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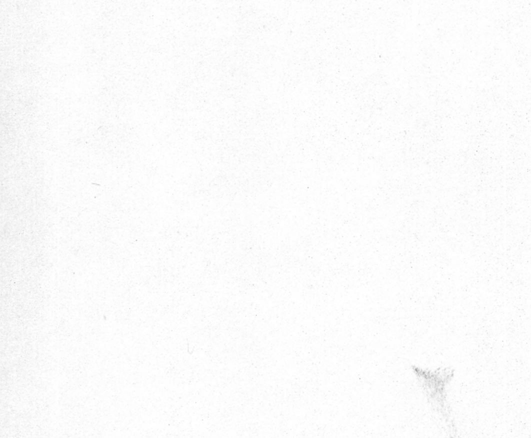

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

EFFECT OF RESIN TREATMENT AND COMPRESSION UPON THE PROPERTIES OF WOOD[1]

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Recent researches dealing with the modification of the properties of wood by resin treatment (1, 2) by compression (3, 4, 5) and by a combination of these two processing methods (6, 7, 8) have made possible the improvement of wood for many uses. In order to properly decide which of the processing methods should be used in preparing wood for a specific use, it is quite important to know which property changes are due to resin and which are due to the fact that the amount of wood substance per unit cross section is materially increased by compression.

Resin-Treated Wood

The chief object of resin treatment is to give the wood stability against swelling and shrinking. This is effectively accomplished only when the wood is treated with chemically active resin-forming constituents that penetrate the cell-wall structure and become bonded to the active groups in the wood upon formation of the resin (1, 2, 6). The authors have

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[1]This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Original report published 1942.

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

shown that the treatment of wood with virtually unpolymerized phenol-formaldehyde mixes that are soluble in water in all proportions, followed by drying and then curing of the resin, within the wood structure, minimizes swelling and shrinking most effectively and permanently of all the resin-forming systems and treatments tested (1, 2, 6). Treatment with appreciably prepolymerized resin systems or nonpolar resin-forming constituents results in resins mechanically deposited within the coarse capillary structure of the wood. Such materials block and hence retard the entrance and exit of moisture, but they in no way affect the equilibrium moisture sorption or equilibrium swelling.

Other property changes which may result from resin treatment are (a) reduction of moisture transfusion through the wood (2), (b) imparting of decay and acid resistance to the wood (2), (c) increase of the compressive strength of the wood (1) (see table 1), (d) fixing of water-soluble impregnants in the wood structure (2), (e) imparting a potential finish throughout the wood, after compression, that can be brought out by sanding and buffing (6), and (f) plasticizing the wood at elevated temperature prior to compression, thus making possible low-pressure compression of the wood (6).

The extent to which these objectives may be accomplished will depend largely upon the nature of the resin, its completeness of distribution throughout the wood, and its chemical bonding power to the wood constituents in a manner similar to the reduction of swelling and shrinking. A possible exception to this is the improvement of the compressive properties of wood. Table 1 shows the effect of forming phenol-formaldehyde resins within the cell-wall structure of wood upon several mechanical properties of the wood (1). The compressive strength both perpendicular and parallel to the grain and the hardness are the only properties tested that were appreciably improved. These properties could, however, be improved by merely depositing any hard solid material within the coarse capillary structure of the wood. A relatively expensive resin treatment of wood is hence not justifiable when only an improvement in the compressive mechanical properties is sought.

Compressed Wood

The strength properties of wood tend to increase with an increase in the specific gravity of the wood (9). It is thus natural to expect that compressed wood will have a greater strength than normal wood of the same dimensions, provided the decrease in strength due to rupture of the fiber walls is less than the increase due to compacting of the wood, or in case the fibers are again bonded by a glue or a slight flow of the lignin. Most of the strength tests on compressed wood have been made on laminated resin-bonded material in which the resin tends to rebond any ruptured fibers. Bernhard, Perry, and Stern (3) and Perry (4) have shown that Tego film bonded compressed plywood made from both birch and poplar plies of 1/48-inch thickness shows increased mechanical properties with an increase in the degree of compression. The tensile strength in the direction of the face plies and the compressive strength perpendicular to the ply faces increase in practically direct proportion to the specific gravity, whereas the shearing strength in a plane parallel to the direction of the application of the compression seems to increase somewhat more rapidly. They also showed that there is an increase in each of these mechanical properties with a decrease in the thickness of the plies used, and a subsequent increase in the amount of resin glue used. The strength is thus greatest under conditions such that a greater rebonding of crushed structure can occur.

In order to determine the effect of compression upon the strength of wood under conditions such that rebonding by glue is eliminated, tests were made on the shear strength of solid blocks of wood compressed under different conditions.

Table 2 gives these results for quarter-sawed Sitka spruce blocks originally 2.75 by 2.75 inches in cross section and at 6 to 8 percent moisture content. Some of the specimens were compressed radially and some tangentially under a pressure of 3,000 pounds per square inch. The blocks were arranged in the press so as to minimize lateral spread. Some of the blocks were pressed and held at room temperature; others were pressed at room temperature, followed by heating in the press with the platens at 300° F. until the temperature at the center of the block, as indicated by inserted thermocouples, had risen to 300° F.; and a third group of blocks was heated in the press, with the platens at 300° F., under a small load for 20 minutes at which time the temperature at the center of the block had risen to 115° F. before the compression load was applied. The smaller compression obtained when the wood was preheated than that obtained on subsequent heating is, undoubtedly, due to greater loss of moisture in the former case.

Shear parallel to the grain tests were made by the Forest Products Laboratory single shearing surface method (10) on specimens cut from the blocks. The data show that only the shear strength in a plane parallel to the direction of pressing is increased by compression. The shear strength is greater when the wood is compressed hot than when it is compressed cold. This may be due to softening of the wood by heat due to plasticization of lignin, to such an extent that less rupture of the fiber walls occurs, or it may be due to the lignin being sufficiently plastic at 300° F. to recement adjacent fractured structure. Under the most favorable of the three pressing conditions the shear strength in a plane at right angles to the direction of pressing is the same as that of the normal wood. The shear strength in a plane parallel to the direction of pressing is appreciably increased, but to a lesser extent than was the specific gravity. Bernhard, Perry, and Stern evidently obtained greater increases in shear strength due to compression because of the use of a resin glue which itself has greater shear strength than wood and because of a more complete rebonding of ruptured structure with the resin than is caused by heat alone.

Compressed wood is subject to an increase in swelling due to the increased specific gravity and a recovery from compression. In other publications the authors have shown that wood compressed at a high temperature (300° to 360° F.) and moisture contents of 6 to 25 percent (on the basis of the dry weight of the wood) tends to retain its compression after being subjected to alternate swelling and shrinking conditions (5, 11). Resin-bonded, laminated, compressed wood may swell and lose its compression more slowly than ordinary compressed wood, but the final equilibrium conditions are not changed by the bonding resin.

Resin-Treated, Compressed Wood

The limited published (3, 4, 6, 7, 8) and unpublished data on the mechanical properties of so-called resin-treated, compressed wood indicate that the quantity of resin present and its distribution in the structure have a small effect upon most of the mechanical properties, with the exception of impact strength which decreases appreciably with an increase in resin content (see Report No. 1386). There seems, however, to be a slight tendency for an increased resin content to decrease the tensile and flexural properties and increase the compressive properties. The condition of cure of the resin likewise seems to have but little effect upon the strength properties.

Further confirmation of this generalization is given by the following data. A series of panels were made up from 1/16-inch birch veneer plies that were treated with a 50 percent aqueous solution of Bakelite Resinoid XR5995 by the cylinder treating method so as to give a potential resin content of 30 percent of the weight of the wood. The plies were then held for 48 hours under nondrying conditions to allow the resin-forming constituents to become uniformly distributed by diffusion throughout the structure, followed by kiln drying at 170° F. for 5 hours at a relative humidity of 45 percent (wet-bulb temperature 140° F.), giving a moisture content of 6 percent. Panels were then pressed up from 17 parallel laminated plies at 1,000 pounds per square inch pressure and different temperatures and times. The curing times given in figures 1 to 6 are the times during which the centers of the panels were held at the pressing temperature. It took 10 to 15 minutes to attain this temperature and about 5 minutes to cool the panels to 200° F. at the center subsequent to curing before the pressure was released. This cooling was necessary to prevent immediate springback of panels pressed under incomplete curing conditions. It further gives improved surfaces on all panels.

Modulus of rupture, modulus of elasticity in bending, and shear in a plane parallel to the direction of compression measurements were made on each of the panels by the Forest Products Laboratory methods. Measurements were also made on the sorption of water or water vapor and the combined swelling and springback in the direction of compression on 1-inch-long sections in the fiber direction, both on water immersion and exposure to 97 percent relative humidity. The data are plotted in figures 1 to 6 against the temperature of curing for three different times of cure. Three measurements of the mechanical properties were made for each of the conditions of cure. In order to plot all the points and thus show the possible experimental error, the time values for each group of points were spread out. The 5-minute curing time points were displaced to a 2° F. lower temperature and the 45-minute curing time points were displaced to a 2° F. higher temperature than the true values.

Figures 1 and 2 indicate that the modulus of rupture in bending and the modulus of elasticity are practically independent of the curing temperature and curing time, with the possible exception of the values at the lower temperature of 235° F. The same generalization holds for the shear values which have not been plotted. Greater deviations between matched specimens occurred, however. The moisture sorption and combined swelling and springback, on the other hand, are highly dependent upon the curing conditions. The specimens cured at 235° F. all give a moisture sorption and combination of swelling and springback that would be expected for untreated controls, indicating that the resin-forming constituents did not polymerize appreciably at this temperature even in 45 minutes. Some reduction in the sorption of water and swelling occurred at 260° F. for the longer curing times. At 285° F. the reduction in water sorption and swelling was practically complete except in the case of the shortest curing time. The data indicate that curing of the resin occurs in the range of 260° to 310° F. for the times used and that curing is complete even in 5 minutes at higher temperatures. It is of interest that the moisture adsorbed at 97 percent relative humidity is considerably less than the combined swelling and springback under the incomplete cure conditions (figs. 5 and 6), thus indicating that a large part of the dimension change is due to springback in this range. In the complete cure range the moisture adsorption and swelling are practically identical, indicating the absence of springback.

The data indicate that the mechanical properties are practically independent of whether the resin-forming constituents in the wood have been converted to a resin, whereas the sorption and swelling properties are highly dependent on the setting of the resin-forming constituents within the cell-wall structure.

The mechanical properties of resin-treated compressed wood considered, with perhaps the exception of the shear values, seem to be independent of the resin and depend more upon the degree of compression of the wood. The prime purpose of the resin treatment is thus to give the wood stability. If resin treatments are resorted to, they should thus be of the type that will insure the maximum and most permanent stability (6).

Summary

The effects of resin treatment, compression, and a combination of resin treatment and compression upon the properties of wood are discussed.

Synthetic resins may increase the water, decay, and acid resistance of wood, fix impregnants in the wood, improve the finish of wood, plasticize the wood prior to setting of the resin, and improve the compressive strength of wood. With the exception of the compressive strength, these properties are largely dependent upon the use of resin-forming constituents that will penetrate the cell-wall structure and bond to this structure.

The tensile, compressive, and shear strengths parallel to the grain and modulus of rupture and modulus of elasticity in bending, with the exception of shearing in a plane at right angles to the direction of compression, are increased by compressing the wood. The improvement in properties, in general, varies as the specific gravity of the wood. This seems to be true regardless of whether the compressed wood is resin treated or not. The chief object of the resin in resin-treated compressed wood is to give the wood stability.

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Table 1. --Effect of phenol-formaldehyde resins on mechanical properties of wood[1]

Species	Resin content of wood	Hardness (Side)	Compression perpendicular to grain, fiber stress proportional limit	Compression parallel to grain, maximum crushing strength	Static modulus rupture	Bending modulus of elasticity	Toughness
	Weight percent						
Sugar maple	23	42	68	18	2	8	0
(Sapwood)		(35)	(45)	(17)	(0)	(4)	(-7)
Sugar pine	48	85	52	23	3	7	8
(Heartwood)		(84)	(56)	(27)	(5)	(4)	(14)

[1] In terms of the percentage increase over the values for the controls. The data represent the average values for two treated specimens, two untreated controls, and two controls that were subjected to the same heat treatment as the treated specimens cut from each of five different planks. The first values are referred to the untreated controls and the values in parentheses to the heated controls. All values are corrected to the moisture content of the untreated controls (about 6 percent moisture content).

Table 2.--Shear tests on air-dry blocks of Sitka spruce compressed under a pressure of 3,000 pounds per square inch

Load applied	Temperature of wood: During pressing	Temperature of wood: After load is applied	Specific gravity ratio, After pressing / Before pressing	Tangential shearing strength[1]	Tangential shearing strength[1]: After compression / Before compression	Radial shearing strength	Radial shearing strength: After compression / Before compression
	°F.	°F.		Lbs. per sq. in.		Lbs. per sq. in.	
None	......	......	1.0	1,472	1.00	1,275	1.00
Tangential face	70	70	[2]2.34	1,158	.78	2,505	1.96
Do.	70	[3]300	3.54	1,242	.84	2,702	2.12
Do.	[4]300	300	3.27	1,403	.95	3,031	2.38
Radial face	70	300	3.54	1,804	1.23	898	.70
Do.	300	300	3.27	2,256	1.53	1,338	1.05

[1] Each of the shearing strength values are averages of two determinations.

[2] Compressed to 2.75, sprung back to 2.34 after removing from press.

[3] 80 percent of compression obtained at room temperature in 15 minutes. The remaining compression obtained as temperature built up to 300° F. at center of wood during the following hour.

[4] Platens brought to 300° F., center of wood 115° F., with wood under small pressure of 260 pounds per square inch in 20 minutes. Pressure applied over following 40 minutes at which time the temperature at the center of the wood rose to 300° F.

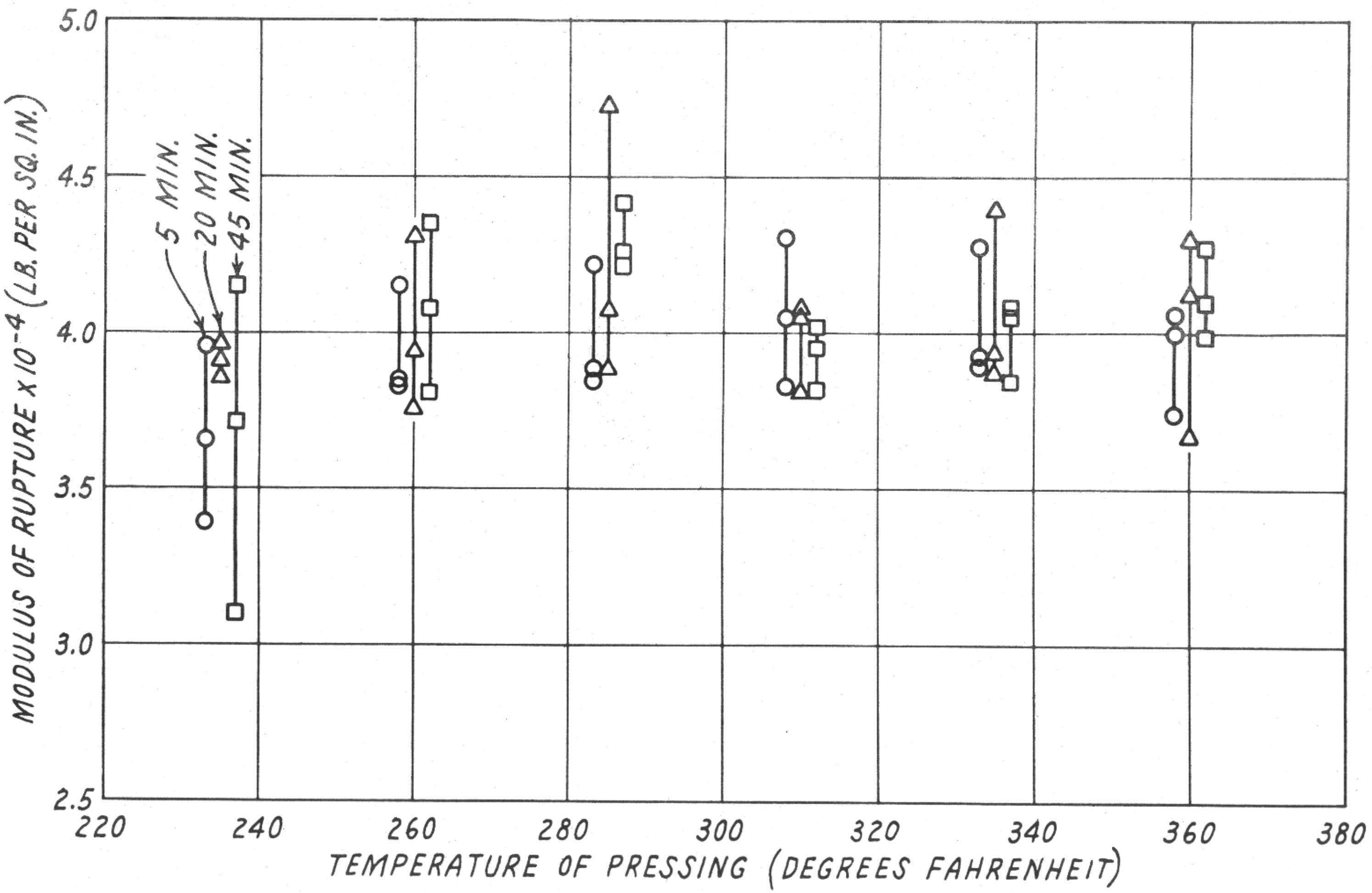

Figure 1.--Relationship between the modulus of rupture of laminated, resin-treated, compressed birch, and the temperature and time of cure. Temperature of cure values are displaced -2° F. for 5-minute cures and +2° F. for 45-minute cures. Times represent the period that the center of the wood is held at the designated temperature.

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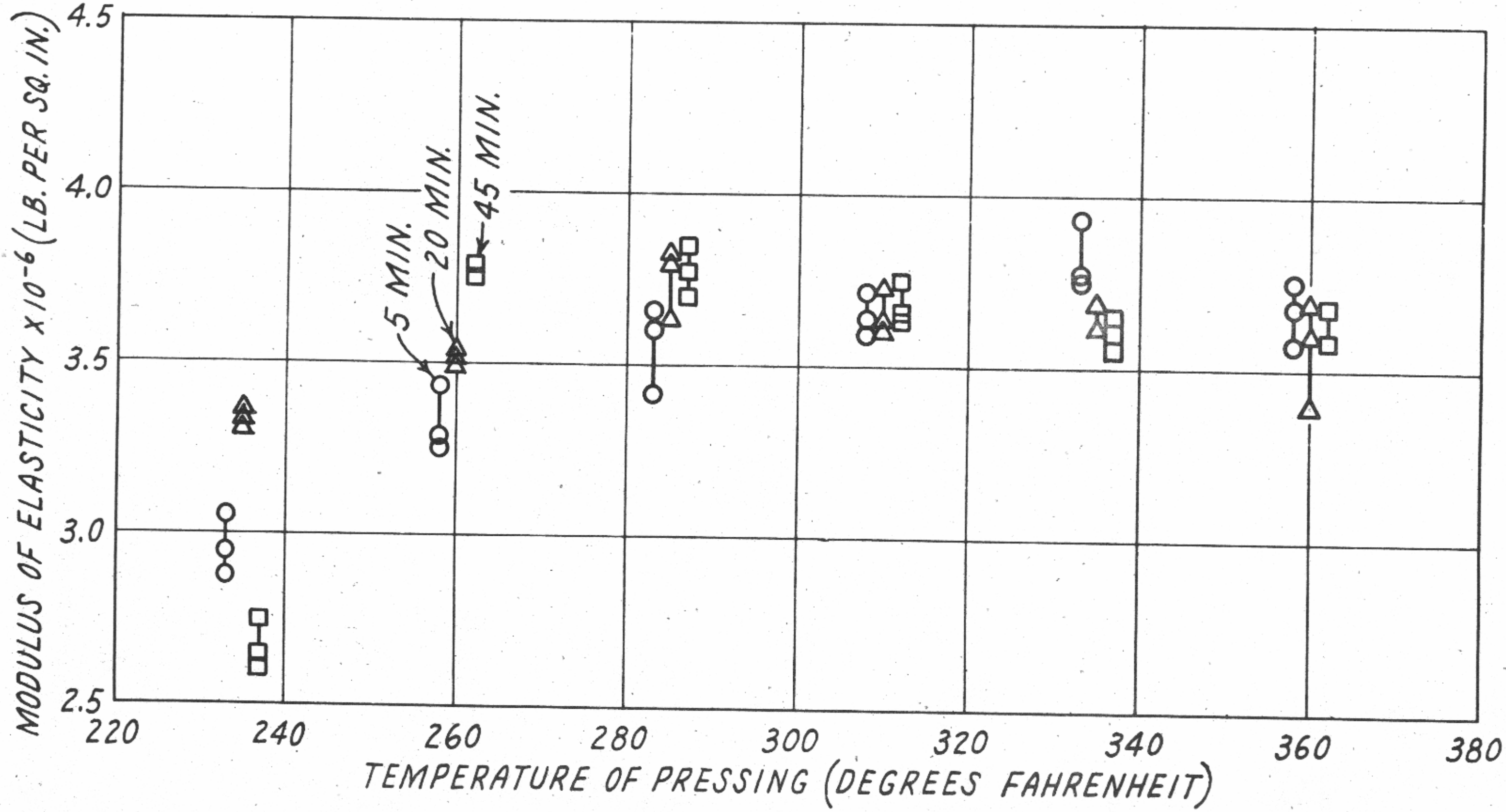

Figure 2.--Relationship between the modulus of elasticity of laminated, resin-treated, compressed birch, and temperature and time of cure. Temperature of cure values are displaced -2° F. for 5-minute cures and +2° F. for 45-minute cures. Times represent the period that the center of the wood is held at the designated temperature.

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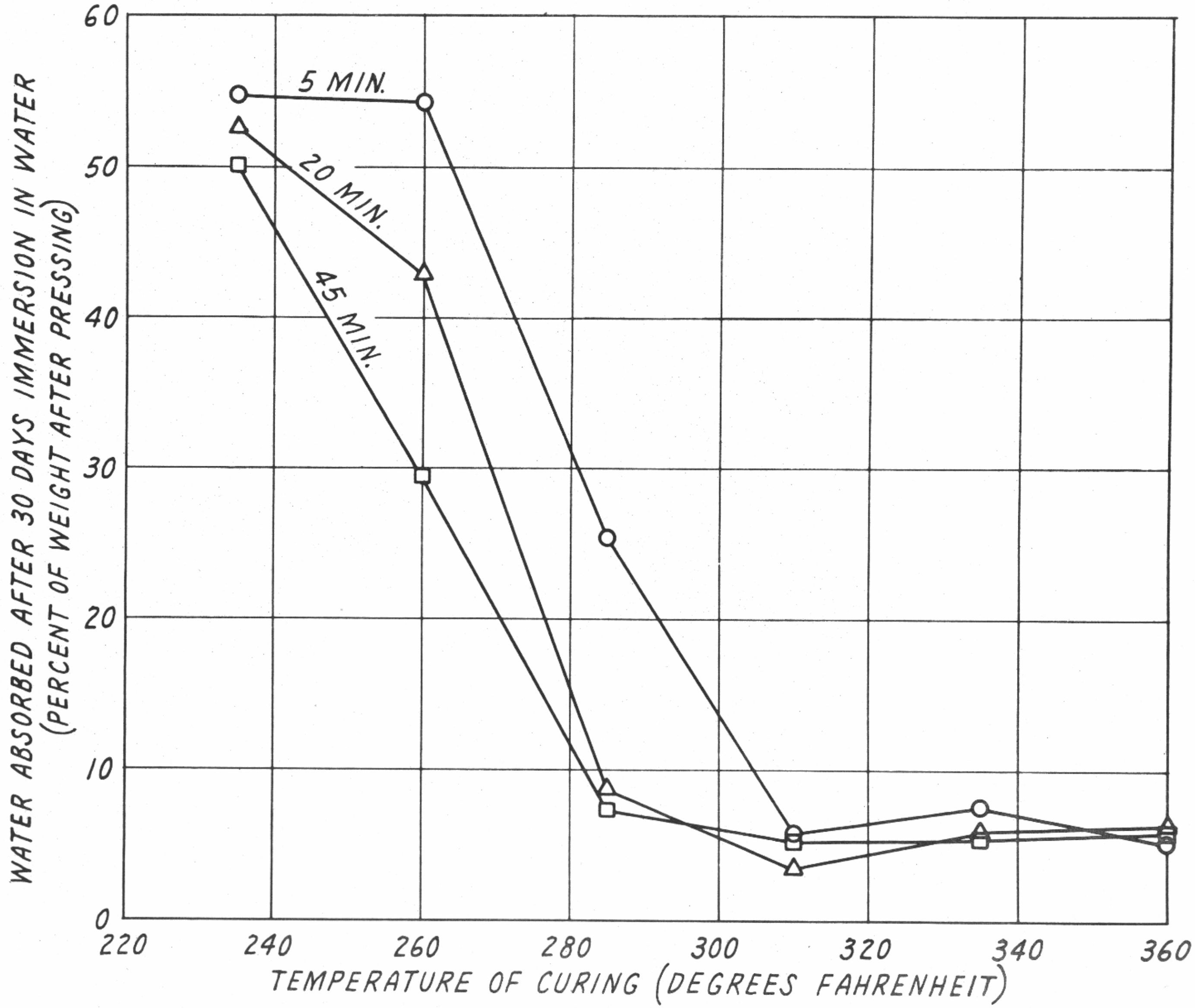

Figure 3.--Relationship between the moisture absorption by laminated, resin-treated compressed birch when immersed in water, and the temperature and time of cure. Times represent the period that the center of the wood is held at the designated temperature.

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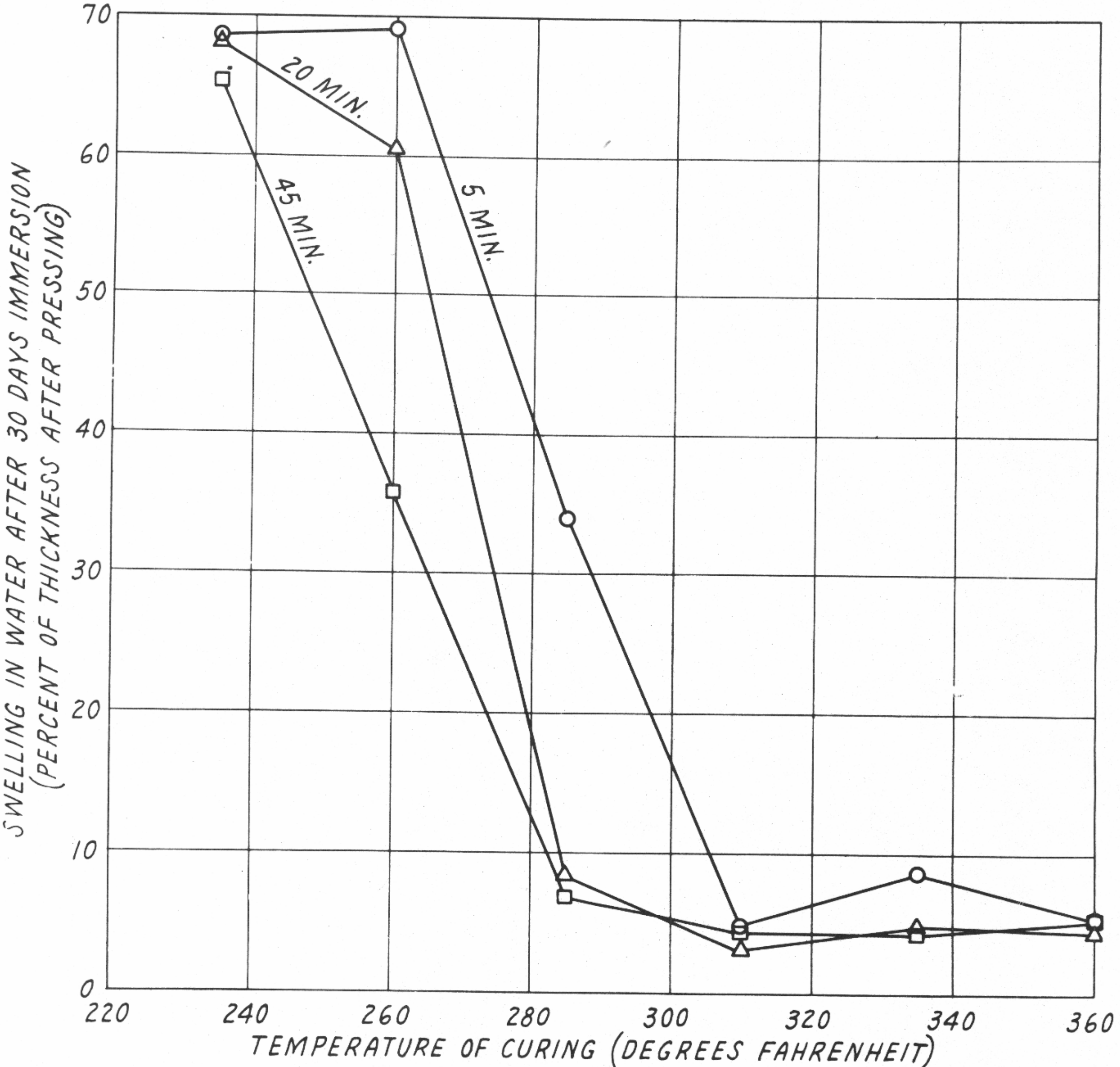

Figure 4.--Relationship between the combined swelling and springback of laminated, resin-treated, compressed birch in the direction of compression when immersed in water, and the temperature and time of cure. Times represent the period that the center of the wood is held at the designated temperature.

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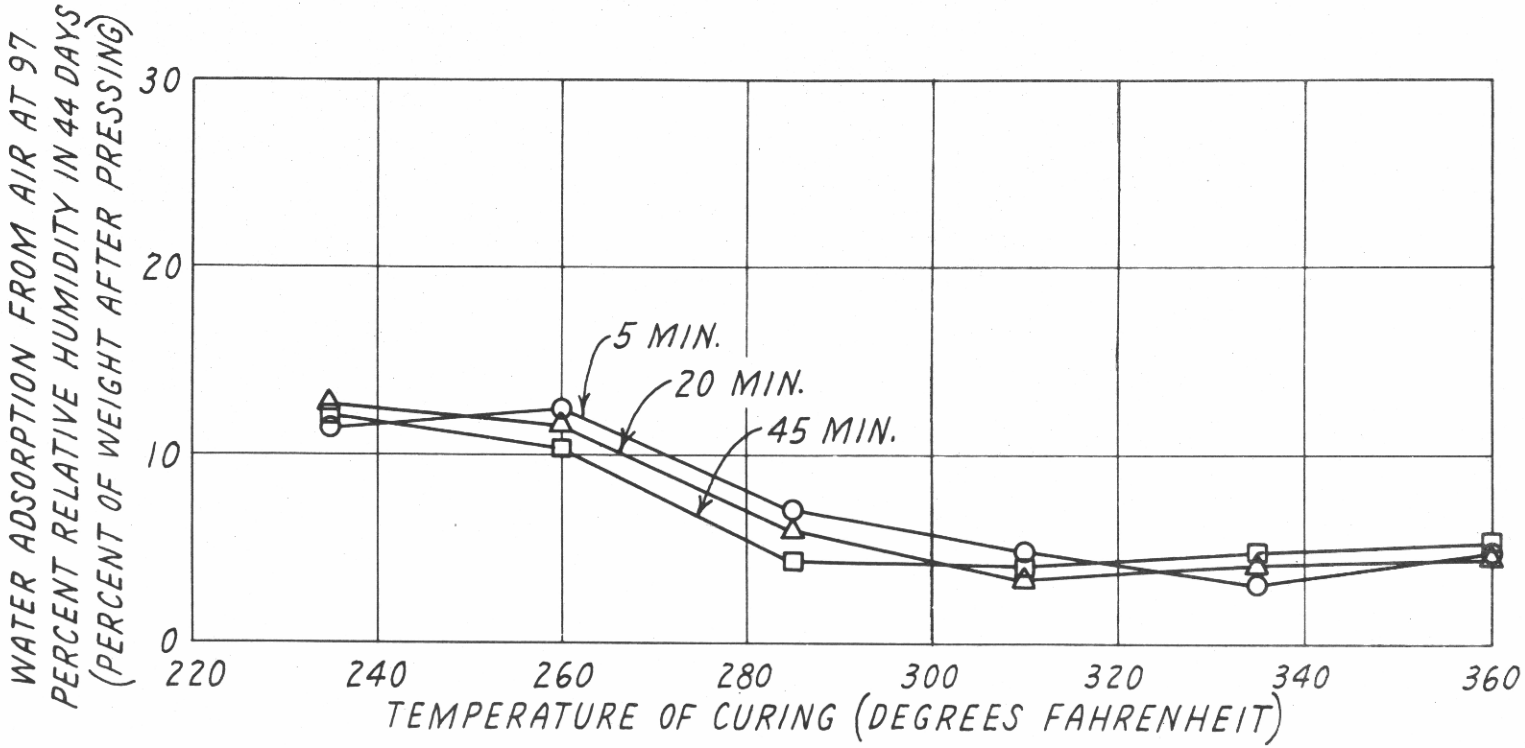

Figure 5.--Relationship between the moisture adsorption by laminated, resin-treated, compressed birch when subjected to a relative humidity of 97 percent and the temperature and time of cure. Times represent the period that the center of the wood is held at the designated temperature.

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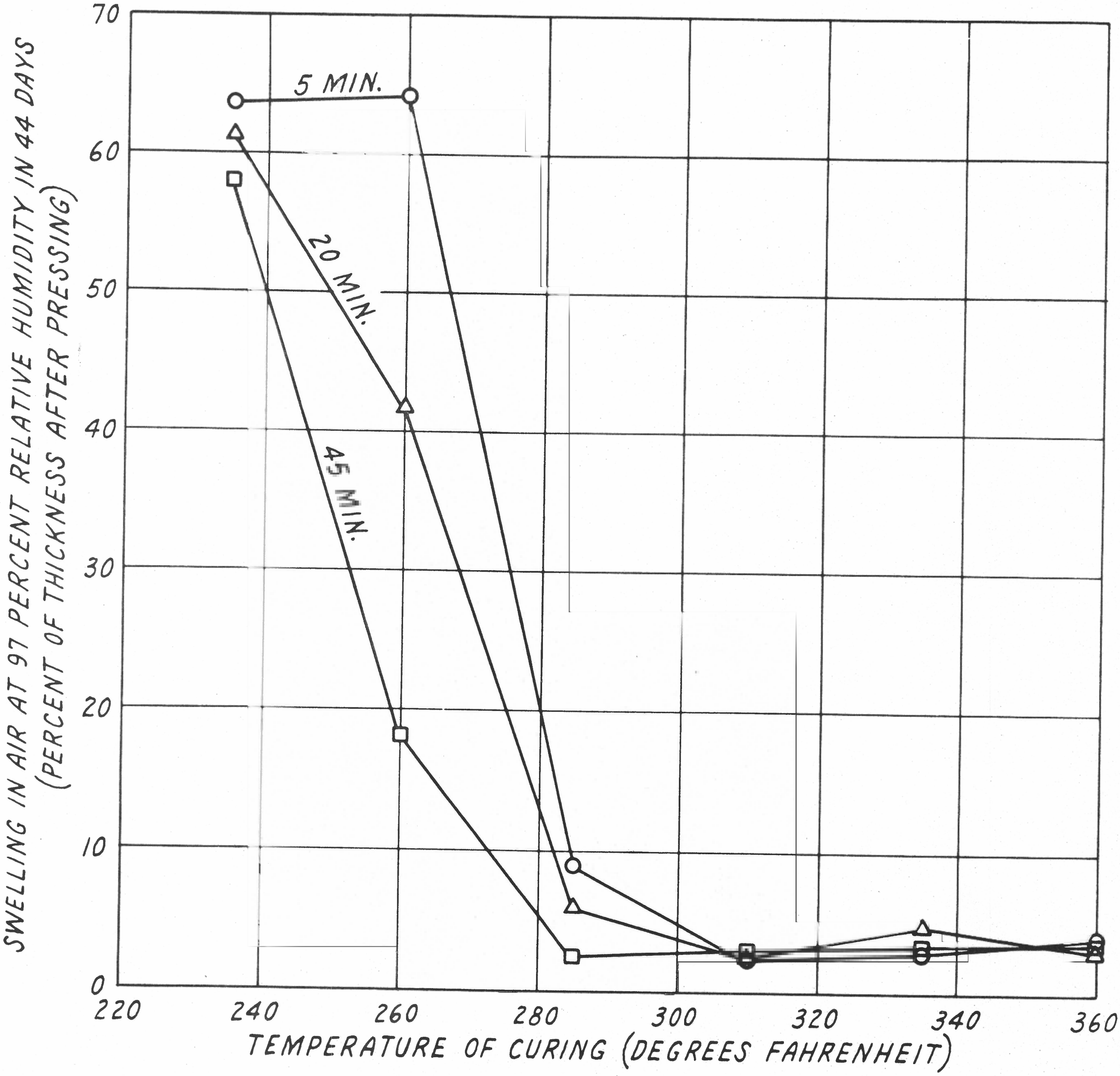

Figure 6.--Relationship between the combined swelling and springback of laminated, resin-treated, compressed birch in the direction of compression when subjected to a relative humidity of 97 percent and the temperature and time of cure. Times represent the period that the center of the wood is held at the designated temperature.

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