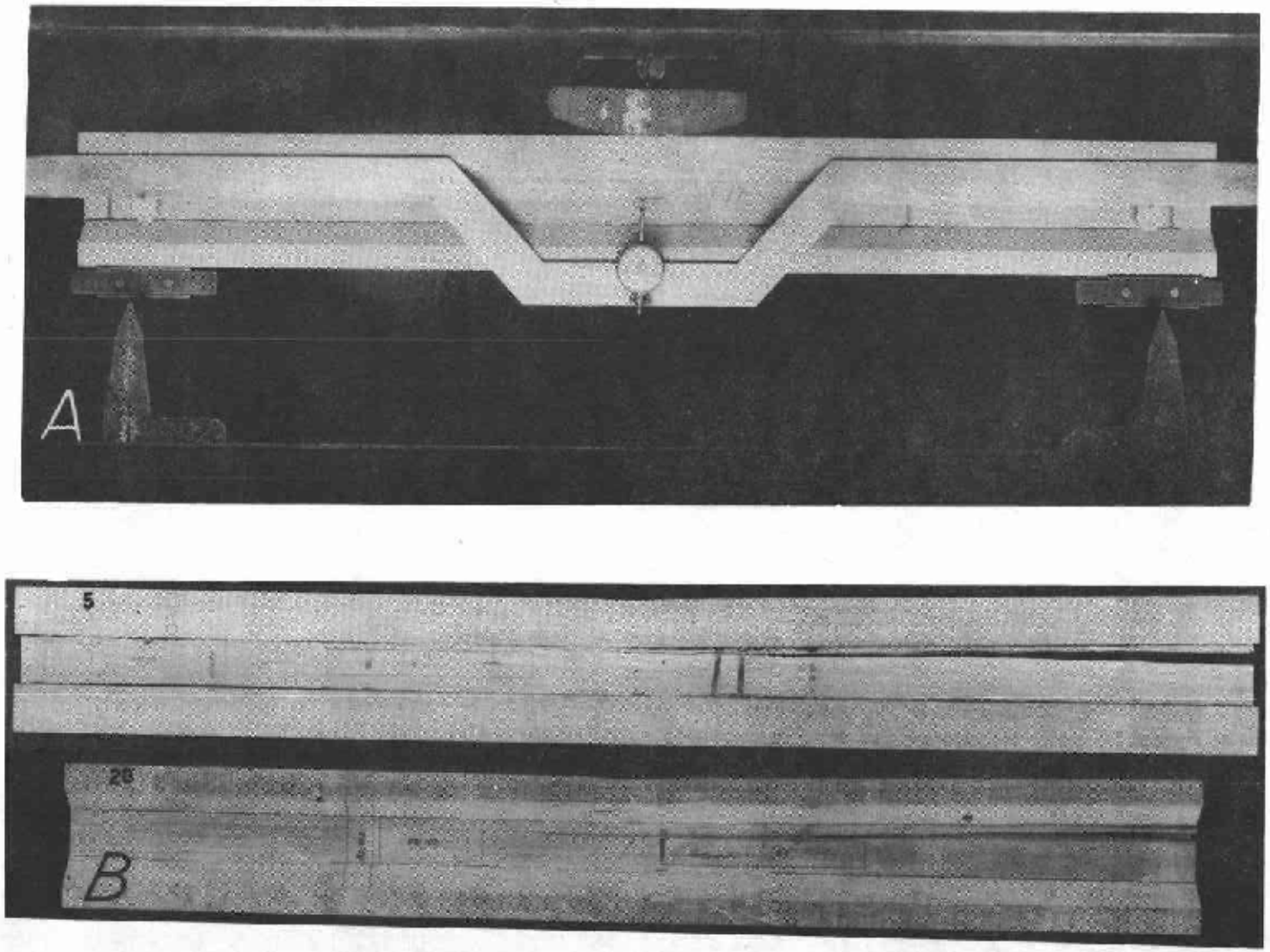

Figure 4.--A, method of making static-bending test. B, I-beams after test showing black streaks and shear failures. In no specimen did shear failure pass through a black streak.

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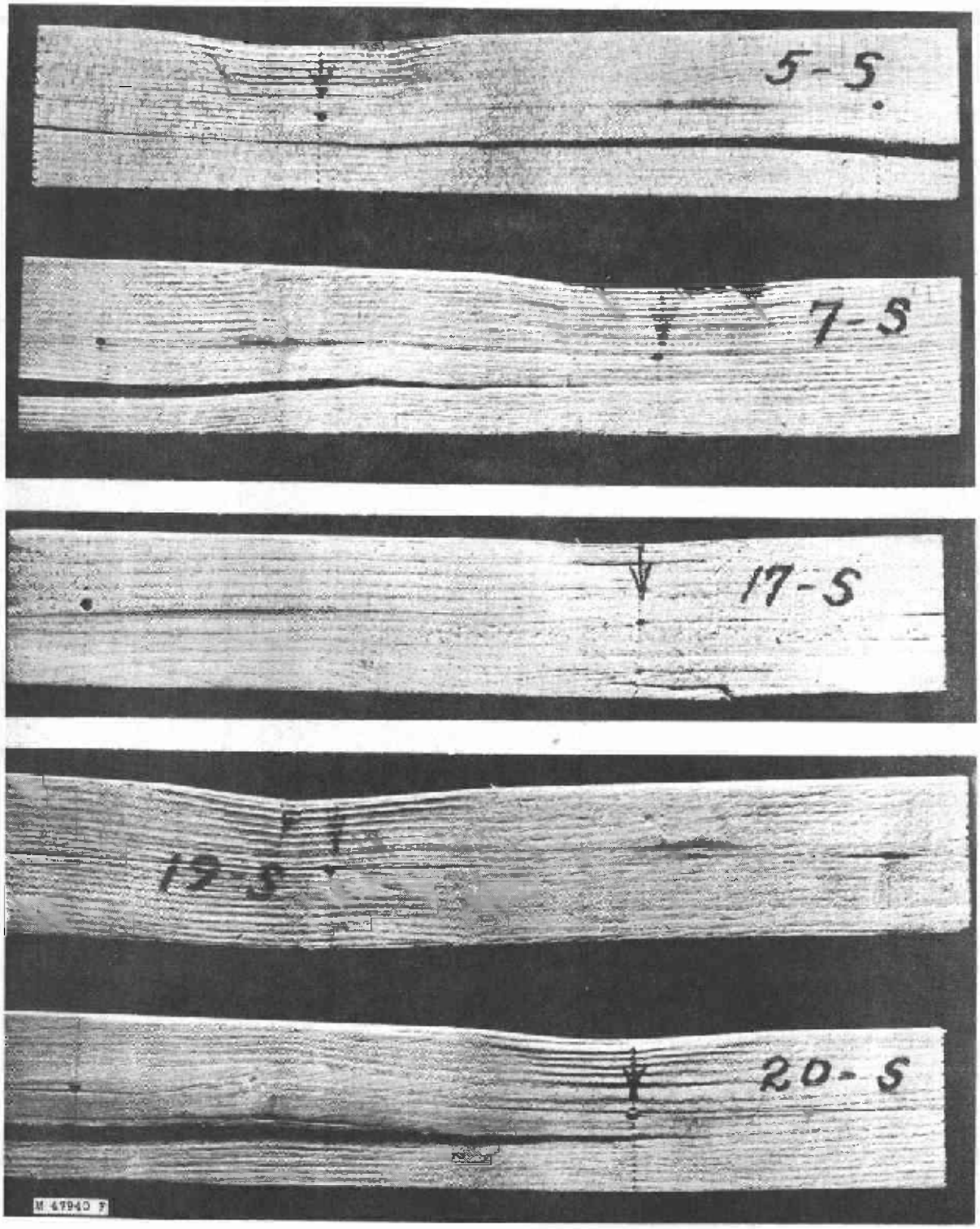

Figure 5.--Failures of small static-bending specimens, one end of which was later cut off for moisture determinations. Specimens 5, 7, and 20 failed in shear but the shear failures did not pass through the black streaks. Specimens 17 and 19 failed in bending (not shear) even though containing the black streaks near mid-height where shear is a maximum.

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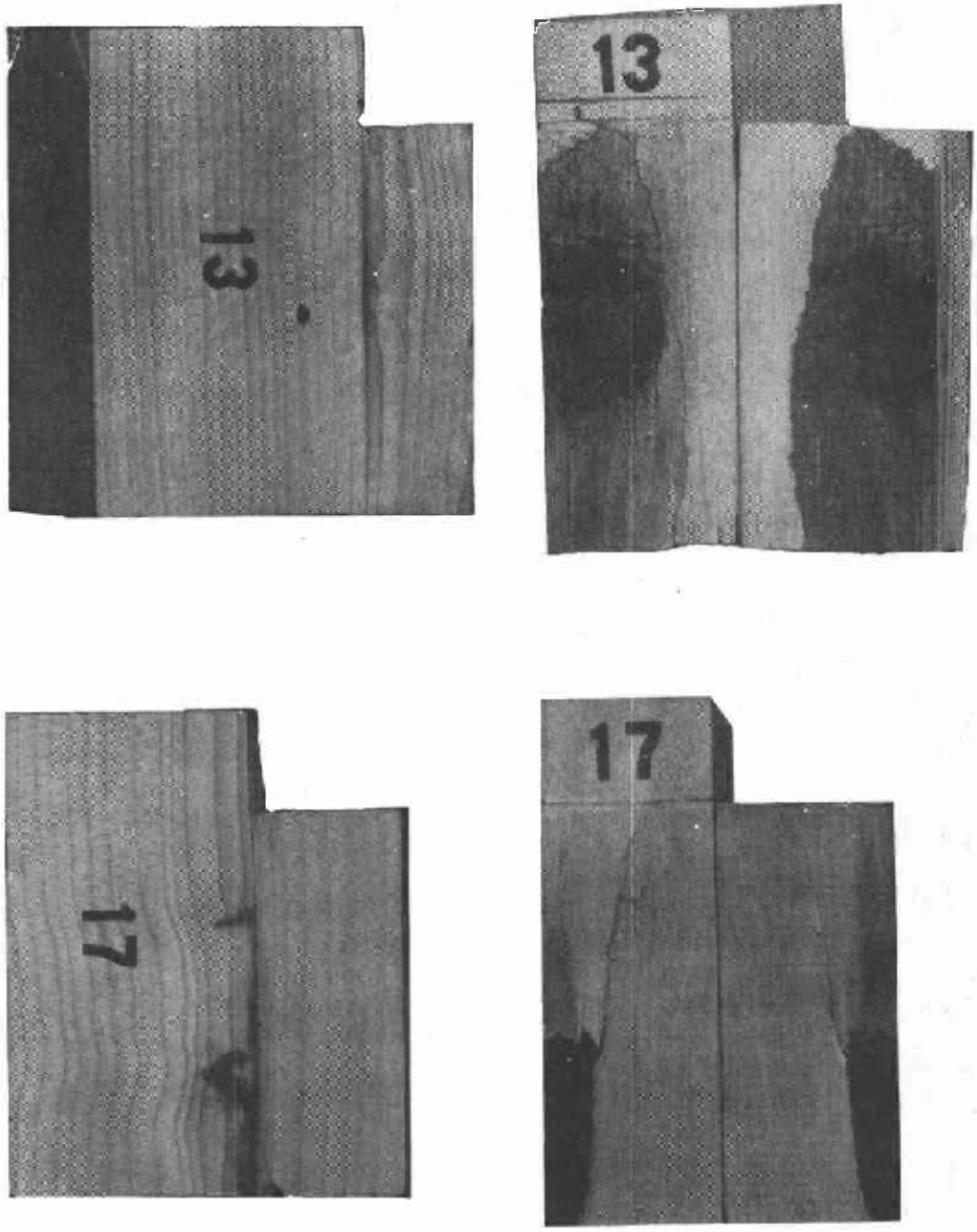

Figure 6.--Shear-block specimens cut so that the plane of probable shear failure would be through a black streak and maggot chamber. At left, edge-grained surface of blocks before test showing black streak and included opening. At right, same specimens showing tangential surfaces after tests. In specimen No. 13 the failure exposed the maggot chamber, while in specimen No. 17 the failure extended through only a part of the black streak. Average shear values of black-streak specimens were the same as for control specimens with no black streaks.

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SUBJECT LISTS OF PUBLICATIONS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following are obtainable free on request from the Director, Forest Products Laboratory, Madison 5, Wisconsin:

List of publications on Box and Crate Construction and Packaging Data

List of publications on Chemistry of Wood and Derived Products

List of publications on Fungus Defects in Forest Products and Decay in Trees

List of publications on Glue, Glued Products, and Veneer

List of publications on Growth, Structure, and Identification of Wood

List of publications on Mechanical Properties and Structural Uses of Wood and Wood Products

Partial list of publications for Architects, Builders, Engineers, and Retail Lumbermen

List of publications on Fire Protection

List of publications on Logging, Milling, and Utilization of Timber Products

List of publications on Pulp and Paper

List of publications on Seasoning of Wood

List of publications on Structural Sandwich, Plastic Laminates, and Wood-Base Aircraft Components

List of publications on Wood Finishing

List of publications on Wood Preservation

Partial list of publications for Furniture Manufacturers, Woodworkers and Teachers of Woodshop Practice

Note: Since Forest Products Laboratory publications are so varied in subject no single list is issued. Instead a list is made up for each Laboratory division. Twice a year, December 31 and June 30, a list is made up showing new reports for the previous six months. This is the only item sent regularly to the Laboratory's mailing list. Anyone who has asked for and received the proper subject lists and who has had his name placed on the mailing list can keep up to date on Forest Products Laboratory publications. Each subject list carries descriptions of all other subject lists.