HEAT STABILIZED WOOD

(Staybwood)

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HEAT-STABILIZED WOOD (STAYBWOOD)[1, 2]

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Introduction

Heating wood under drying conditions at higher temperatures or for longer periods of time than are normally encountered in kiln drying has been shown to reduce appreciably the hygroscopicity and subsequent swelling and shrinking[4] (3, 4, 6, 7, 9).

Experiments in which the specimens were heated in bombs containing different gases indicate that the nature of the gas has only a minor

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[1] An up-to-date version of an article published in Industrial and Engineering Chemistry, June 1946.

[2] Staybwood is uncompressed wood that has been dimensionally stabilized by heat alone. It differs from staypak (7) in that the hygroscopicity of the wood is reduced. The wood is not compressed.

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

[4] Numbers in parentheses indicate literature cited and refer to the listing at the end of the paper.

effect upon the resulting hygroscopicity, an oxidizing atmosphere being only slightly more effective than a reducing atmosphere.

Previous data also show that the effect of heat upon the hygroscopicity of wood is permanent (6, 9). After an initial humidification-dehumidification cycle or soaking-drying cycle subsequent to heating, no gain in hygroscopicity occurs within the time or number of cycles tested. The phenomenon thus cannot be explained on the basis of a hysteresis effect.

Heating in Molten Metal

It seemed desirable to extend heating measurements over a much broader range of heating temperatures and times to analyze the nature of the phenomenon better and to determine the practicability of such a process for commercially stabilizing the dimensions of wood. To minimize oxidation and its effect on strength and to make possible rapid heat transfer so as to avoid making corrections for the length of time required to attain the desired temperature in high temperature-short time combinations, a method of heating wood beneath the surface of molten metal was adopted (6). A lead-tin-cadmium alloy (approximately 50 percent tin, 30 percent lead, and 20 percent cadmium) with a melting point of about 150° C. (302° F.) was used. This alloy had but little tendency to stick to the specimens when they were removed from the bath except when used at temperatures only slightly above its melting point. Any small amount of adhering metal was readily scraped off with a steel spatula. In later work, Wood's metal was tried in order to determine if it could be used at lower temperatures. This metal tended to stick to the wood sections and hence its use was abandoned.

The experiments with western white pine were made by heating the wood in an iron pan, under a steel weight with an insulated handle for holding the specimens immersed. The pan was heated with two Bunsen burners.

The bath, with the weight immersed, was heated to about 2° C. (3.6° F.) above the desired temperature for temperatures below 270° C. (518° F.). The weight was rapidly lifted, the specimens were placed on the molten-metal surface, and the weight placed on them to immerse them in the molten metal. The wood specimens cooled the bath by about 2° C. (3.6° F.), thus minimizing the necessary manual adjustment of the burners. When the heating temperature was above 270° C. (518° F.) the exothermic reaction was sufficiently great so that one of the burners could be removed, slightly before or at the time the specimens were put into the bath, and not replaced for a period of 2 to 5 minutes. This agrees with the findings of Kobe and Goin (2) who found 273° C. (523° F.) to be the temperature at which exothermic decomposition of wood becomes appreciable.

The temperature control by this manual method was accurate to only 2° to 5° C. (3.6° to 9.0° F.). It was not suitable for long-period heating. For this reason the heating of the Sitka spruce veneer specimens and the larger eastern white pine specimens was conducted in an electrically heated bomb with an automatic temperature control. The bomb lid was designed to hold the specimens immersed. The molten metal could not be used for heating at temperatures below 175° C. (347° F.). Because of this, the veneer specimens were heated at 125° and 150° C. (257° and 302° F.) in sand with dry nitrogen slowly circulating through the sand to prevent oxidation. Veneer specimens were also heated in an electrically heated oven at 125°, 150°, and 175° C. (257°, 302°, and 347° F.) to determine the extent to which oxidation affects the results.

Hygroscopicity and Dimensional Stability

The heated specimens, when removed from the heating medium, were cooled in a desiccator, scraped free of any adhering metal, weighed, and measured. They were then subjected to relative-humidity cycles in which they were successively brought to equilibrium with 90 percent and 30 percent relative humidity in rooms held at 26.7° C. (80° F.), together with matched unheated controls that were oven-dried to determine the oven-dry weight at the conclusion of the measurements.

The western white pine cross section specimens were all cut from a single flat-sawn board 1 inch thick and 4-3/8 inches wide into pieces one-half inch in the fiber direction. Every seventh specimen was used as a control. The flat-sawn western white pine specimens were also cut from a single flat-sawn board 13/32 inch thick into strips 1-1/4 inches wide in the tangential direction. The strips were cut into 6-inch lengths. All the specimens heated at a given temperature, together with two controls taken from the two ends, were cut from a single stick, thus assuring optimum matching. The rotary-cut 1/16-inch Sitka spruce veneer specimens were 5-7/8 inches long and 1 inch wide. They were similarly matched except that specimens Nos. 1, 6, 11, and 16, all cut from a single 1-inch-wide strip, were used as controls. The eastern white pine specimens were cut into 6-inch lengths from a single stick 2 inches wide by 15/16 inch thick. The two end specimens were used as controls.

The specimens were put through three complete relative-humidity cycles of 90 percent to 30 percent to 90 percent, with the exception of the eastern white pine, allowing sufficient time under each condition (about 2 weeks) to come to moisture equilibrium. The percentage reduction in hygroscopicity and the percentage increase in the dimensional stability (antishrink efficiency) was calculated for each half cycle of 90 to 30 percent and 30 to 90 percent relative humidity. The percentage reduction in hygroscopicity is equal to 100 times the difference between the weight change of the control and the relative weight change of the heated specimen divided by the weight change of the control. The percentage increase in the dimensional stability is equal to 100 times the difference between the dimension change of the control and the relative dimension change of the heated specimen divided by the dimension change of the control. The percentage reduction in hygroscopicity and the antishrink efficiency are practically equal under the experimental conditions of this research. In view of this equality and inasmuch as the accuracy of weighing is greater than that of measuring, the values recorded in this paper are actually the reduction in hygroscopicity as found by weighing except in the case of the eastern white pine. In this case dimension changes between the water-soaked and the oven-dry condition were measured.

Figure 1 gives the average antishrink efficiencies for the complete second and third cycles plotted against the heating temperature for several different times of heating obtained on the western white pine cross sections. Figures 2 and 3 give similar data for the flat-sawn western white pine and the rotary-cut Sitka spruce veneer, respectively. Figure 4 gives the antishrink efficiency values from a water-soaked to an oven-dry condition for the specimens of eastern white pine. These measurements were made on 1/8-inch-thick cross sections cut from the ends of the larger specimens. An approximately linear relationship exists between the antishrink efficiency and the temperature for each time of heating, the lines becoming slightly steeper with increasing time.

Wood when heated at temperatures and for periods sufficient to give an appreciable antishrink efficiency is materially darkened. The lightcolored softwoods used in these experiments darkened to about the color of walnut.

The minimum heating times used in these experiments, 15 minutes for the 1/2-inch and 13/32-inch-thick western white pine and 1 minute for the 1/16-inch-thick Sitka spruce veneer, have been theoretically shown to be such that the center of the wood rises in temperature at least 95 percent of the temperature rise at the surface in a fraction of the total time. Practically uniform antishrink efficiencies should hence result throughout the thickness of the wood, even in these short heating times.

Figure 5 shows the data of figures 1 to 4 plotted as the logarithm of the heating time against the heating temperature necessary to obtain three different antishrink efficiencies. The slope of the lines is such that the reaction rate practically doubles for each rise in temperature of 10° C. (18° F.).

Figure 6 shows the relationship between the antishrink efficiency and the loss in weight caused by heating, for the data of figure 3. The loss in weight per unit antishrink efficiency obtained is greater when the wood is heated in air than in the molten metal. Evidently a greater degree of oxidation occurs in air; this contributes less to the antishrink efficiency than the other degradative reactions.

Figure 7 gives the relationship between the toughness and the antishrink efficiency of the flat-sawn western white pine specimens in equilibrium with 30 percent relative humidity. The measurements were made on the Forest Products Laboratory toughness machine (1), using a 4-inch span. The toughness values are for the actual cross section of the specimens corrected, for the slight variation in thickness and width, to an area of 0.53 square inch by considering the toughness directly proportional to the cross-sectional area. As was expected, the toughness of the wood was appreciably decreased by the heat treatment. The reduction in toughness of wood on heating is not attributable to the reduced moisture content at test which results from the reduced hygroscopicity of the wood. The variation in toughness of wood with changes in moisture content is small compared to the loss in toughness obtained on heating. The loss in toughness must thus be due to an embrittlement of the fiber itself.

Figure 8 shows the relationship between the face hardness and the antishrink efficiency of the eastern white pine specimens as determined by the Forest Products Laboratory method in which the load required to embed a 0.444-inch diameter ball one-half its diameter is measured.

The specimens were preconditioned at 65 percent relative humidity. The hardness is reduced significantly at the higher degrees of heating, but not so much as the toughness.

Figure 9 shows the relationship between the antishrink efficiency of the spruce veneer and the modulus of rupture in equilibrium with 30 percent relative humidity. The measurements were made on a cantilever beam stiffness tester. The veneer heated in the molten metal showed a much smaller decrease in modulus with increase in antishrink efficiency than did the veneer heated in air.

The modulus of elasticity is also decreased by the heating process, but to an appreciably lesser degree than the modulus of rupture. Heating in air again causes a greater loss in strength than when heating is done beneath the surface of molten metal. It is thus of considerable importance to heat wood in the absence of air in any commercial operation aimed at stabilizing wood for uses in which moderate strength is important.

A few preliminary pure-culture decay tests were made on the flat-sawn western pine specimens. Both the heated specimens and controls were cut into 2-inch lengths, oven-dried, weighed, and placed in jars containing a good growth of the wood-destroying fungus, Trametes serialis. The jars were held under favorable growth conditions for 2 months. The fungus grew over the surface of all the specimens. This growth was carefully removed and the specimens were again oven-dried and weighed. The controls sustained an average weight loss of 28. 4 percent. Heated specimens with antishrink efficiencies of 30 to 33 percent gave an average weight loss of 12. 5 percent. Specimens with antishrink efficiencies of 33 to 38 percent gave weight losses of 0 to 4. 5 percent. All the specimens with antishrink efficiencies of 40 percent or more gave no weight loss.

Decay resistance produced by heating the wood is similar to that resulting from resin treatment in that the resistance results largely from the inertness of the material rather than to the presence of a toxic ingredient. The decay resistance in both is presumably due to either or both the reduced hygroscopicity whereby sufficient water is prevented from entering the cell-wall structure to support decay, or to a chemical change occurring within the wood that made it no longer susceptible to fungus attack (7).

Abrasion resistance tests have been made on specimens heated so as to attain an antishrink efficiency of 30 to 40 percent. The abrasion resistance was found to be only one-third of that of the unheated controls. The seriousness of this reduction can be best appreciated from the fact that fibers can be pulled from the surface of a specimen. This indicates that the fiber bond is greatly reduced by the heat treatment.

Conclusions

An appreciable degree of dimensional stabilization and decay resistance can be imparted to wood by dry heat. This can be accomplished over a broad range of temperatures and times, the time of heating decreasing rapidly with an increase in temperature.

This heat treatment causes a serious loss in strength properties, especially toughness and abrasion resistance. When the wood is heated beneath the surface of a molten metal the strength loss for any antishrink efficiency is less than when heated in air. The strength loss is still too great to make this a commercially applicable method for obtaining dimensional stabilization of wood, except perhaps for some abnormal use where strength is of relatively little importance.

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*Available from the U. S. Forest Products Laboratory, Madison 5, Wisconsin.

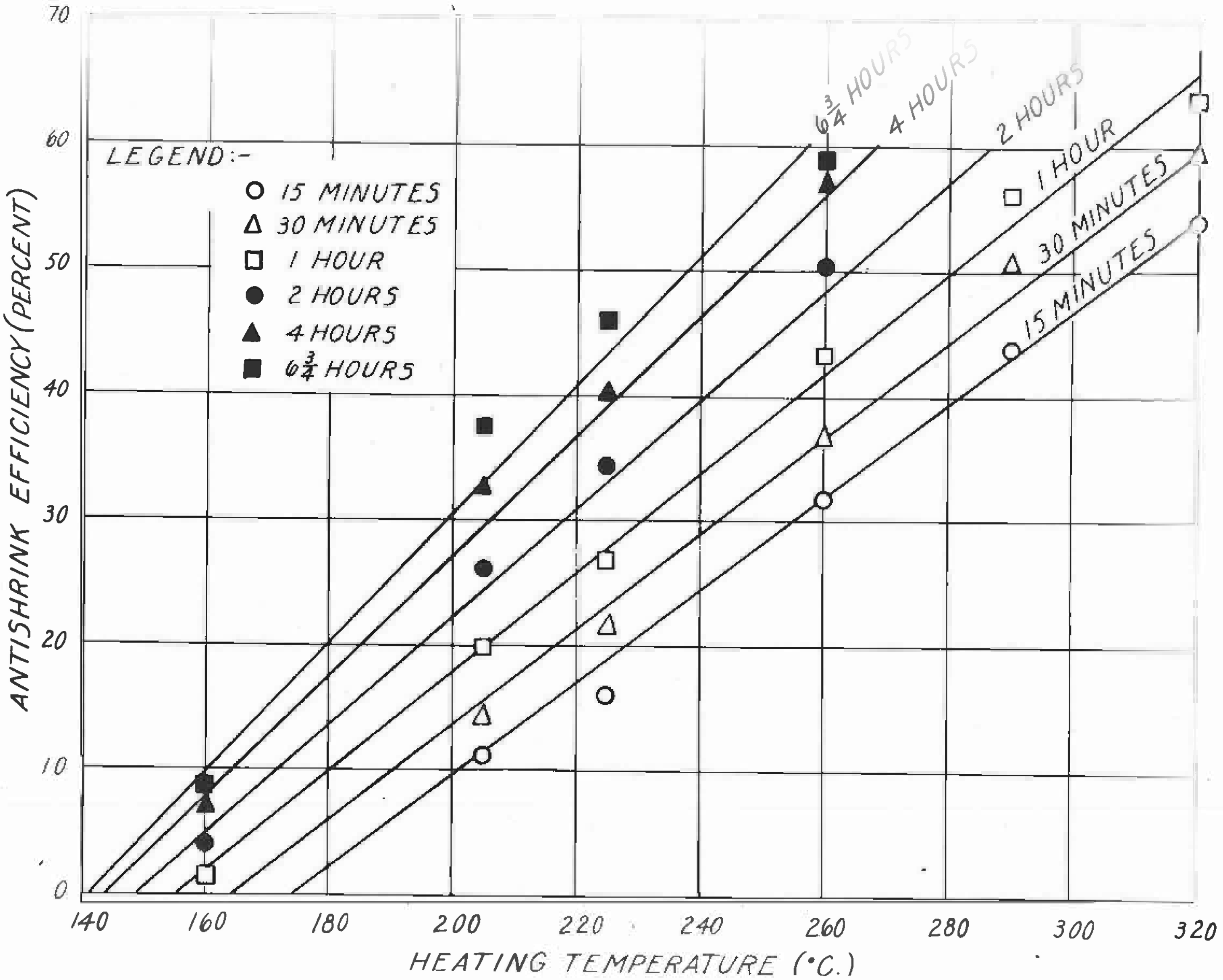

Figure 1.--Antishrink efficiencies obtained by heating Western white pine cross sections one-half inch thick in the fiber direction under molten metal at different temperatures for different periods of time.

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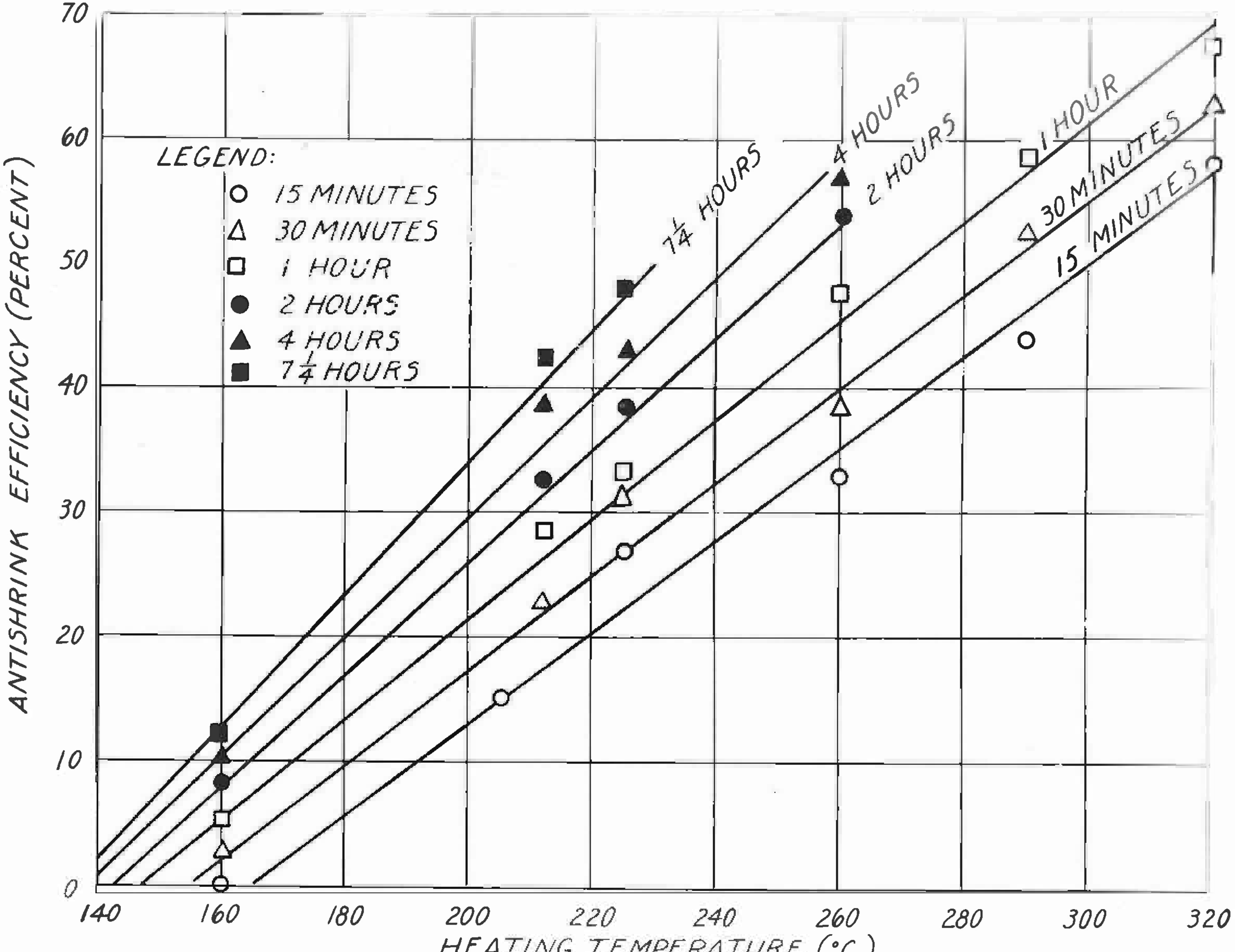

Figure 2.--Antishrink efficiencies obtained by heating flat-sawn Western white pine specimens thirteen-sixteenths inch thick under molten metal at different temperatures for different periods of time.

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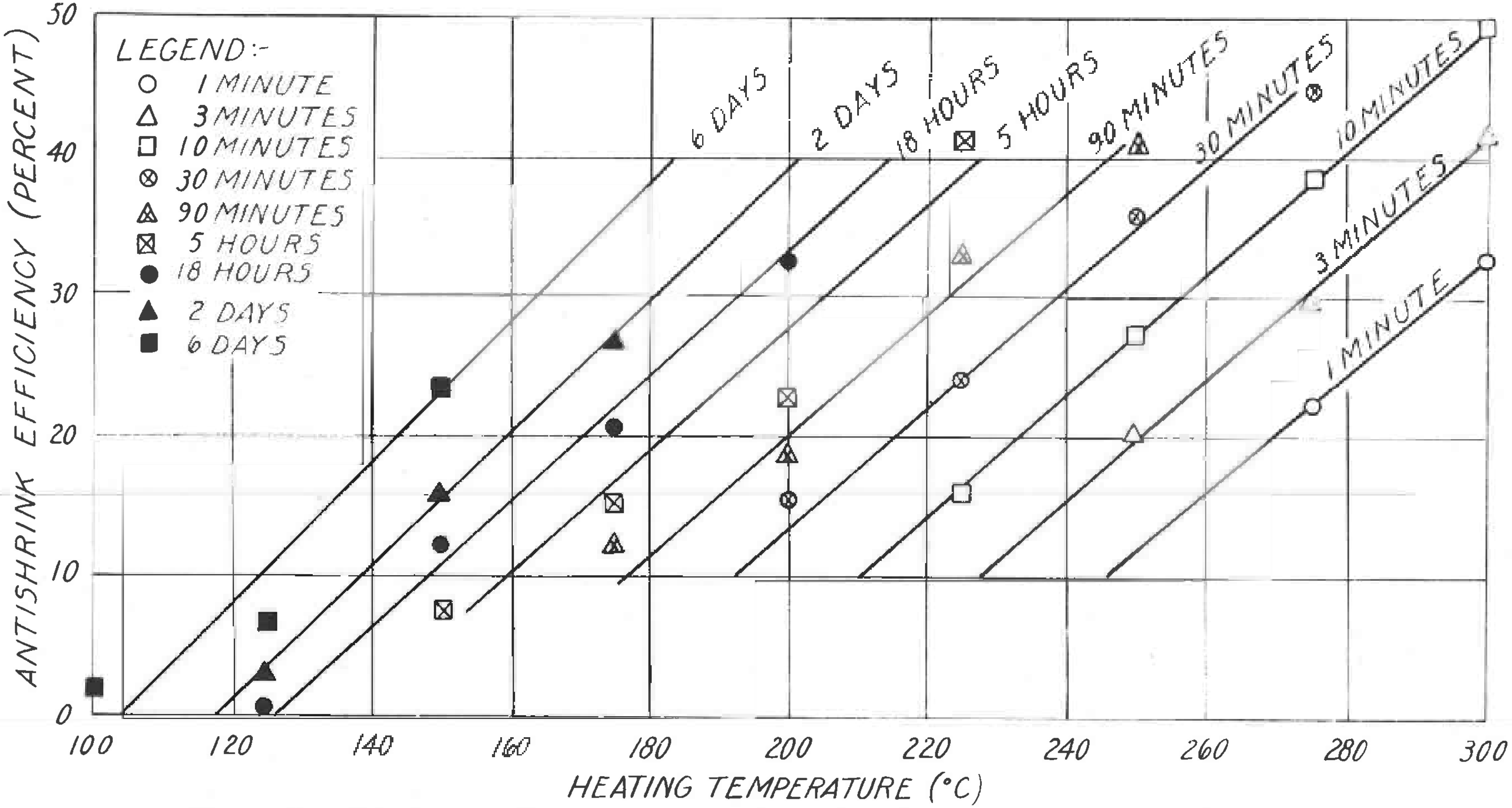

Figure 3.--Antishrink efficiencies obtained by heating 1/18-inch-thick Sitka spruce rotary-cut veneer under molten metal at different temperatures for different periods of time.

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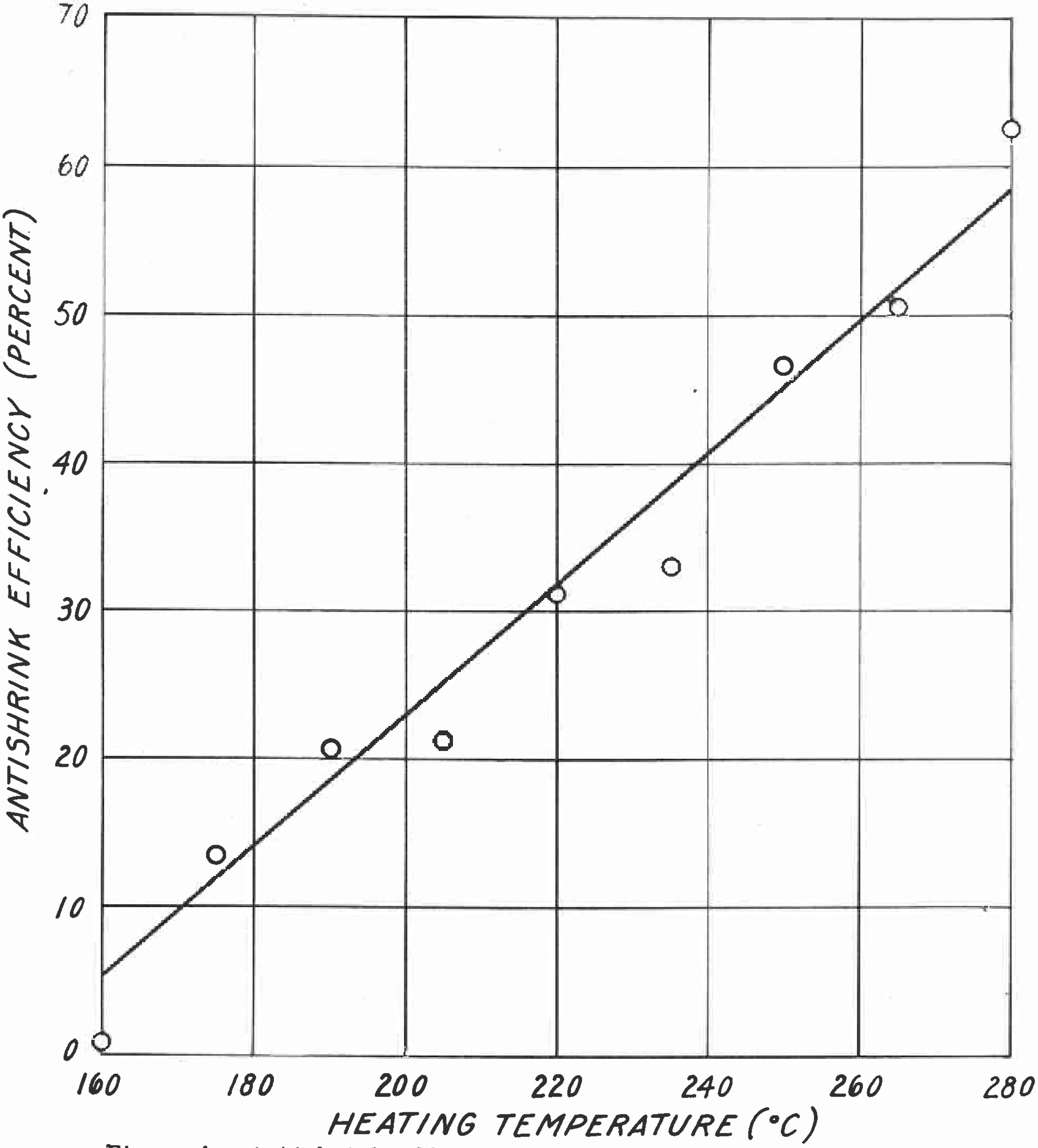

Figure 4.--Antishrink efficiencies obtained by heating Eastern white pine specimens 6 by 2 by 15/16 inches under molten metal at different temperatures for 2 hours.

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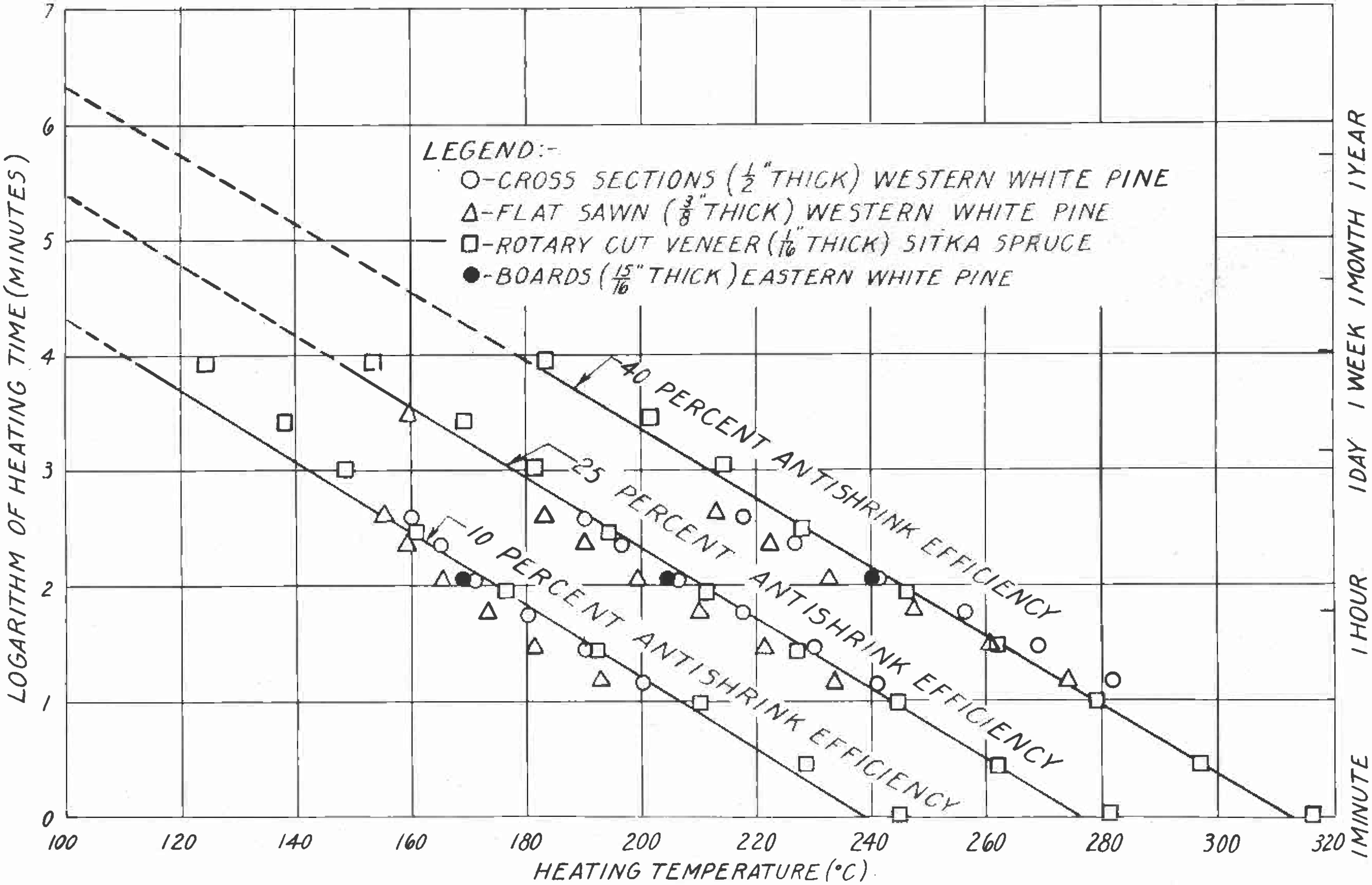

Figure 5.--Heating time and temperatures necessary to obtain antishrink efficiencies of 10, 25, and 40 percent on Western white pine cross sections, flat-sawn Western white pine, rotary-cut Sitka spruce veneer, and Eastern white pine boards.

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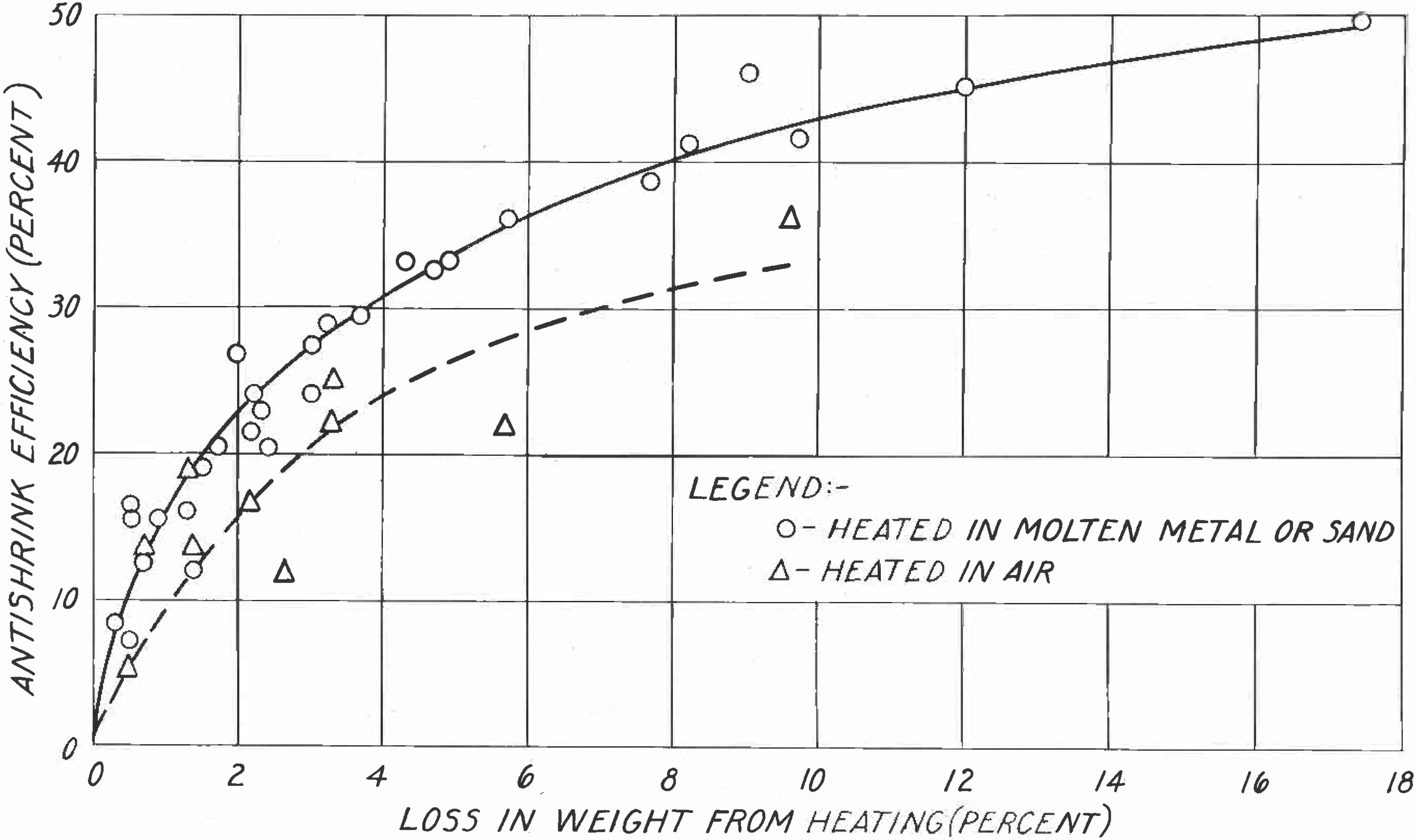

Figure 6.--Antishrink efficiencies versus loss in weight on heating, for rotary-cut Sitka spruce veneer.

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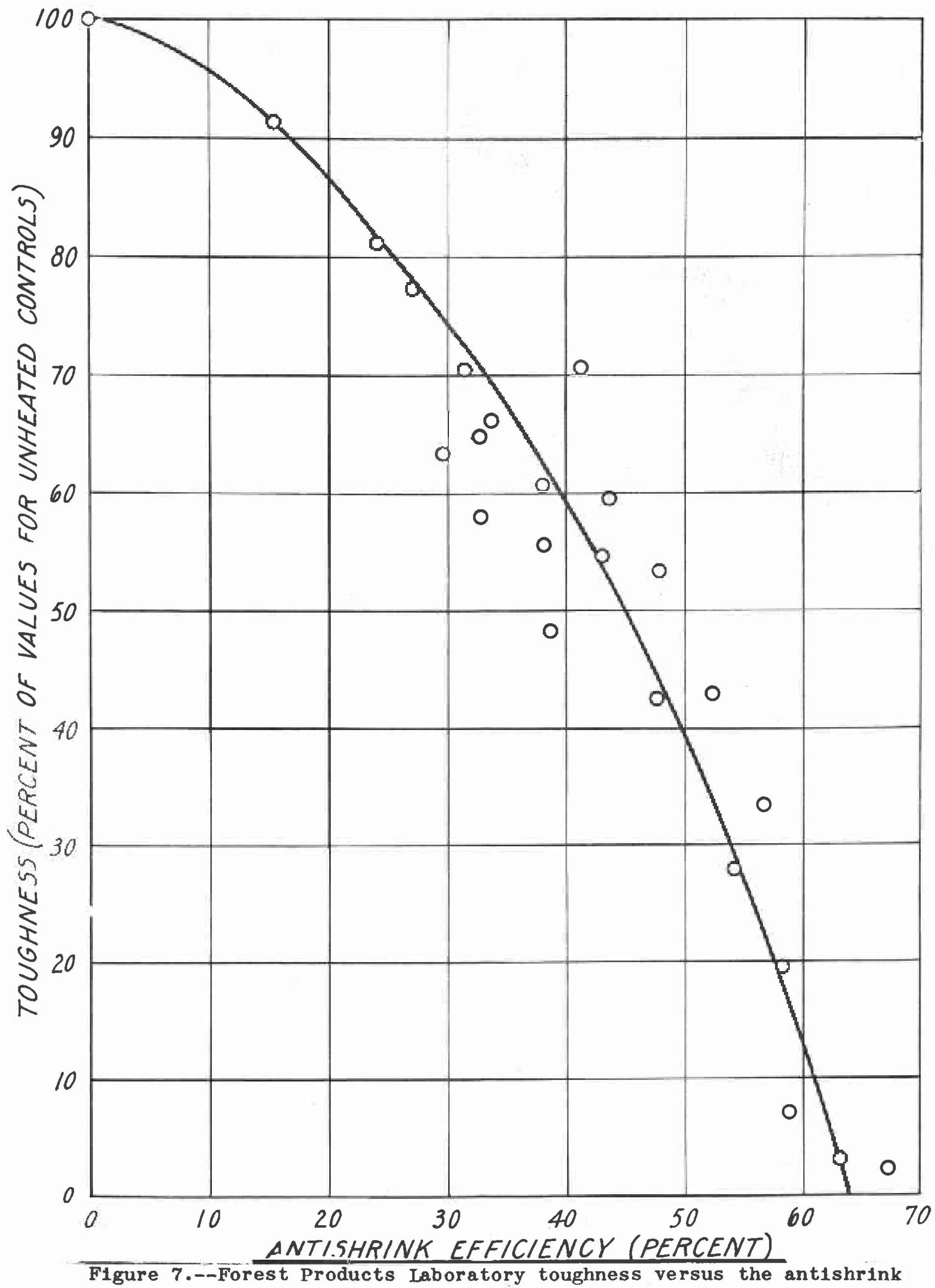

Figure 7.--Forest Products Laboratory toughness versus the antishrink efficiency obtained by heating flat-sawn Western white pine specimens as indicated in figure 2.

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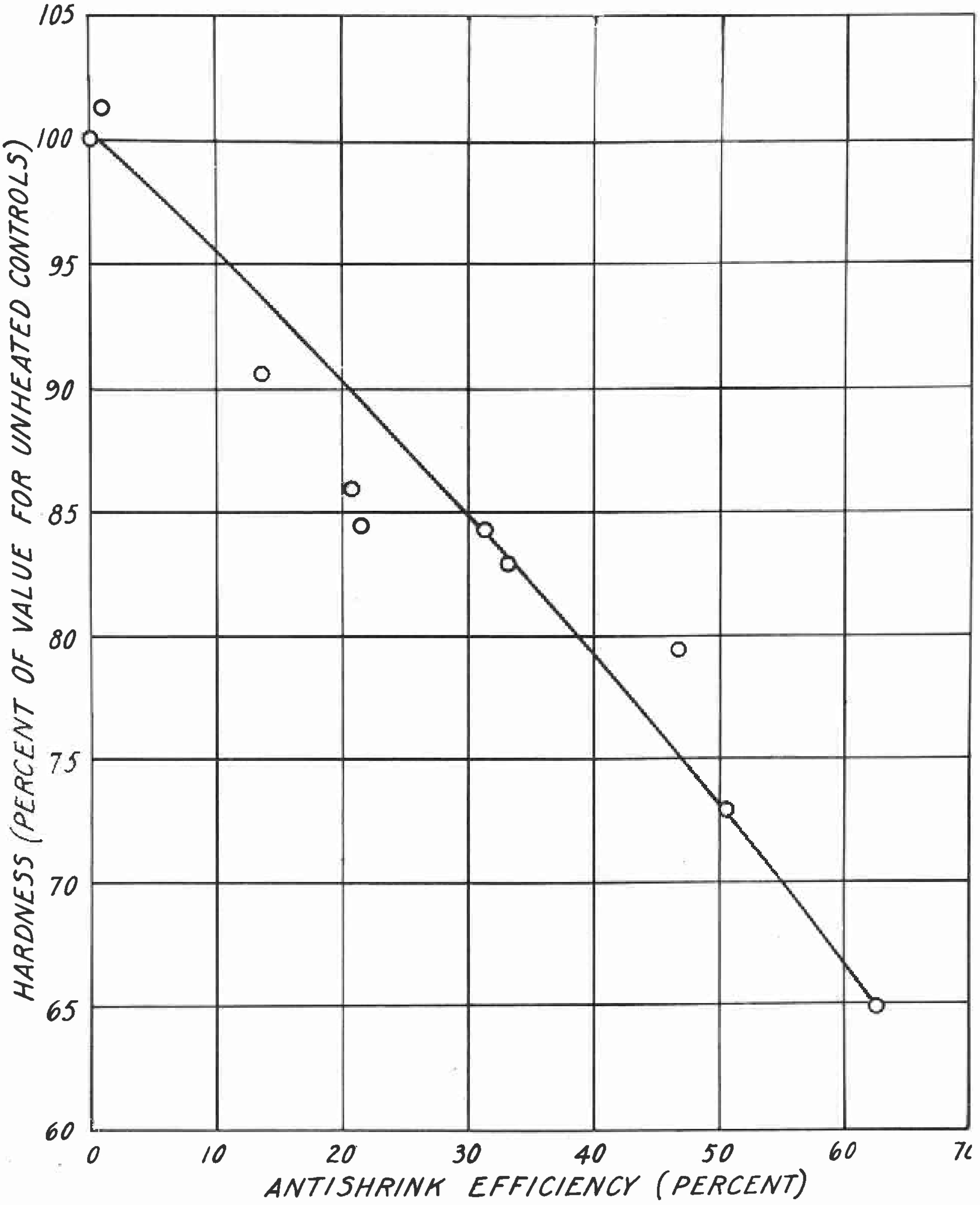

Figure 8.--Hardness (ASTM standard test method) versus the antishrink efficiency obtained by heating Eastern white pine specimens as indicated in figure 4.

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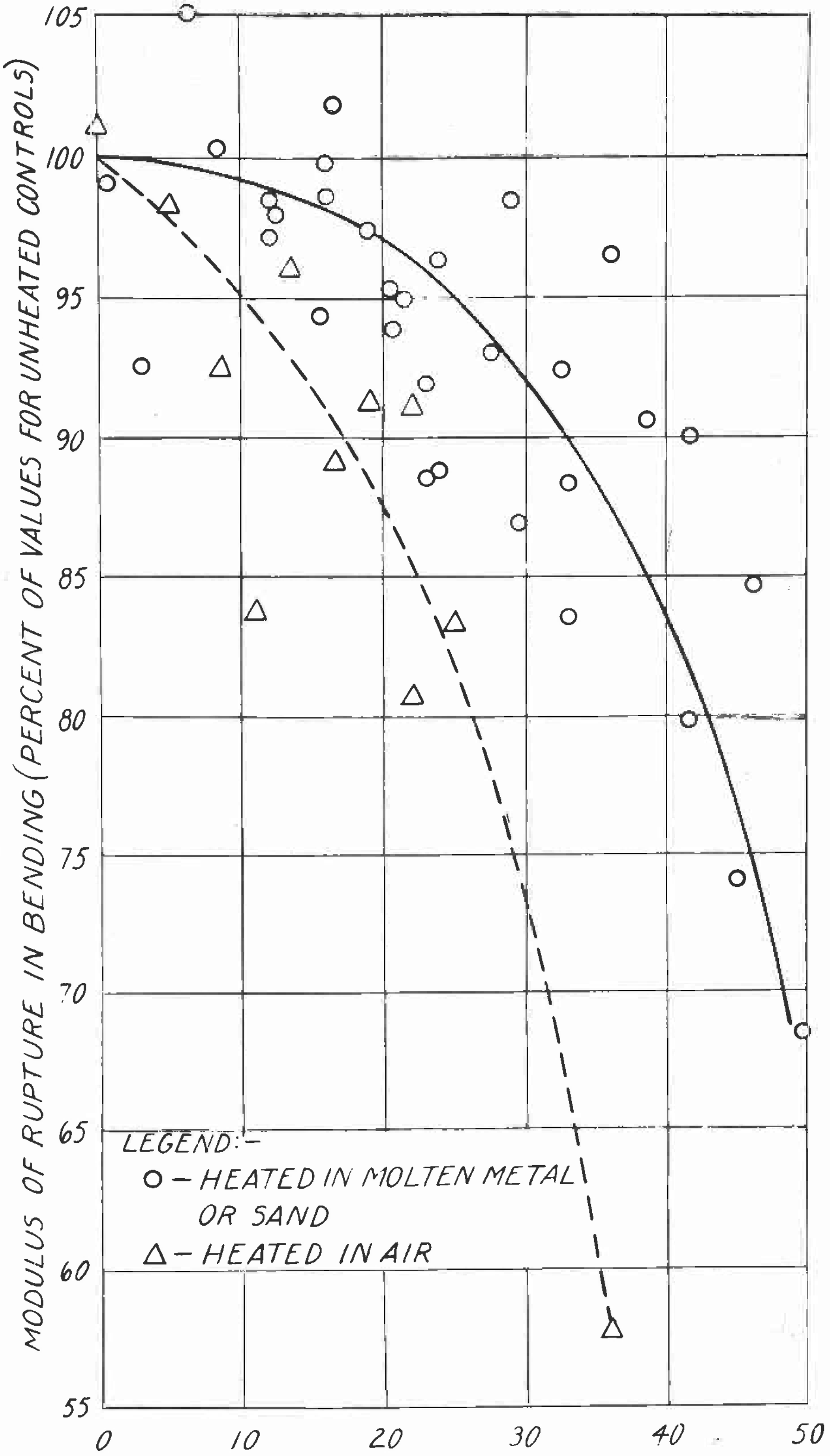

Figure 9.--Modulus of rupture in bending versus the antishrink efficiency obtained by heating rotary-cut Sitka spruce veneer specimens as indicated in figure 3.

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