

SEASONING OF OHIO "RED" WILLOW ARTIFICIAL-LIMB BLANKS

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SEASONING OF OHIO "RED" WILLOW ARTIFICIAL-LIMB BLANKS

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Introduction

During World War II, the Forest Products Laboratory was informed by the Association of Limb Manufacturers of America, and by some of its members, that there was a very definite and acute shortage of dry willow stock throughout their industry. This shortage was due not only to increased demands that had used up existing supplies of dry wood, but also to a labor shortage and to difficulty in obtaining suitable trees. Without any immediate prospect of restoring a reserve sufficient to cover manufacturing operations during the usually long seasoning period of the wood, the industry needed a faster drying method, such as the method used in kiln-drying lumber, to produce satisfactorily dried blanks in a shorter time.

A similar shortage existed during World War I. At that time some kiln-drying experiments were made at the Forest Products Laboratory that indicated possibility of kiln drying some kinds of blanks without excessive end checking and honeycombing, provided the following precautions were taken: (1) application as soon as possible of a good end coating to freshly cut green ends to prevent checks, (2) extension of holes of maximum practical diameter clear through the piece for best results in seasoning, and (3) whenever practical, the sorting of pieces of the same diameter into a group and the kiln drying of each group separately so that each piece could be adequately treated and uniformly dried in a minimum of time. Those experiments, however, were not sufficiently extensive and satisfactory to result in any definite conclusions or to warrant any change in commercial seasoning practice.

This report describes some kiln-drying experiments on Ohio "red" willow blanks at the Laboratory during World War II. The Ohio Willow Wood Company, Mount Sterling, Ohio, cooperated by providing the test material. The principal objective was to determine if kiln drying artificial-limb blanks would be feasible compared to room and to outdoor drying.

¹Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

Letters received by the Laboratory during the war, as well as visits by members of its staff to various shops, revealed that because of the shortage of thoroughly dried stock, limb manufacturers were forced to accept practically green blanks from the wood producers. Because most of the shops lack both experience and adequate facilities for seasoning green or high-moisture-content stock, these drying experiments were made at the Forest Products Laboratory as a possible aid to the limb manufacturers as well as the producers of the wood.

Procedure in Producing Blanks

Species Used

From long experience, the artificial-limb industry has found that willow has properties more suitable for its product than the many other species that it has tried. Light weight with good strength, resistance to checking in seasoning and to splitting under mechanical stress, uniform texture, workability, ability to absorb and give off some moisture without warping and splitting, and good gluing properties are the principal factors that the industry must consider. Basswood and buckeye are also used, but, in general, these species are considered less suitable than willow.

The willow particularly preferred is called "English," "red," or "yellow" willow. The name "English willow" originated from the fact that certain European species, namely, white willow (Salix alba) and crack willow (Salix fragilis), having the suitable properties were introduced and extensively planted in the United States. The name "red willow" originates from the color of its heartwood, which has the reddish or pinkish color usually found in willow of the desired physical properties. A native species, presumably peachleaf willow (Salix amygdaloides), growing in the Rocky Mountain region, has similar characteristics and is used locally for artificial limbs. Black willow (Salix nigra), a commercial lumber tree in parts of the eastern half of the United States, has gray or brown heartwood and is not considered so suitable, largely because the older and larger trees often are defective and the color is different from that to which the trade is accustomed. The term, "yellow willow," is associated with a willow paler and more yellowish in color than "red willow." It has been reported to be somewhat more difficult to season.

The main supply of willow has come from Ohio, New York, Pennsylvania and Canada with some from Colorado; but, no doubt, satisfactory willow is or could be found in other areas.

Production Procedure and Seasoning Methods

One common production procedure is to cut the tree trunks into 5-foot lengths, split the lengths into quarters and then crosscut and slab them to the required sizes and shapes. A longitudinal hole is drilled part way through the shin and the long thigh blanks and all the way through the short thigh blanks. The ends of these blanks, together with the solid knee and foot blanks, are then dipped in hot paraffin. Their seasoning takes place in a vented and sometimes partly heated room or shed for 1 to 3 years before their shipment to the limb manufacturers. At the factory they are usually piled on racks indoors for an indeterminate period of further seasoning until selected for use. Rough shaping is sometimes done to reduce factory drying time. In some cases, additional dryness is obtained in an oven after rough shaping. Apparently, there has been no standard routine nor systematic procedure that has guaranteed a satisfactory moisture condition for use.

The seasoning problem is somewhat involved because a considerable number of sizes and kinds of blanks must be kept on hand to fit various customers to order. Although the drying time for the small pieces varies greatly from that needed for the large ones and definite knowledge would seem necessary to determine when the moisture content of any particular blank is sufficiently low for use, apparently very few, if any, moisture-content determinations are made by the oven-dry method,² and the manufacturer's decision as to proper dryness is based mainly upon his observation and judgment.

Accelerated-drying Problems

Under equivalent-humidity conditions, the rate of moisture trans-fusion through wood increases considerably with increases in temperature. Unfortunately, however, the tensile strength decreases with increases in kiln temperatures, and willow is one of the woods that are then prone to honeycomb, either because of interior tensile failures or the extension of end checks and surface checks into the interior of the wood. The particular temperature that is critical in this respect varies with the thickness and moisture content of the wood.

The relative humidity² of the air also influences the drying rate of wood, but if the humidities used to speed drying during its early stages are too low, excessive end checking and surface checking may occur. Willow surfaces, however, do not check readily; but the end grain of large willow blocks does, and must be protected by a suitable end coating.

² Explained in the appendix.

Laboratory Seasoning Experiments

Material

Nine each of the knee, shin, foot, and long thigh, and three of the short thigh artificial limb blanks were used in the tests. Each kind of blank had been cut to the following approximate shape and size:

Long thigh.--Octagon in shape and somewhat tapered lengthwise; 9 inches in diameter and 17 inches in length; a longitudinal hole drilled from the large-diameter end of the blank to taper from approximately 2-3/4 inches in diameter at its top to a blunt point at a depth of about 13 inches.

Short thigh.--Octagon in shape; 9 inches in diameter, 14 inches in length; a 3-3/4 to 2-3/4-inch-diameter tapered hole drilled completely through the length.

Knee.--Octagon in shape; 7-1/2 inches in diameter, 9 inches in length; solid full length.

Shin.--Octagon in shape and somewhat tapered lengthwise; 6-1/2 inches in diameter, 17 inches in length; a longitudinal hole 1-1/2 inch in diameter drilled 8 to 9 inches deep from the large-diameter end of the blank.

Foot.--Square in shape; 4 by 4 inches in cross-section, 12 inches long; solid full length.

The ends of each blank had been dipped in paraffin, but as this coating would melt at kiln temperatures, the ends were trimmed off and recoated, when the blanks were received at the Laboratory, with a molten mixture of 60 percent (by weight) of 213° F. and 25 percent of 155° F. coal-tar pitch and 15 percent of 230° F. asphalt. At the same time, a disc was cut from near the solid end of each shin and long thigh blank from which to obtain their moisture-content data, which, with the weights of the blanks, were used to compute their oven-dry weights. These computed weights were then used as a guide in following the drying schedule, although corrected values were necessarily obtained at the end of the drying period by cutting moisture sections farther from the ends so as more nearly to represent the average moisture content of the individual blanks.

Seasoning Groups and Drying Conditions

Each blank was numbered individually and placed in one of eight seasoning groups (table 1) under various drying conditions. The dry kilns used for these experimental runs were equipped with fans that provided a very brisk rate of internal air circulation. The seasoning groups were, as follows:

Seasoning Group A.--Kiln-dried at a temperature of 110° F. for 75 days, after which the temperature was increased to 165° F. The initial relative humidity was 87 percent.

Seasoning Group B.--Kiln-dried at a constant temperature of 110° F. The initial relative humidity was 87 percent.

Seasoning Group C.--Kiln dried at a temperature of 130° F. for 75 days, after which the temperature was increased to 165° F. The initial relative humidity was 89 percent.

Seasoning Group D.--Kiln dried at a constant temperature of 130° F. The initial relative humidity was 89 percent.

Seasoning Group E.--Kiln dried at an initial temperature of 120° F., then at increases up to 140°, and then at 165° F. for final conditioning. The initial relative humidity was 80 percent.

Seasoning Group F.--Placed indoors within a small tunnel through which room air was circulated by means of an office fan. The room temperature was usually about 70° F. and the relative humidity was very low.

Seasoning Group G.--Placed indoors near group F, but outside of the wind tunnel under ordinary room conditions.

Seasoning Group H.--Placed outdoors in December under complete protection from the sun, rain, and snow.

The exact temperatures and relative humidities used in the kiln drying are shown graphically in figures 1, 3, 5, 7, and 9. The drying conditions for the outdoor group and the two indoor groups were obtained in terms of the moisture content of thin pieces of wood which were located with each group of blanks. The moisture-content values obtained are shown in figure 11 as "equilibrium moisture content,"² and are expressed in percent of the oven-dry weight of the wood. The moisture content of the blanks are also shown in figure 11.

Results

The results are shown both graphically and photographically in figures 1 to 14, inclusive. The drying times obtained are shown in figures 1, 3, 5, 7, 9, and 11, along with the records of drying conditions. The photographs, figures 2, 4, 6, 8, 10, 12, 13, and 14 show sections of every blank after drying. Figures 15 and 16 show factors causing defects.

One or two blanks in each of the five kiln-dried groups honeycombed, while no honeycombing occurred in the air-dried or room-dried blanks. Practically no surface checking occurred in any of the groups, and end checking was prevented by the pitch coating.

Shin blanks.---Apart from the temperature effect, there appeared to be another assignable cause in each case where honeycombing occurred. The honeycombing in shin blanks 13 (group A) and 14 (group B) originated in the bottom of the hole where a groove had been cut by the lip of the bit during boring. This is clearly shown in the photograph, figure 15. The first section was cut sufficiently close to the bottom of the hole to show the groove where checking and honeycombing started. The honeycombing in shin blank 18 (group E) appeared to have originated from a split or check in the side of the hole; while that in shin blank 16 (group D) appeared to have started from the solid end, possibly from a small end check that developed in a spot where a little of the end coating had come off. Shin blank 15 (group C) dried with no defect, possibly because of a difference in the characteristics of the wood itself or because the wood was more sound and had been less injured by the bit.

Knee blanks.---The solid knee blanks dried more slowly than the drilled blanks and honeycombed. knee blanks 23 (group A), 25 (group C), and 27 (group E) all had a relatively high moisture content (25 percent or more) when the kiln temperatures were increased to 140° F. or above.

Thigh blanks.---Honeycomb checks did not occur in the long thigh blanks where a tapered drill had been used and where the bottom of the hole had been cut rather smoothly to a blunt point. Furthermore, no honeycombing occurred in the short thigh blanks that had a center hole completely through the blank.

Foot blanks.---The foot blanks were kiln dried without defects. Although not fully verified, a few miscellaneous tests indicated that foot blanks may honeycomb in ordinary kiln temperatures under low initial relative-humidity conditions. This may be due to a considerable amount of tension set (set in an expanded condition) that is apt to occur under low initial relative humidity conditions.

Drying time.---Three months or more were required to kiln dry green blanks completely. Considering the cost phase, such kiln-drying periods do not compare favorably with those required in air-drying outdoors and indoors for a similar result even though these drying periods were two or more times as long.

conclusions

1. Willow end checks readily and, consequently, requires durable end coatings. End checks once started are difficult to stop; and, under kiln temperatures, they extend inwardly and open into a honeycomb failure.

2. Willow has very little tendency to surface check except at knots and other defects, despite the fact that its tangential shrinkage is approximately three times its radial shrinkage, an indication of its ability to stretch and to take a tension set (set in an expanded condition). Because of such shrinkage characteristics, it can be room dried or air dried under rather low-humidity conditions without a great deal of danger from surface checking.

3. Full-length splits that appear on radial faces early in the drying process are not surface checks or seasoning splits, but are caused either by what appear to be shakes or by weak planes that existed in the tree.

4. In some cases, checking and honeycombing started at knots and then progressed inwardly. Any form of knot is a potential source of honeycombing.

5. Honeycombing in some of the shin blanks originated in the groove or cut made by the lip of the 1-1/2-inch bit at the bottom of the longitudinal hole. Such honeycomb checks did not occur in the larger thigh blanks where a tapered drill was used and where the bottom of the hole was shaped to a blunt point with a much smoother cut. Honeycombing from this cause, therefore, might be prevented by avoiding the use of a bit having a lip and by using one that does not thus injure the wood fibers at the bottom of the hole. Dropping some end coating into the hole to cover the end-grain fibers might help by reducing the more rapid rate of drying in this area.

6. No honeycomb checks occurred where there was a through center hole; therefore, the chance for success in an accelerated drying process would be increased greatly if a sizable center hole could be extended completely through the block.

7. The short, solid knee blocks, when well end-coated, dried at a slower rate than the other items, a fact that makes high-moisture-content cores and consequent honeycombing a greater possibility in these than in the other blanks. This danger indicates the desirability of drilling and cutting them to rough shape and size before seasoning.

8. Temperatures above 130° F. should not be used until the average moisture content is below 20 percent. At moisture content below this point, however, 165° appears satisfactory for sound wood.

9. Although not fully verified, there is an indication that foot blanks tend to honeycomb under a low-humidity schedule even if the temperature is limited to 120° to 140° F.

10. Although it may be possible, by avoiding the danger points mentioned in this report, to kiln dry green willow artificial-limb blanks satisfactorily with respect to seasoning defects, nevertheless, it probably would not always be practical to bring about optimum conditions, without which some cull blanks would inevitably result. The loss of even a few such expensive blanks and the relatively high cost of kiln drying due to its slow drying rate, might be considered sufficient reasons for not using the method for drying green blanks.

11. If, however, every blank were air dried or room dried to a moisture content of about 20 percent and then kiln dried, the chance for complete success would be very favorable. The end coating in this case would have to be durable enough not to break down under the kiln temperatures. Paraffin is very good for air seasoning, but melts and becomes ineffective under kiln temperatures.

12. When the drying rates of groups F and G are compared, it can be concluded that the effect of added air velocity around the blanks was negligible. In both cases the moisture was evaporated as fast as it diffused to the surface from the interior of the wood. Within large piles, however, where the evaporated moisture cannot so readily get away, the need for forced-air circulation is much greater than when each blank is surrounded with much air space.

Suggestions for Seasoning Procedure

Preparation of Blanks

1. Use as large a center hole as practical.

2. Use a design permitting a full-size center hole. This is now being done for shin blanks, but the hole is drilled into the small or ankle end after drying. This hole could be drilled a little under size through the green blank if carefully centered, and then bored out to its full size and shape after drying. The hole, of course, is plugged with a tapered birch or maple plug for added strength in attaching the foot piece.

Long thigh blocks that include both thigh and knee sections now have a hole drilled only part way through. This block can be replaced by the two-piece design that permits a full-size center hole entirely through the relatively thick, but short, thigh blank. The separate knee blank, being large and solid, dried slowly and with more danger of seasoning defects. These blanks could just as well be rough-cut when green to provide a short center hole at the top end and a cutaway and drilled portion where the bottom end joins the shin piece.

3. Avoid defects and tool injuries. Watch out for shakes that may appear as splits on edge-grain surfaces.

4. Dip all ends in hot paraffin as soon after crosscutting as possible; or in a hot high-temperature pitch and asphalt coating if any drying is to be done in a kiln or oven.

5. Weigh each green blank to the nearest ounce or tenth of a pound and record its weight on the blank. If the wood is green it may have a moisture content of about 100 percent, in which event about one-half of the weight of the blank will be water and the other half the weight of the dry wood. Of course, the green moisture content varies to such a great extent that, if possible, some moisture-content determinations should be made occasionally to determine the degree of variation. Some willow has a green moisture content of 150 percent or more. Such variations make it a very good practice to become familiar with the weight and moisture content of blanks.

6. Keep all green blanks out of the sun and away from hot surfaces or heated areas.

Drying Conditions

1. Provide a room or shed with some type of heat-control system and with controllable vents, such as inlets through the floor or near the floor line and outlets through the roof or near the roof or ceiling line.

2. The heat source should be such as steam or hot-water radiation along, or hot-air registers in, the side walls. Heating surfaces directly below the piles of blanks are not recommended.

3. Use an open foundation to provide an air space of 1-1/2 feet or more below the pile.

4. Pile layers of blanks on stickers about 1 by 2 inches in size and leave an inch or two between each blank in a layer to permit the naturally vertical air circulation. Piling racks are very satisfactory, but the blanks should not be nested together without spacing sticks or stickers. Vertical open flues or chimneys must be provided for uniform drying and maximum drying rate.

5. Use very little, if any, heat during the initial drying stages, and adjust the amount used to weather conditions and to the relative humidity within the room. Some idea of the temperature to use can be obtained from the chart in figure 17. For instance, if the outside conditions were 60° F. and 70 percent relative humidity, according to the chart the vapor pressure would be 0.360 in inches of mercury as shown on the lines that slope downward to the right. Assuming that this air is heated to 70° F. and ignoring the moisture added to it by that evaporated from the blanks, the vapor pressure is unchanged and this line can be followed downward from 60 to 70° F. The relative humidity would then be 50 percent and the equilibrium moisture content of wood would have been changed from 13 to 9 percent. The original condition of 60° F. and 70 percent relative humidity, however, would give a very satisfactory initial drying rate.

From this example it can be seen that the use of a hygrometer² would be very desirable for all those with drying or conditioning problems.

6. With its original weight marked on each blank, any of them can be weighed periodically to determine loss of moisture. When about 40 percent of the moisture is lost, the severity of the drying conditions can be increased more rapidly; and when 60 percent of the moisture is gone (30 percent of the original total weight, if the original moisture content was 100 percent), the relative humidity can be as low as desired. The procedure is simply to drop the relative humidity by heating whenever the drying rate becomes excessively slow. Kiln- or oven-drying at temperatures above 130° F. should not be attempted while the moisture content of the wood is much above 20 percent.

By weighing blanks from various portions of the pile, some idea of the uniformity of the drying can be obtained. Each lot should always contain some dummy or defective blanks from which moisture-content sections can be cut and oven dried near the end of the drying process to check the earlier estimate of the original green-moisture content of the lot.

7. When wood is being dried, particularly under low relative humidities, the surface fibers will take a tension set; that is, a set in a stretched or expanded condition. If such a blank is not completely dry and its core is still at a relatively high moisture content when exposed by rough cutting, the drying or shrinkage stresses of its core plus the tension stress brought about by the set of its expanded shell, may result in checks in all end-grain surfaces of the freshly exposed wood. It is therefore suggested that partly seasoned blanks, after being rough-cut to shape, be placed under a rather mild drying condition for a week or two before subjecting them to low relative humidities such as exist in ovens or in fully heated rooms during winter time.

Because of this danger of end-grain checking, as well as to obtain faster drying rates, it would be better to rough-cut knee blanks to shape when the wood is green.

Appendix

Moisture Content of Wood

The amount of moisture in wood is expressed as a percentage of the weight of the wood when oven-dry. A common and standard method of determining this percentage is to cut from the wood a 3/4- to 1-inch section along the grain, to weigh it immediately in grams to the nearest one-tenth of a gram, and then to oven-dry it at temperatures of 212° to 220° F. until of constant weight. The drying takes several hours to a day or two, depending upon the wetness of the piece and how many blanks are in the oven. The piece is weighed again when taken out of the oven. Dividing the difference between the original and the oven-dry weight by the oven-dry weight and multiplying the result by 100, gives the percentage of moisture based on the dry weight.

Relative Humidity of Air

The amount of moisture (water vapor) in air per unit volume is called the absolute humidity. It is more common, however, to think of this amount of moisture in terms of the ratio of its weight to the weight of water vapor that would saturate the unit volume of air at the same temperature and atmospheric pressure. When multiplied by 100, this ratio, which is called relative humidity, gives the amount of moisture in the air as a percentage of the maximum moisture that the air could hold at that temperature and pressure.

The most common instrument for measuring relative humidity is the wet-and-dry-bulb hygrometer. A hygrometer is simply two thermometers, the bulb of one of which is covered with a wet wick. When the wick is fanned vigorously to obtain a brisk air velocity past it (needed for ordinary temperatures), the evaporation of water from the wick causes a cooling of the wet-bulb thermometer and its temperature will be less than that of the dry-bulb thermometer. The difference between these temperatures is called the wet-bulb depression; and, from it the relative humidity can be obtained by referring to table 2. The values given above the diagonal lines are relative-humidity values expressed in percent. Hygrometers with suitable temperature ranges can be obtained from any of several instrument companies. A common type is one in which two similar thermometers are mounted on a wood or metal frame with a detachable glass cistern between them. This cistern is filled with water and the end of the wick is inserted into it so as to be kept moist at all times. Another type is the sling psychrometer that is whirled around a handle to create the necessary air velocity for maximum evaporative rate.

Under kiln temperatures, the accuracy of the instrument is less affected by air velocity and it is common practice to read the thermometers without producing additional air velocity over the bulbs.

Equilibrium Moisture Content of Wood

"Equilibrium moisture content" is that moisture-content value at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature. This relationship between wood and air is given in table 2 below the diagonal lines and represents the amount of water in wood expressed in percent of weight of oven-dry wood. It takes a great deal of time for wood to reach an equilibrium moisture content, and the equilibrium values reached differ somewhat among species and also between wood that is losing and that which is gaining moisture at the same relative humidity and temperature for both. The exactness of the values given in the table, therefore, are important only as they represent the average. In some particular case, values obtained may differ from the values given by as much as 1 percent, but they are sufficiently accurate for all practical purposes.

By table 2 the temperatures and relative humidities used in the kiln runs can be converted into equilibrium-moisture-content values.

Table 1.—Seasoning groups of individually numbered artificial-limb blanks

Kind of blank	Individual piece numbers ² by groups							
	A	B	C	D	E	F	G	H
Long thigh	5	4	6	7	8 & 9	3	2	1
Shin	13	14	15	16	18	12	11	10
Knee	23	22	25	24	26 & 27	21	20	19
Foot	32	31	34	33	.....	30	29	28
Short thigh	¹ 38	.....	39	.....	.....	37	.....	.....

¹Boxed heart.

²Shin blank 17 and foot blanks 35 and 36 were used for preliminary tests.

RELATIVE HUMIDITY AND EQUILIBRIUM MOISTURE CONTENT TABLE
FOR USE WITH DRY BULB TEMPERATURES AND WET BULB DEPRESSIONS

TEMPERATURE DRY BULB (°F)		WET-BULB DEPRESSION (°F)																				TEMPERATURE DRY BULB (°F)																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50	
30	88	10.5	9.5	8.5	7.5	6.5	5.5	4.5	3.5	2.5	1.5	0.5																											
35	90	9.8	8.8	7.8	6.8	5.8	4.8	3.8	2.8	1.8	0.8																												
40	92	9.2	8.2	7.2	6.2	5.2	4.2	3.2	2.2	1.2	0.2																												
45	93	8.5	7.5	6.5	5.5	4.5	3.5	2.5	1.5	0.5																													
50	94	7.8	6.8	5.8	4.8	3.8	2.8	1.8	0.8																														
55	95	7.2	6.2	5.2	4.2	3.2	2.2	1.2	0.2																														
60	96	6.5	5.5	4.5	3.5	2.5	1.5	0.5																															
65	97	5.8	4.8	3.8	2.8	1.8	0.8																																
70	98	5.2	4.2	3.2	2.2	1.2	0.2																																
75	99	4.5	3.5	2.5	1.5	0.5																																	
80	100	3.8	2.8	1.8	0.8																																		
85	101	3.2	2.2	1.2	0.2																																		
90	102	2.5	1.5	0.5																																			
95	103	1.8	0.8																																				
100	104	1.2	0.2																																				
105	105	0.8																																					
110	106	0.5																																					
115	107	0.3																																					
120	108	0.2																																					
125	109	0.1																																					
130	110	0.1																																					
140	111	0.1																																					
150	112	0.1																																					
160	113	0.1																																					
170	114	0.1																																					
180	115	0.1																																					
190	116	0.1																																					
200	117	0.1																																					
210	118	0.1																																					

NOTE: RELATIVE HUMIDITY VALUES ABOVE AND EQUILIBRIUM MOISTURE CONTENT VALUES BELOW DIAGONAL LINES

Table 2.--Relative humidity and equilibrium moisture content table for use
with dry bulb temperatures and wet bulb depressions, with relative humidity
and equilibrium moisture content values expressed in percent.

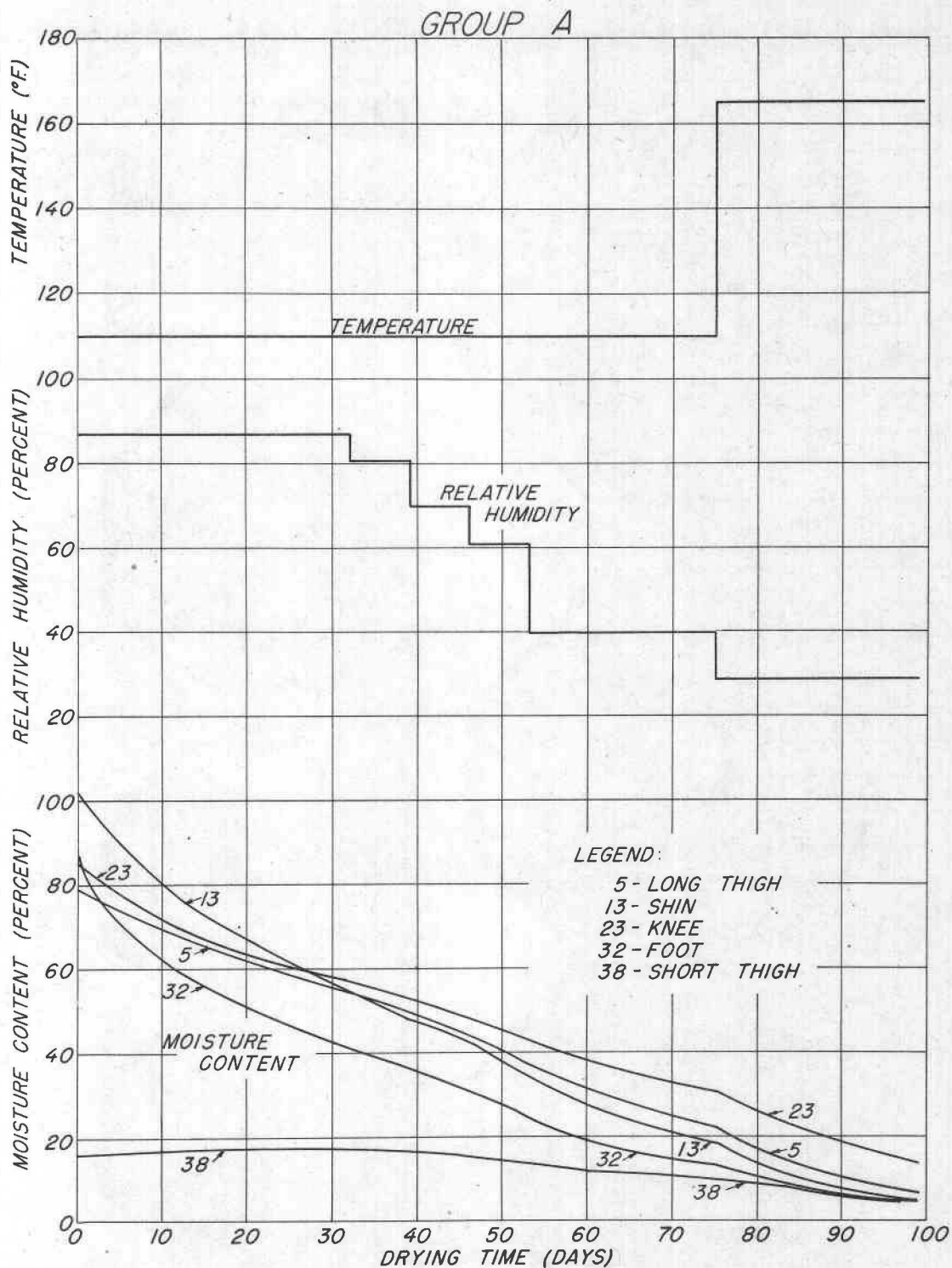


Figure 1.--Kiln-drying time of seasoning group A, Ohio "red" willow artificial-limb blanks, with record of drying conditions.

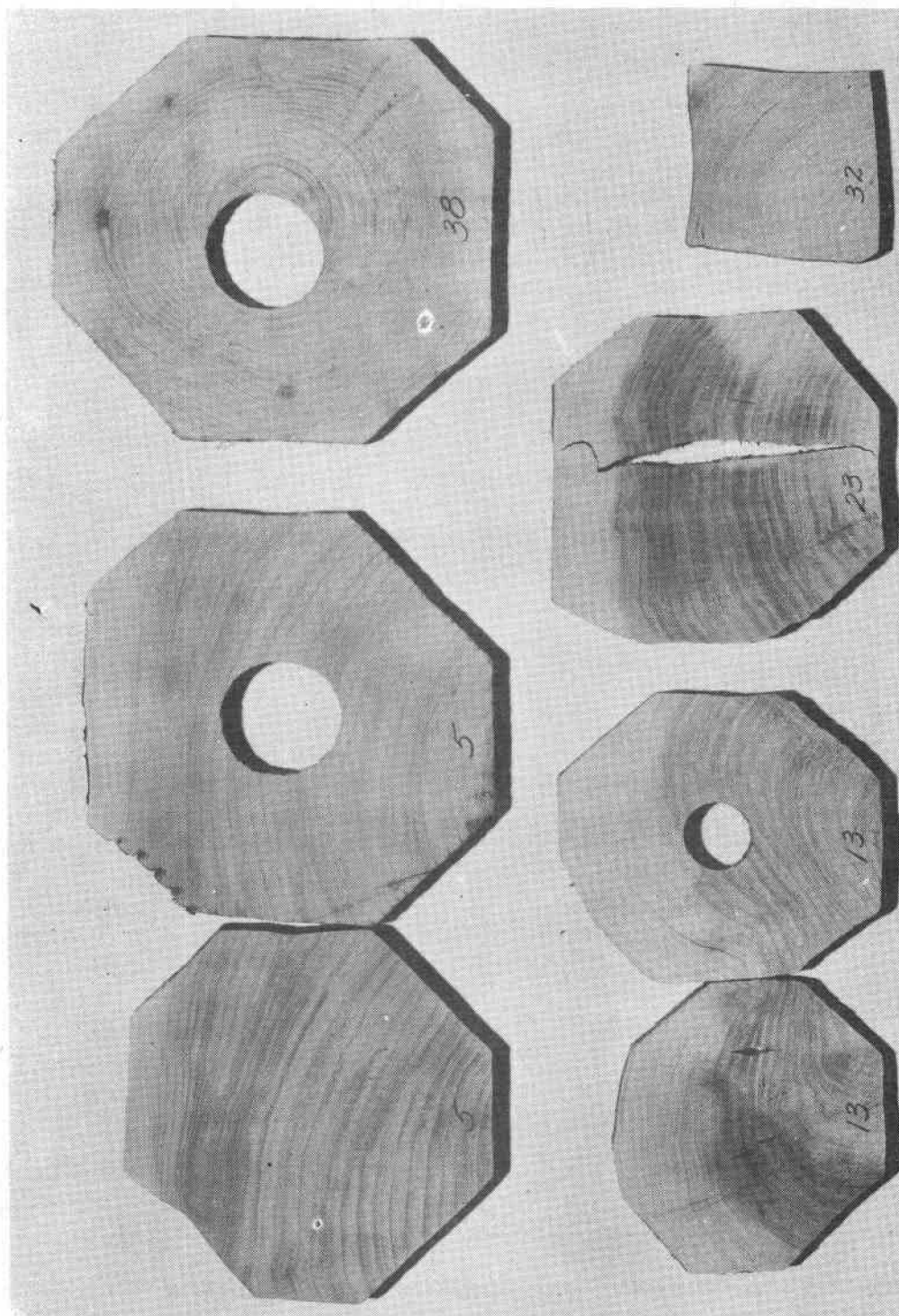


Figure 2.--Seasoning group A, Ohio "red" willow artificial-limb blanks, after kiln-drying.

Z M 71482 F

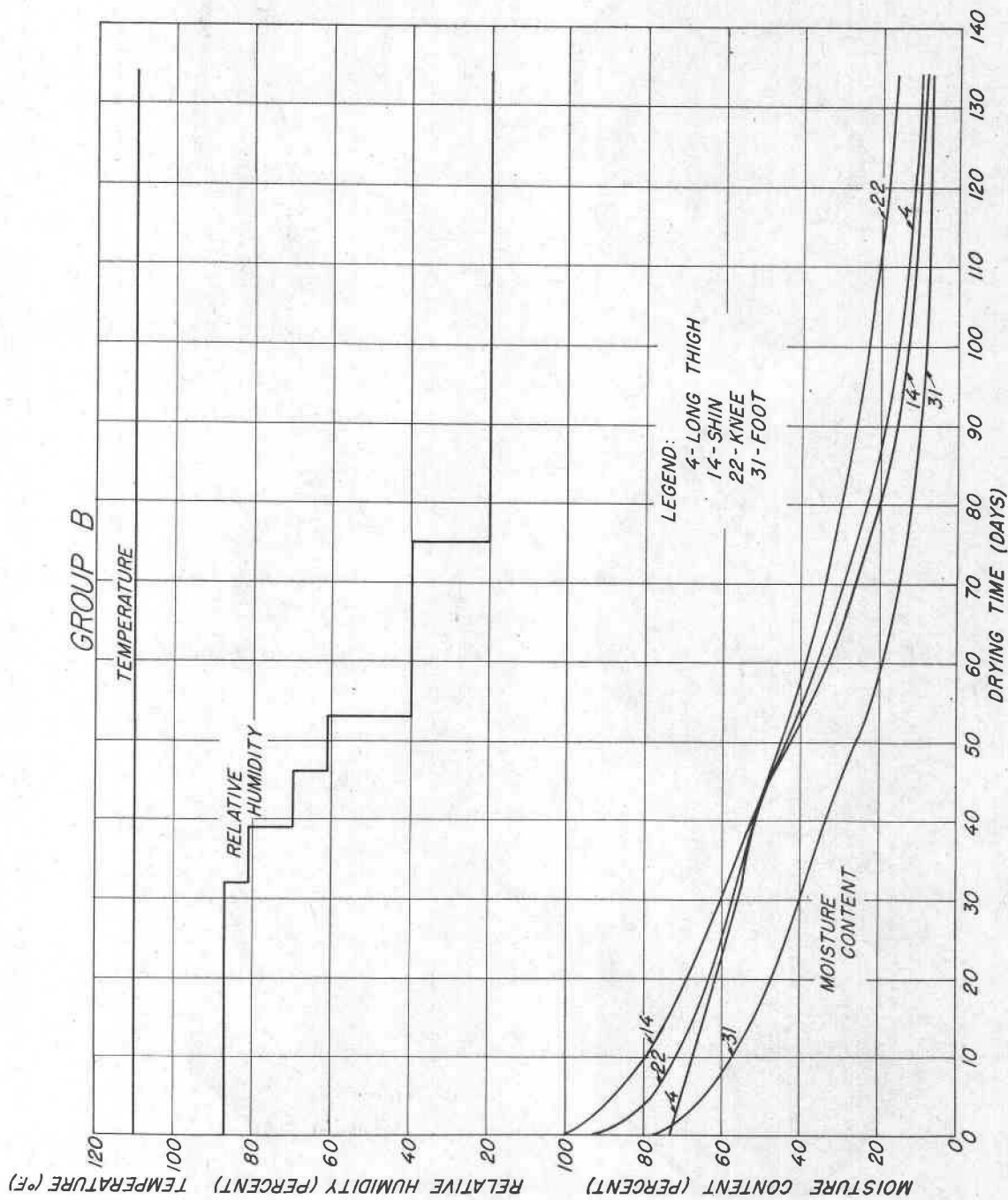


Figure 3.--Kiln-drying time of seasoning group B, Ohio "red" willow artificial-limb blanks, with record of drying conditions.

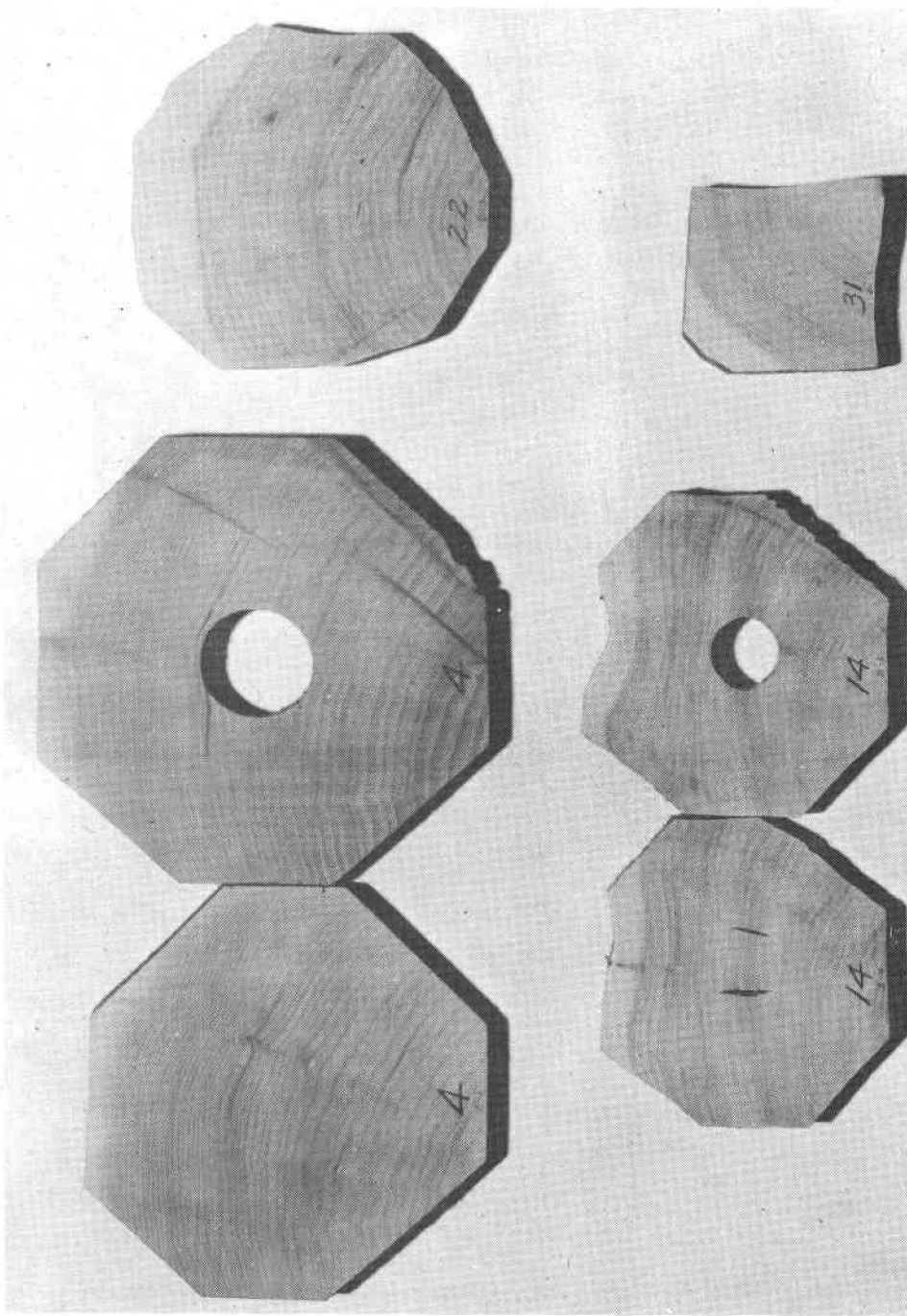


Figure 4.--Seasoning group B, Ohio "red" willow artificial-limb blanks, after kiln-drying.

Z M 71464 F

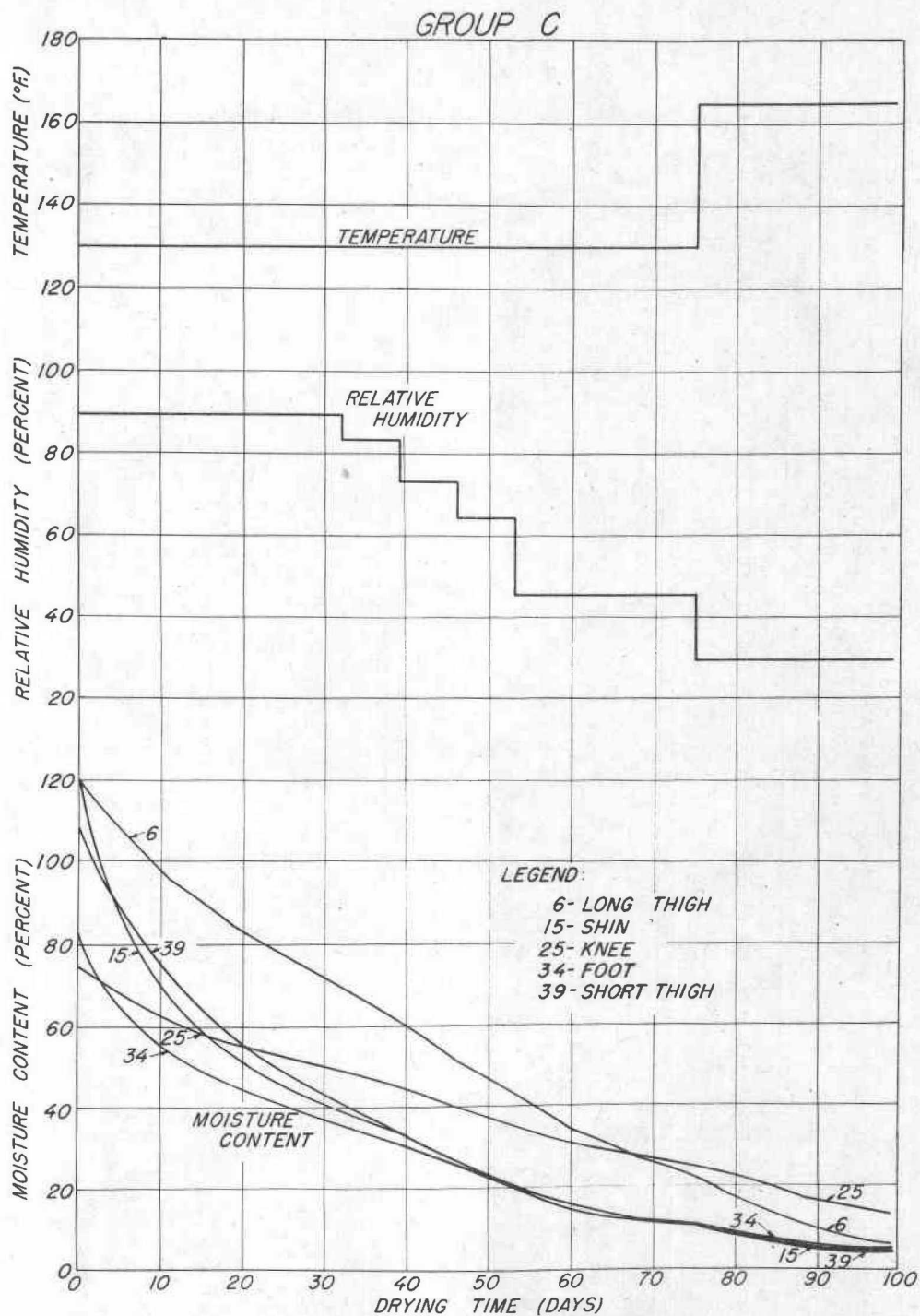


Figure 5.--Kiln-drying time of seasoning group C, Ohio "red" willow artificial-limb blanks, with record of drying conditions.

Z M 71485 F

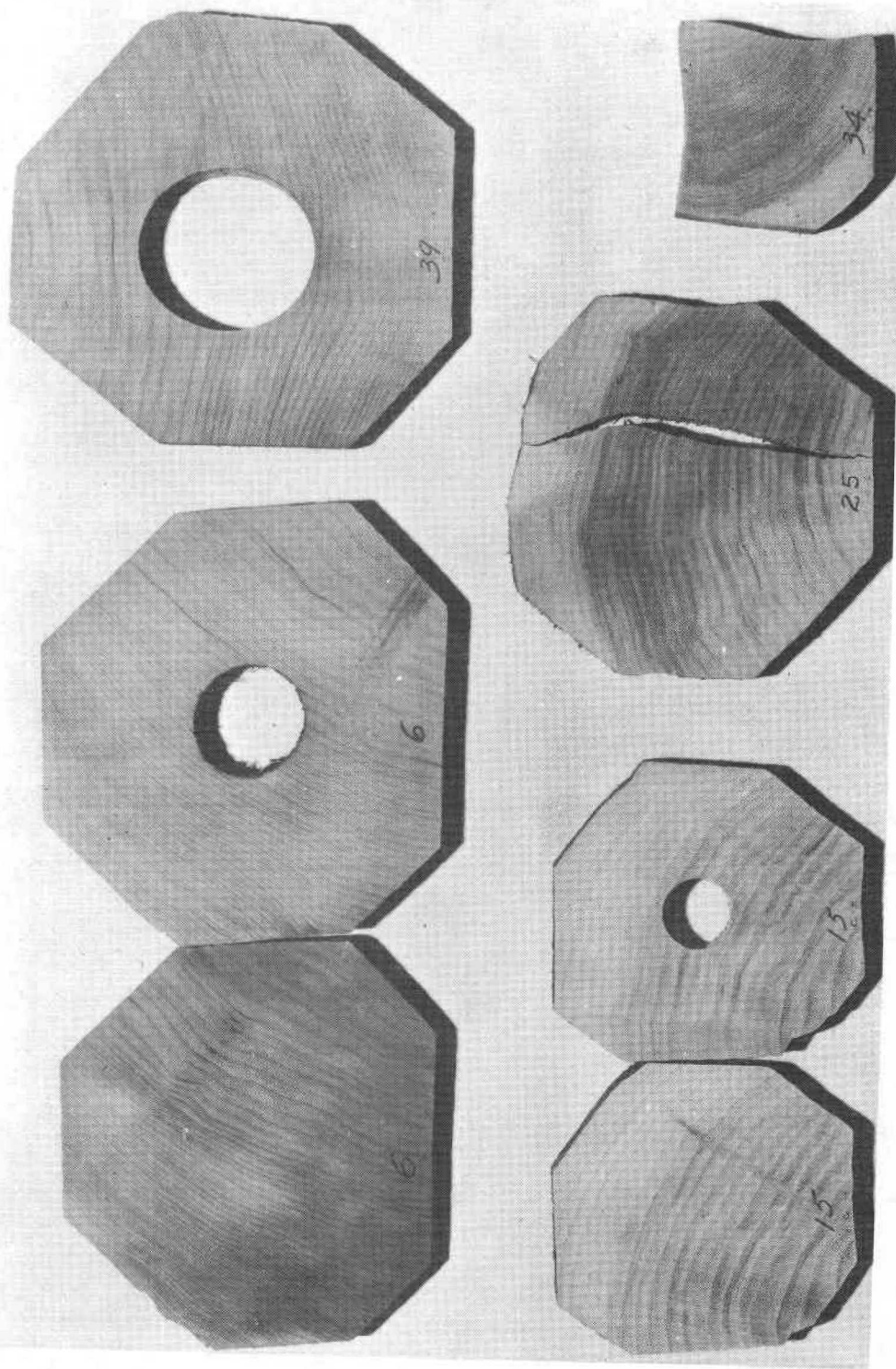


Figure 6.--Seasoning group C, Ohio "red" willow artificial-limb blanks, after kiln-drying.

Z N 71486 F

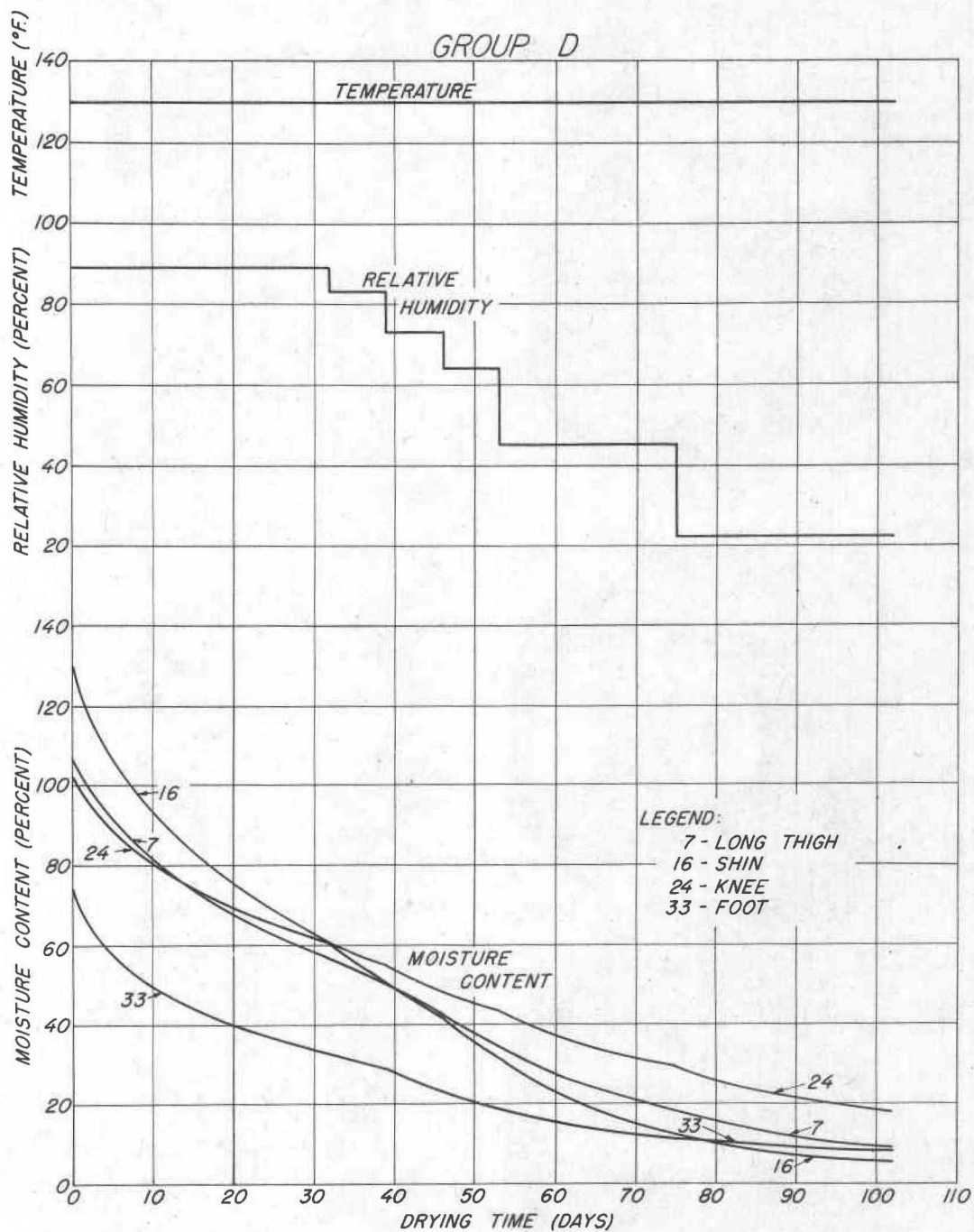


Figure 7.--Kiln-drying time of seasoning group D, Ohio "red" willow artificial-limb blanks, with record of drying conditions.

Z M 71487 F

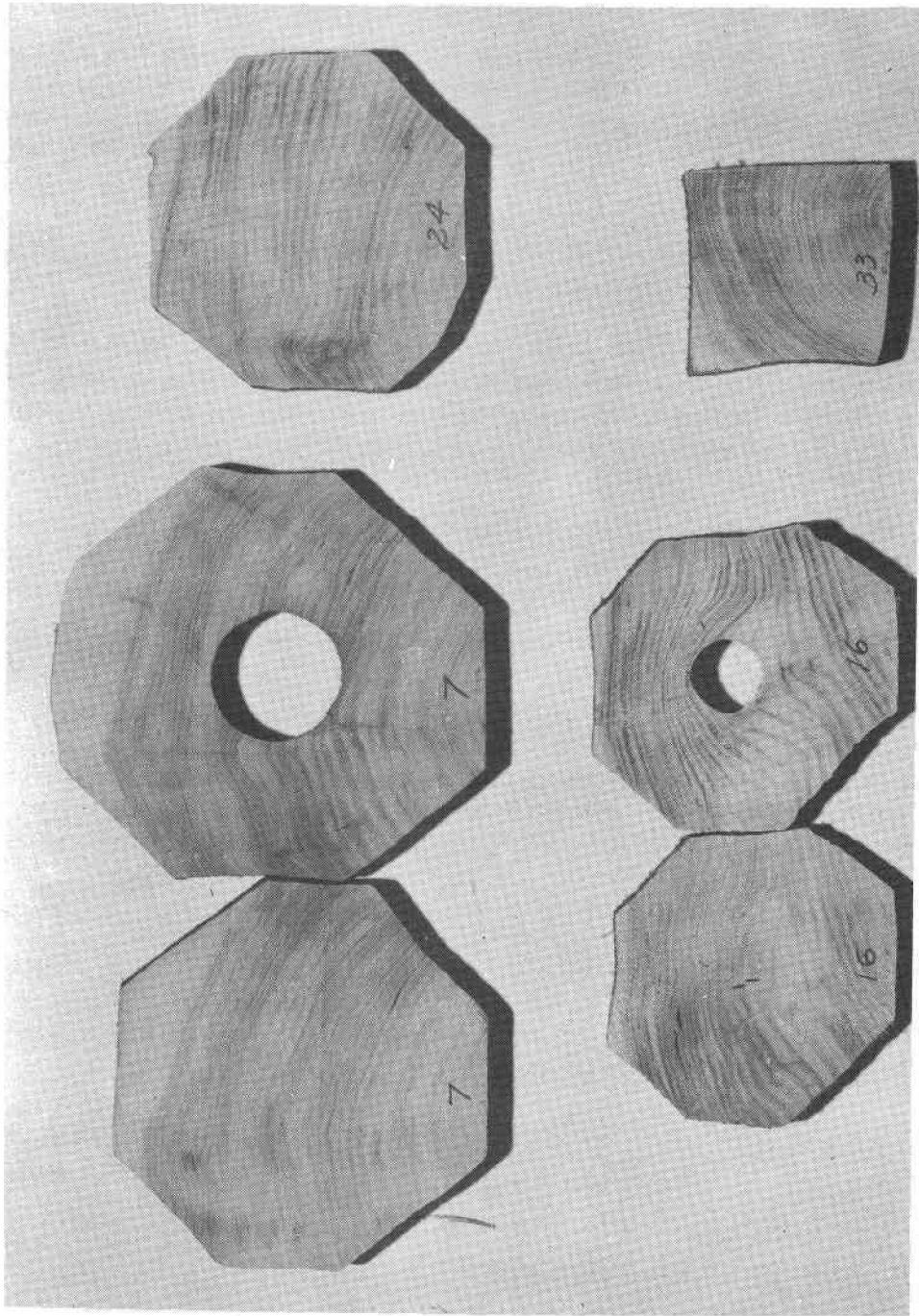


Figure 8.--Seasoning group D, Ohio "red" willow artificial-limb blanks, after kiln-drying.

Z N 71498 F

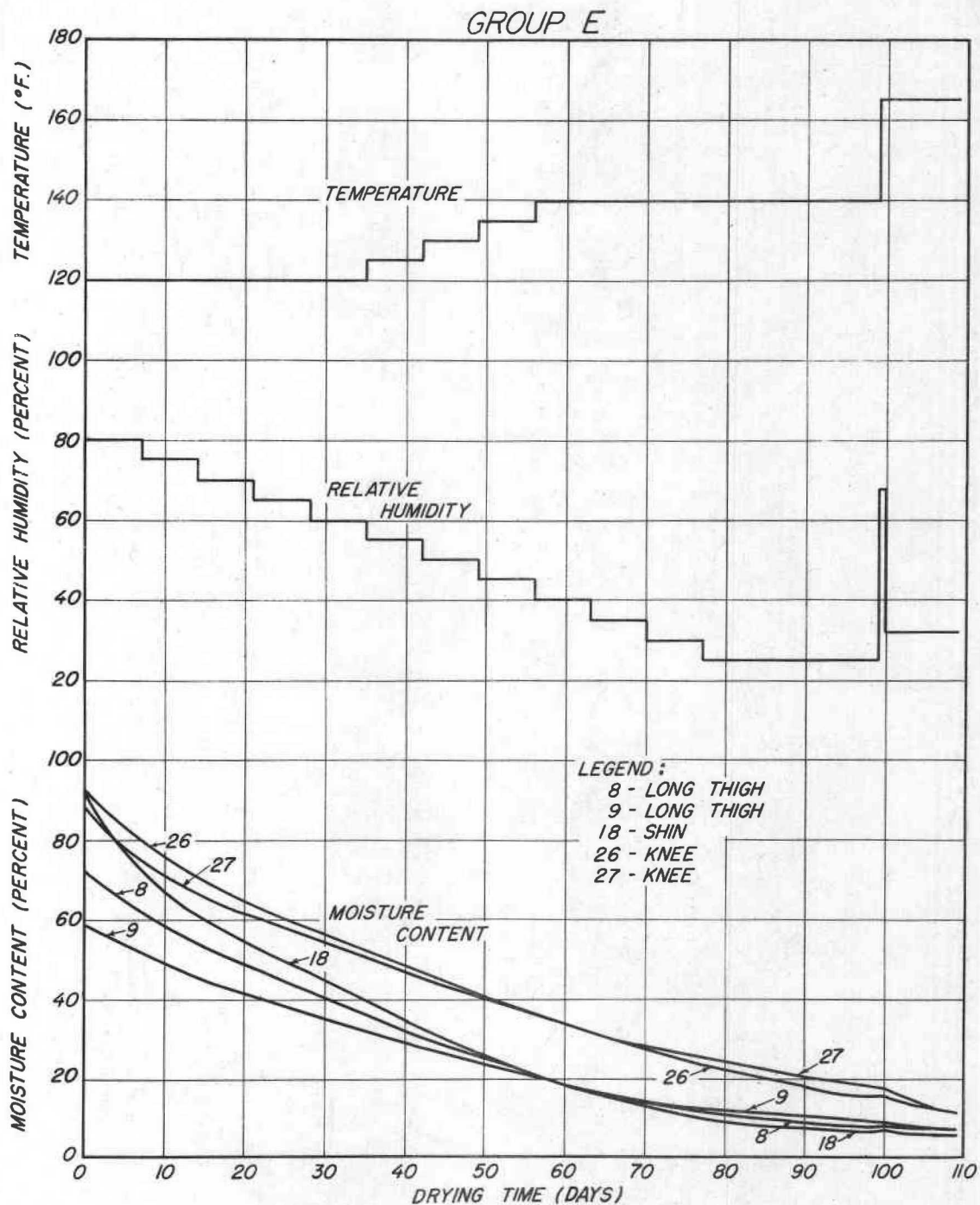


Figure 9.--Kiln-drying time of seasoning group E, Ohio "red" willow artificial-limb blanks, with record of drying conditions.

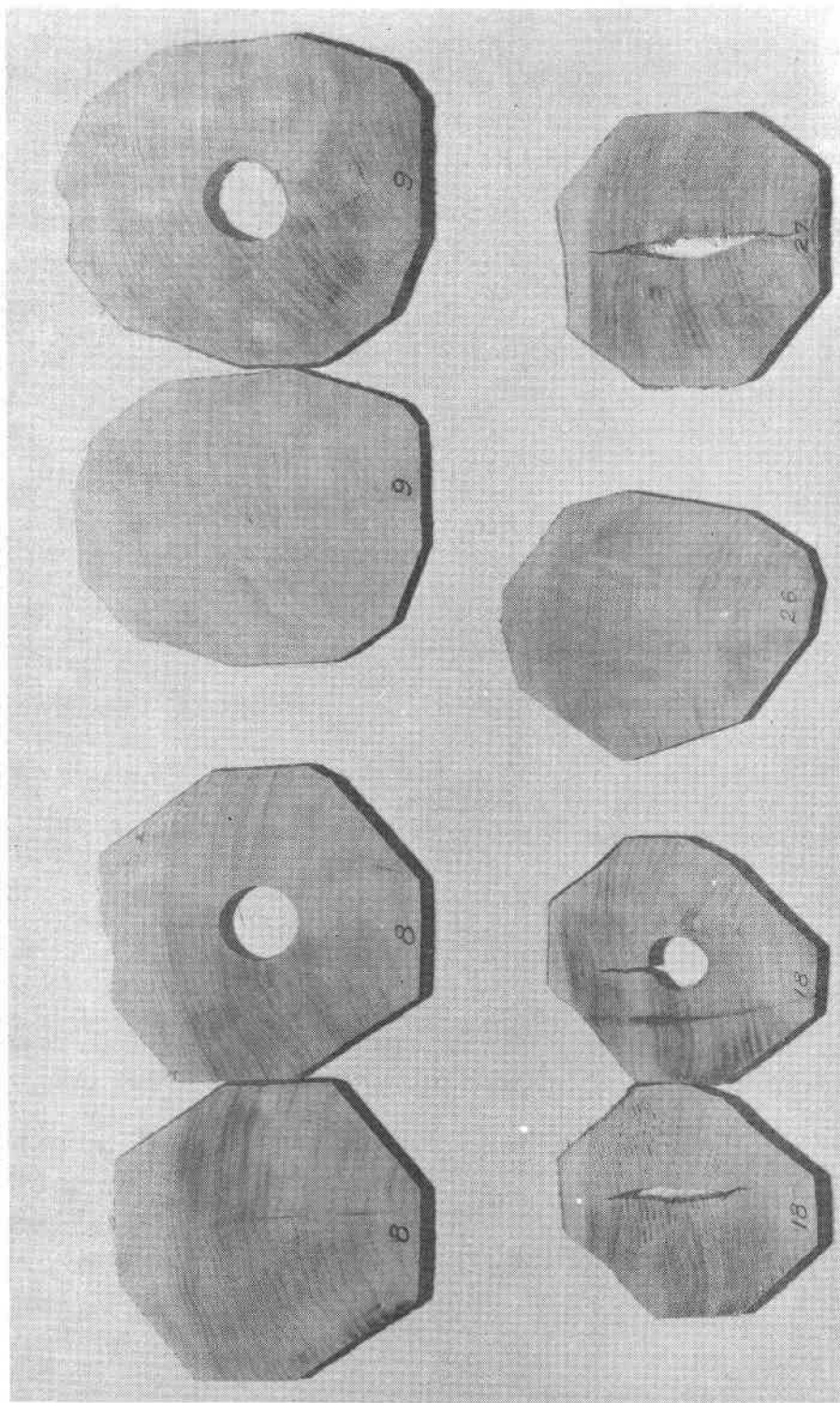


Figure 10.--Seasoning group E, Ohio "red" willow artificial-limb blanks, after kiln-drying.

Z M 71490 F

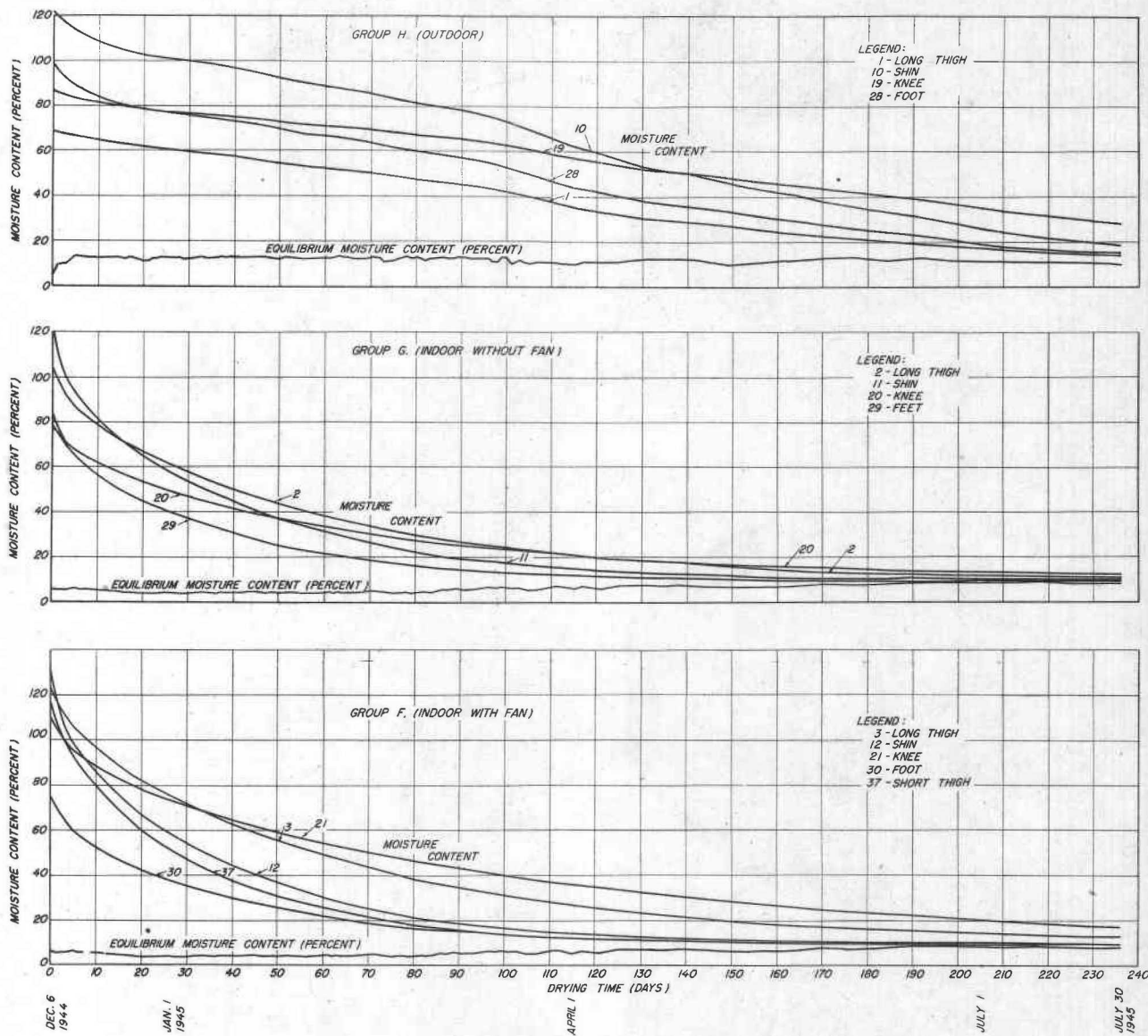


Figure 11.--Moisture-content values obtained for seasoning groups F, G, and H, Ohio "red" willow artificial-limb blanks and the equilibrium moisture content conditions expressed in percent of the oven-dry weight of the wood.

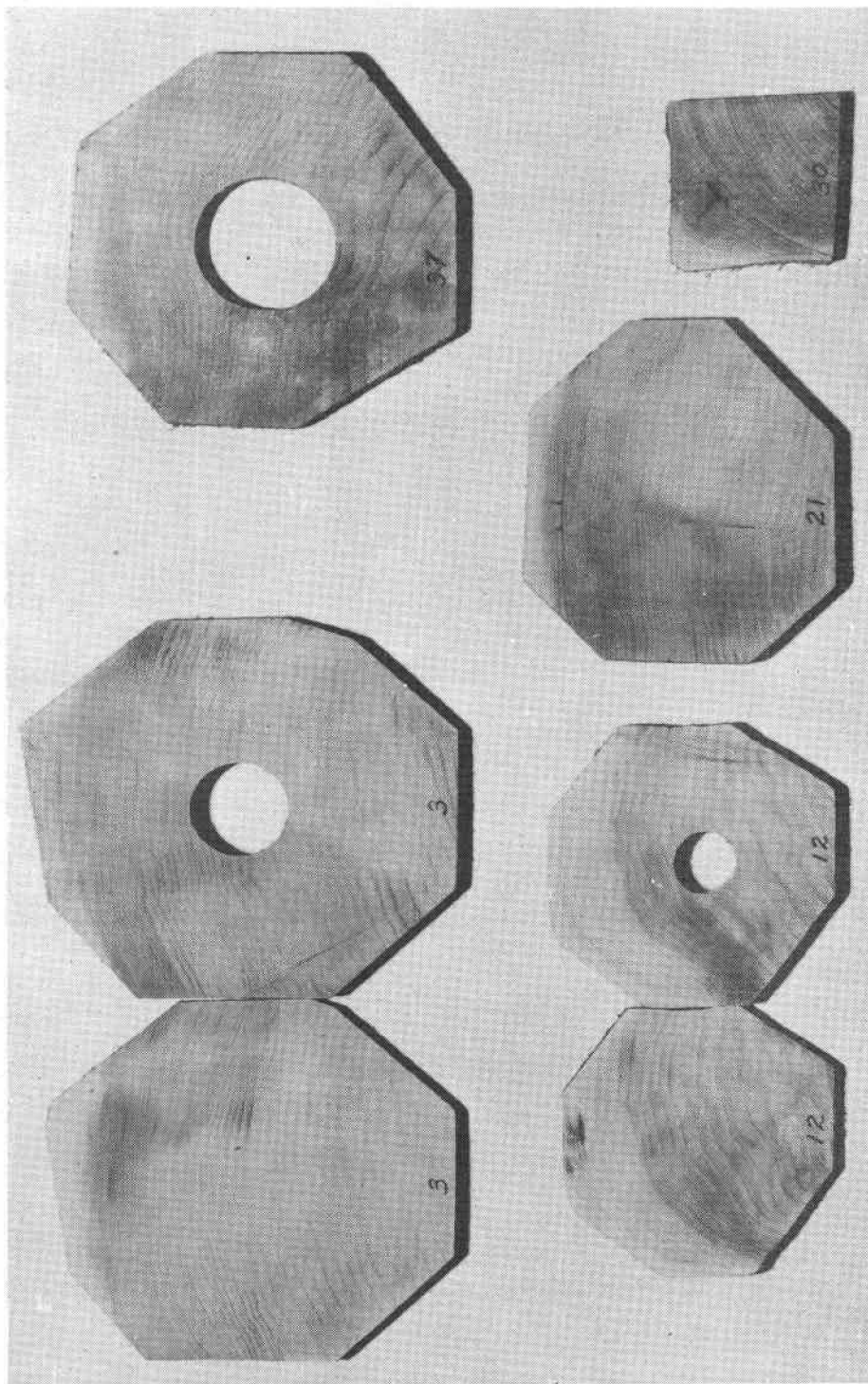


Figure 12.--Seasoning group F, Ohio "red" willow artificial-limb blanks, after room-drying with air circulation.
Z M 71492 F

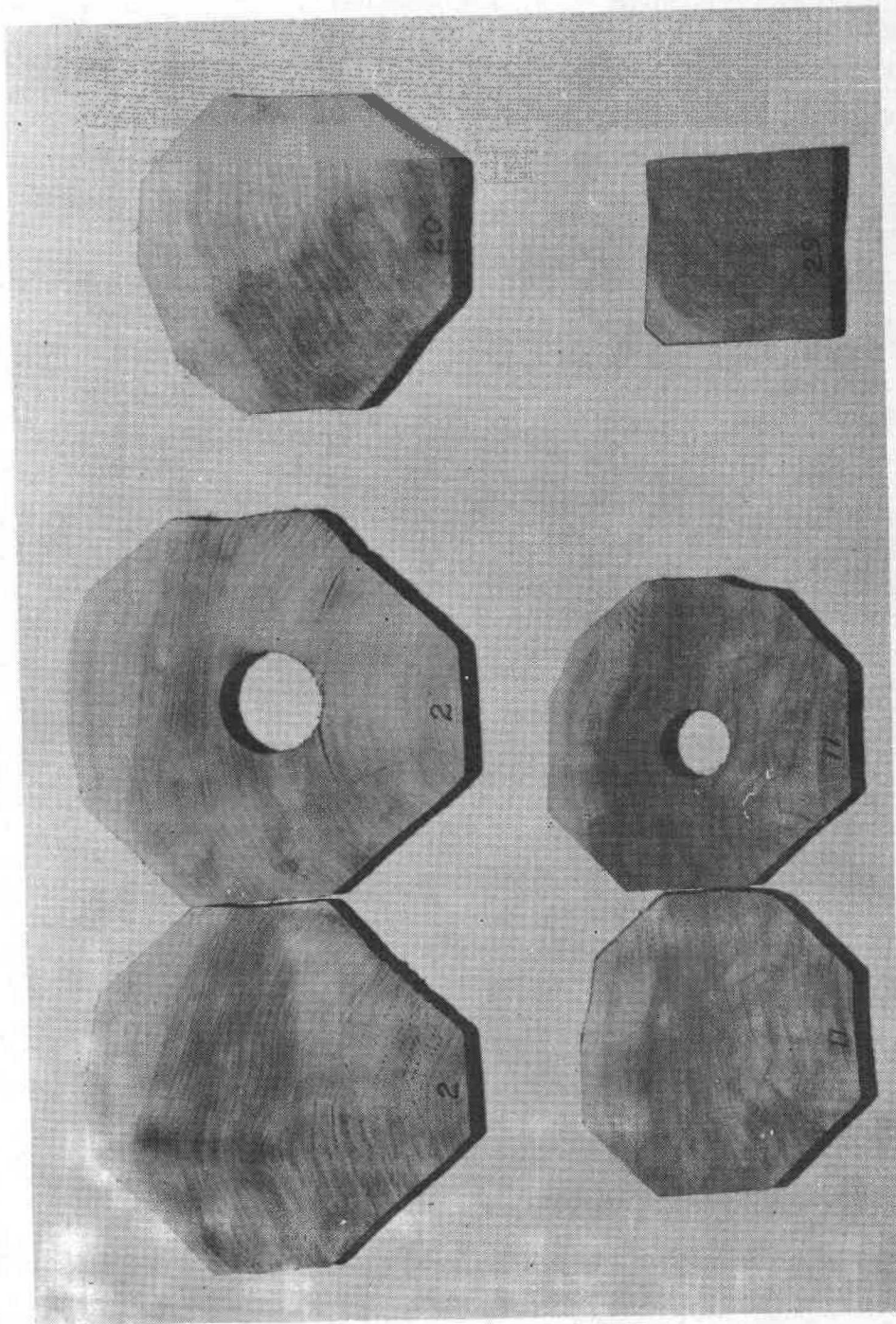


Figure 13.--Seasoning group G, Ohio "red" willow artificial-limb blanks, after room-drying without air circulation.

Z M 71493 F

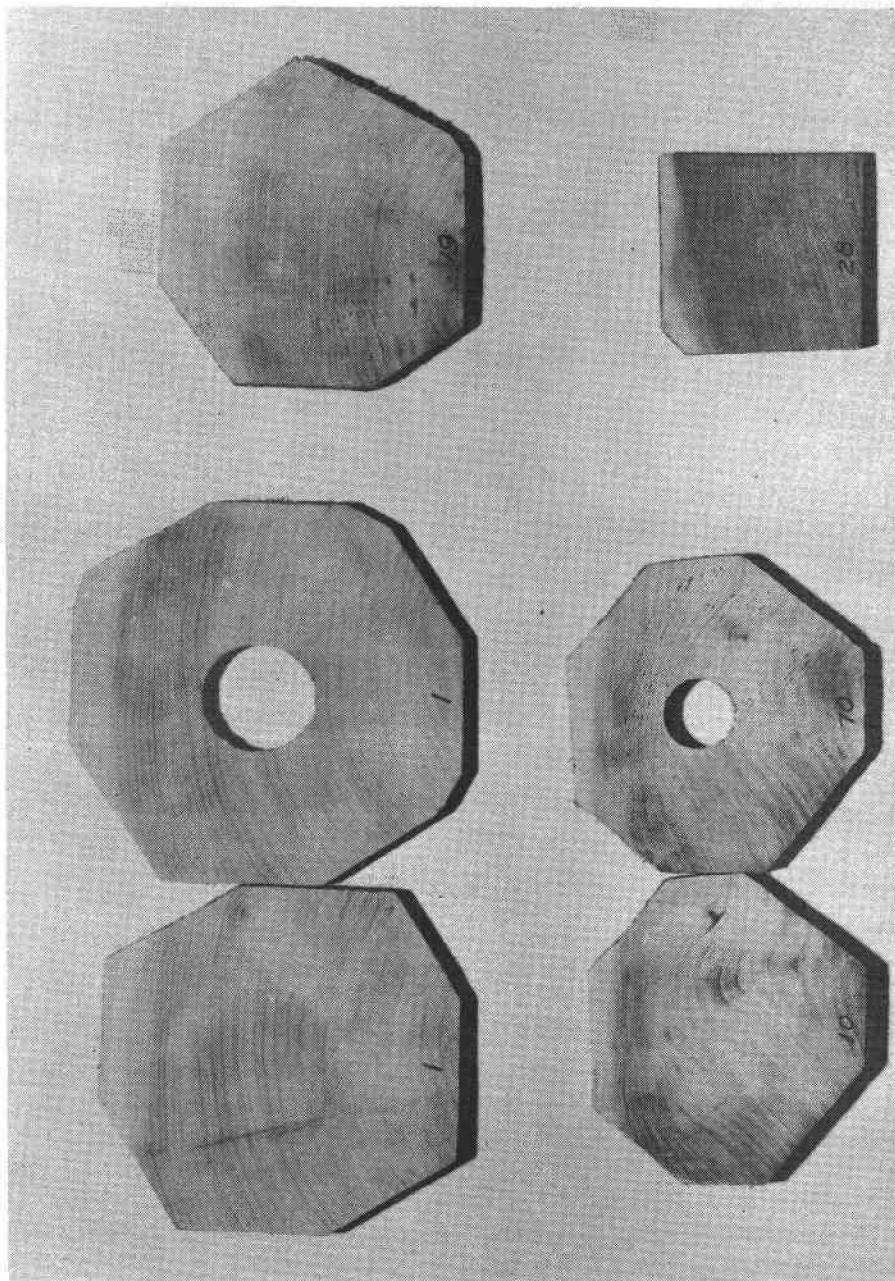


Figure 14.--Seasoning group H, Ohio "red" willow artificial-limb blanks, after
air seasoning under cover.

Z M 71494 F

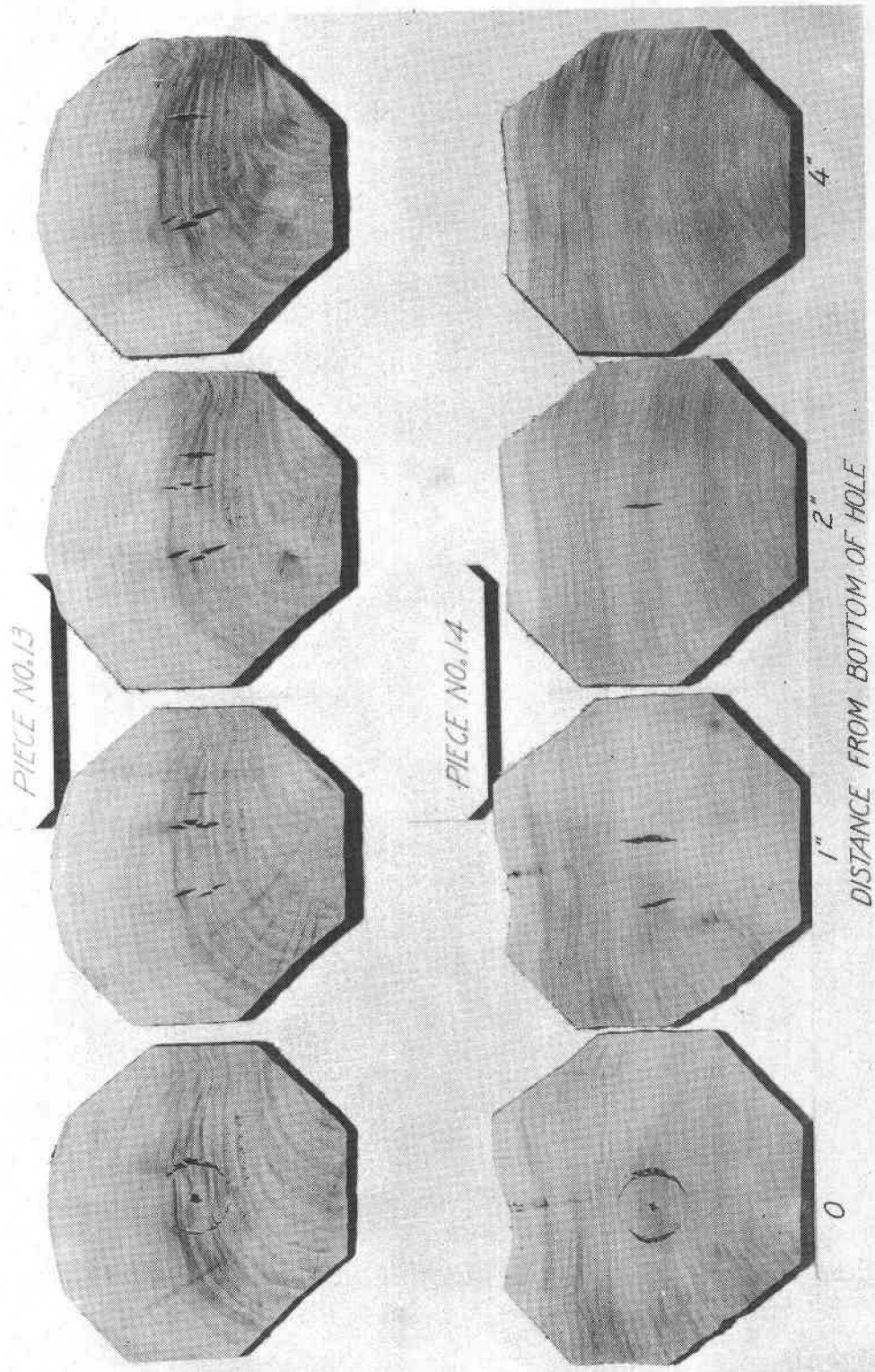


Figure 15.--Cut made by lip of bit at bottom of hole caused honeycombing during kiln-drying of Ohio "red" willow artificial-limb blanks.

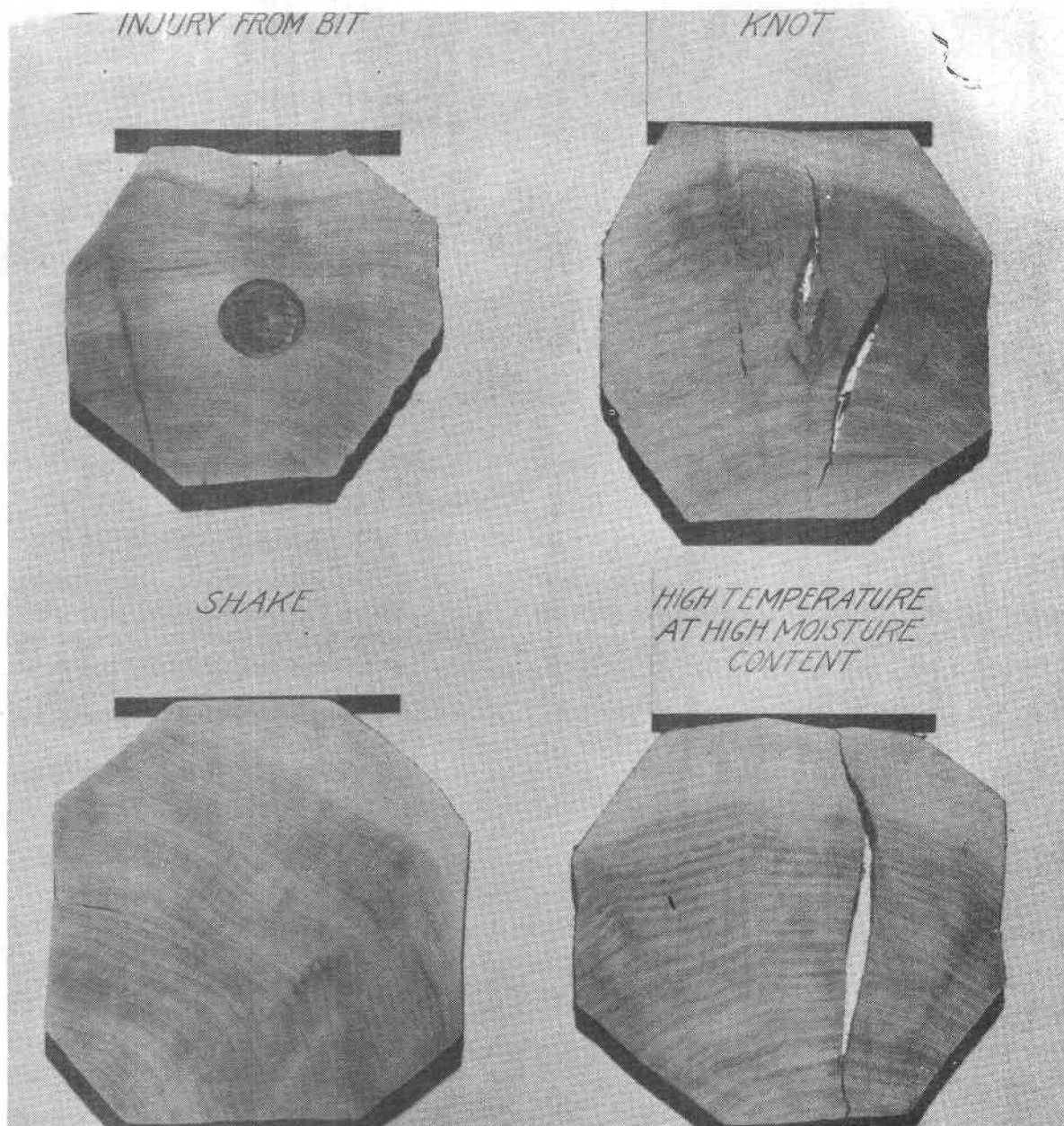


Figure 16.--Factors causing splits and honeycombing in Ohio "red" willow artificial-limb blanks.

Z M 71496 F

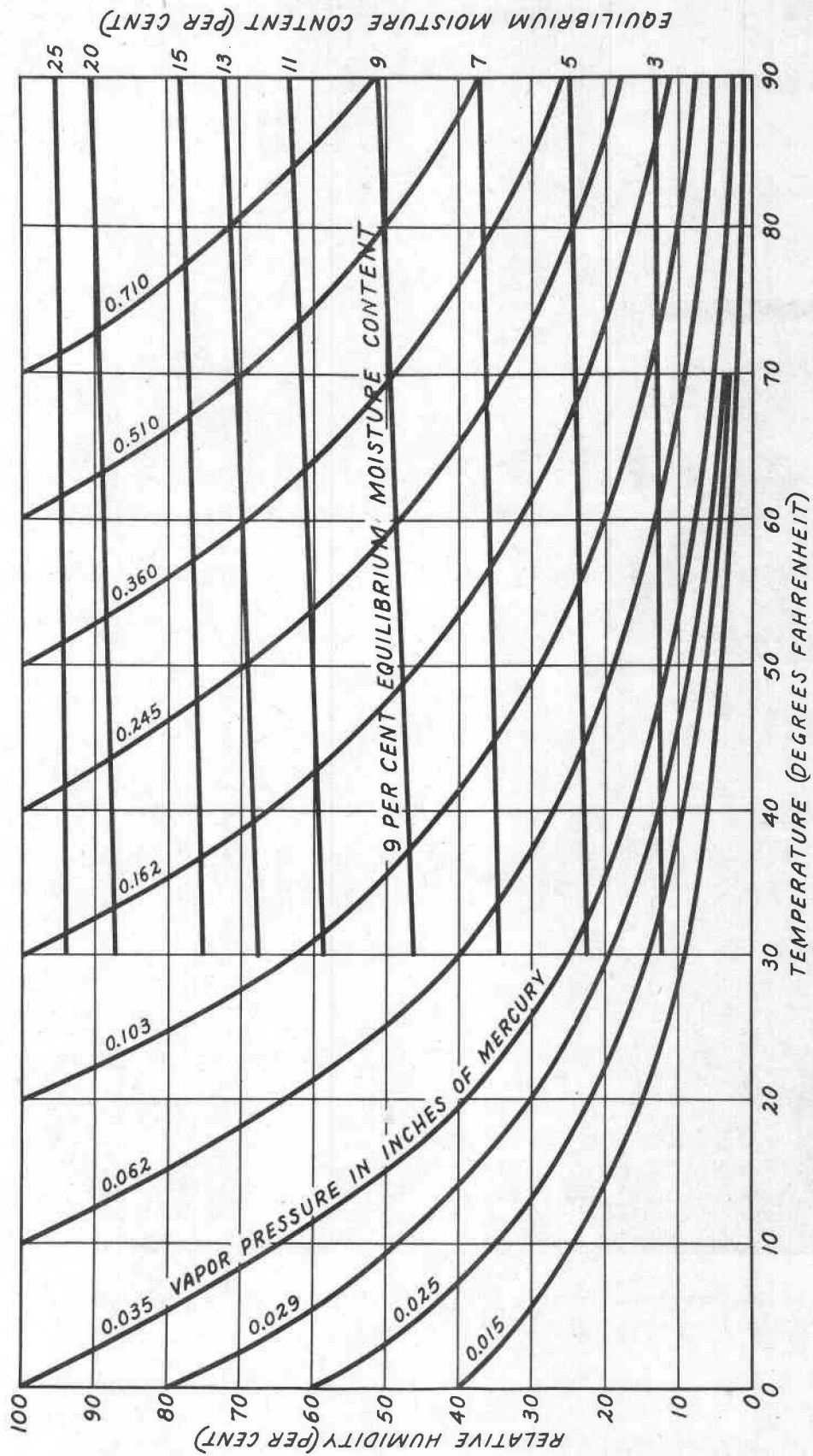


Figure 17.--Chart showing temperature, relative humidity, and equilibrium moisture content relationships. The vapor pressure lines represent the amount of moisture in the air.