REPORT No. 68

THE EFFECT OF KILN DRYING ON THE STRENGTH OF AIRPLANE WOODS

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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THE EFFECT OF KILN DRYING ON THE STRENGTH OF AIRPLANE WOODS

Prepared in the Forest Products Laboratory of the Forest Service
(In cooperation with the University of Wisconsin)

BY

T. R. C. WILSON, Engineer in Forest Products

CONTENTS.

FOREWORD.

This monograph is one of a series contributed by the Forest Products Laboratory, which is maintained at Madison, Wis., by the Forest Service, United States Department of Agriculture, in cooperation with the University of Wisconsin.

The investigations described have been carried out with the aid of funds provided by the War and Navy Departments, and the results have been used by these departments in connection with specifications for the kiln drying of airplane material.

The author desires to make acknowledgment to Mr. H. D. Tiemann, specialist in kiln drying, and to Mr. J. A. Newlin, in charge section of timber mechanics, whose extensive investigations of kiln drying and the strength of timber have been basic in planning the tests and analyzing the data described and presented. Messrs. L. A. Welo, C. A. Plaskett, R. P. A. Johnson, and H. J. Rosenthal aided in preparation of material, superintendence of tests and tabulations and analysis of data and their persevering, painstaking, and loyal efforts are acknowledged.

It is also desired to acknowledge cooperation of numerous lumber associations and companies in furnishing material for test.

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THE EFFECT OF KILN DRYING ON THE STRENGTH OF AIRPLANE WOODS.

By the Forest Products Laboratory.

SUMMARY OF GENERAL CONCLUSIONS.

The general conclusions stated below are the outcome of a series of tests which included 26 species, approximately 100 kiln runs, and over 100,000 mechanical tests. The series was undertaken in cooperation with the War and Navy Departments, and in continuance of earlier investigations on the basis of which the Forest Products Laboratory had drafted, for the War Department, Signal Corps Specification 20500, General Kiln-drying Process for Airplane Stock.[1]

This specification was based on the results of tests of Sitka spruce and white ash material representing three preliminary kiln runs at the laboratory, and on the general knowledge of kiln drying and the properties of wood which the researches of the laboratory in earlier years had developed. The material for the first tests had been arranged for before the United States entered the war, as it was antecipated that kiln drying of airplane stock would become necessary; and the preliminary runs antedated the adoption by the Government of its aircraft program. Signal Corps Specification 20500 was submitted to the War Department in July, 1917. While its adoption as an emergency measure was believed entirely justified, additional tests of its safety for spruce and ash and of its applicability to many other species were considered essential. It was desirable also to ascertain the possibility of using more rapid processes. The present monograph presents results of the tests made for these purposes.

The general conclusions reached are:

1. That wood may have its strength properties, particularly toughness or resistance to shock, quite seriously damaged without any *visible* evidence of such damage. Hence, *appearance* of the material can not, where maximum strength is essential, be accepted as the sole basis of judgment of the effect of a drying process on wood.

2. That the effect of a given process is not the same on all species of wood.

3. That apparently a given process may be entirely safe for some but quite detrimental to other material of a species.

4. That proper kiln drying produces material fully equal in all strength properties to that resulting from air drying under the most favorable conditions.

5. That specification 20500–A of the Bureau of Aircraft Production (Table 1 or 2 as specified) can in most cases be expected to produce material fully equal to air-dried.

6. That best results (with respect to strength properties) on Douglas fir will result from the use of somewhat milder drying conditions than those laid down in Specification 20500–A (Table 1). Table 2 of this specification (temperatures 105° F. initial to 135° F. final and relative humidities 85 per cent initial to 40 per cent final) is recommended for drying Douglas fir.

7. That in some species there is apparently no relation between drying temperatures up to 180° F. and the strength properties of the dry material. Such a conclusion, however, needs further confirmation, and temperatures higher than those of Specification 20500–A have not been recommended.

This work has been done under the necessity of getting results as quickly as possible and with the primary object of checking the safety of the general kiln-drying specifications when applied to the drying of airplane lumber on a commercial scale, together with the more or less incidental object of ascertaining if conditions adapted to more rapid drying could be used. Under these circumstances it has not been possible to investigate the subject in the fundamental

[1] Now with some slight modification Specification 20500–A of the Bureau of Aircraft Production.

way which it merits. Completion of the work already begun is contemplated and it is hoped to be able later to carry out experiments to determine the effect of the various factors involved, both separately and in combination, and to ascertain the maximum temperature and minimum humidity that can be safely applied at any stage of the drying process. It is hoped also to carry on comprehensive investigations of the closely related subject of the bending of wood, for the purpose of determining the steaming or other processes best adapted to successful bending and to secure more accurate knowledge of the effect of such processes on the strength of the wood.

NECESSITY FOR KILN DRYING.

Previous to the entrance of the United States into the war aircraft engineers had not encouraged the use of other than air-seasoned wood, particularly for those parts requiring the maximum strength. It had not been believed that it was possible for material to be properly prepared for such exacting service in any other way than by air seasoning over a period of several months or even years, depending on the size of the stock and on the climatic conditions at the point where the seasoning took place. The use of kiln-dried material had been tabooed because it had not been demonstrated that optimum results with respect to the strength properties could be secured through kiln drying. Some of the prejudice against kiln drying was undoubtedly due to acquaintance or experience with material which had been improperly kiln dried and hence greatly damaged.

Upon the adoption by our Government of an aircraft production program of great magnitude it was easy to be seen that the stock of air-dried material of the species then accepted for aircraft construction would be exhausted before even a fraction of the production planned for the first year could be accomplished. Hence, the kiln drying of material for airplanes became imperative. The prime requisite was to find or develop methods of kiln drying which would assure material of maximum strength properties. The problem of cutting the period of drying to the minimum was not so important, as it was the opinion that a period of from one to two months for the drying of such species as spruce would answer, if necessary.

PREVIOUS INVESTIGATIONS.

For some 12 years previous to this time the Forest Service had been carrying on investigations of the best types of kiln construction and methods of kiln operation to produce dry stock of maximum quality. These investigations had resulted in the invention, patenting, and dedication to public use of a new type of dry kiln in which excellent control of the important factors of temperature, humidity, and circulation could be secured. However, few of the species of importance in airplane construction had been included in these kiln-drying investigations. Also, the effort had been largely directed toward preventing the great losses from checking, casehardening, hollow-horning, and the like, which in many commercial drying operations had been excessive; and consequently tests had not been made to determine whether material having the maximum strength properties was being secured. However, about the time the kiln-drying studies were first started a very carefully planned and executed series of tests had been made to determine the effect, on strength, of exposure for various periods of time to dry air and to steam, both at various temperatures and pressures. These experiments [1] were on loblolly pine, white ash, and red oak. Additional knowledge of the effects of various temperatures had been gained from the results of tests of material which had been subjected to various steps involved in the application of preservative treatment.

Foreseeing the necessity for knowledge of the effect of kiln-drying operations on the strength of airplane woods, the Forest Products Laboratory before the declaration of war arranged to secure a quantity of partially air-dry spruce and white ash. Strength tests made on material dried in three preliminary kiln runs with a range of temperatures and humidities, indicated that spruce and ash could be successfully and safely kiln dried by using moderate temperatures and fairly high relative humidities, with careful control of kiln conditions. That material might be seriously damaged in strength properties without displaying visible signs of deteri-

[1] A résumé of the results was published in the Lumber World Review, Apr. 10, 1918.

oration was also indicated. This denoted that perfection of appearance did not constitute a safe criterion for the acceptance of material for exacting uses such as aircraft construction, and emphasized the need for standardization of drying practice and the specifying of limiting conditions to be used.

ADOPTION OF SPECIFICATIONS AND BEGINNING AND SCOPE OF PRESENT WORK.

With these tests and the previous experience of the laboratory in many lines as a basis, Signal Corps Specification 20500 (now with some slight modification Bureau of Aircraft Production Specification 20500–A) was drawn up. The general problem of kiln drying airplane stock, however, was by no means solved. Although the tests which had been made were sufficiently extensive to form, in the existing emergency, a basis of kiln-drying specifications, it was very desirable to get a further check upon their applicability through additional tests. It was also desirable to determine if it would be possible to use conditions adapted to more rapid drying. Moreover, there were a considerable number of species which were looked upon as suitable substitutes for spruce, ash, and the other woods which experience had already shown to be adapted to aircraft construction. It was regarded as essential that safe methods of drying these species be developed. In addition to this, the laboratory was undertaking tests of numerous features of airplane construction and it was necessary to have dry material for use in these tests.

The work has now covered 26 [1] species, with approximately 100 kiln runs and with some 100,000 mechanical tests to determine the effect of the processes. It is the purpose of this monograph to set forth in detail the methods used, to give in considerable fullness the data secured and conclusions drawn, and thus to make available information for the guidance of those engaged in aircraft construction and others who may be interested in kiln drying wood in such a manner as to retain the maximum strength.

BASIS OF TESTS AND COMPARISONS.

Since kiln drying was to take the place of extended periods of air seasoning, it was but natural to adopt air drying as a basis by which to judge the effect of kiln drying. It might seem to one not well acquainted with the phenomena revealed by tests of strength properties of wood that it would be feasible to kiln dry a given lot of material, make tests upon it, and compare directly with the strength of air-dry material of the same species, as determined by previous tests. Such a method, it is true, might suffice to detect any severe damage or excessive deficiency in strength properties brought about by the drying processes. In the present experiments, however, the aim was to find kiln processes such that the resulting material would be at least equal in strength properties to the same material had it been carefully air seasoned. The decision as to whether this has been accomplished requires more exact comparisons than can be obtained by the method given above. Also in such work it is desirable to be able to distinguish small differences in the effect of two or more different treatments in order to discover the tendency of a change in the treatments.

The study of data derived from some 130,000 tests on 129 different species of native woods tested at the Forest Products Laboratory previous to the beginning of this work has shown something of the variability that may be expected. It has been found, for instance, that even when as many as possible of the factors contributing to the variation of timber are under control, the average of material from a tree selected at random would be expected to differ from a true average of the species by from 7 to 15 per cent, depending upon which of several important strength properties was considered. The variation of individual specimens is, of course, much greater. Consequently, it is essential to make certain that the material subjected to any treatment whose effect is to be found is as inherently like that with which it is to be compared as possible. In other words, no very close estimate of the effect of kiln drying upon the strength is possible from comparisons of the properties of two lots of material, one being kiln dried and the other air dried, and both selected at random.

[1] Data and information on but a part of the species are available and included herein.

The problem presents two alternatives. One is to divide the green stock of a given tree or trees into two lots, one of which is tested after kiln drying and the other after air drying. This involves a delay in the analysis until the air drying is complete and the tests made, and was deemed impracticable because of the demand for immediate information.

The second alternative is to make a comparison with the results previously obtained from material of the same species and tested in both the green and the air-dry conditions. On the basis of this comparison a conclusion may be drawn as to whether kiln drying has produced as favorable a change in properties as had been found, from the previous tests, to result from air drying. This second method is, of course, the best adapted to securing quick results. On the other hand, it does not, for reasons which have been mentioned and which will be further discussed later, justify as definite and certain conclusions as the first.

The plan actually followed was a combination of the two alternatives.

The material for testing was brought to the laboratory in log form, and was there cut up into three lots. The first was tested green, the second after kiln drying, and the third after thorough air seasoning. Methods of making this division are further discussed under "Preparation of Material."

As soon as the tests on kiln-dried material were available they were analyzed and preliminary conclusions drawn from a comparison with previously air-dried material of the same species. This can be safely done only on the part of those who are experienced and familiar with strength values and particularly familar with the variations that are likely to be met with in stock of a given species grown in different localities. If the kiln-dried material proves to be greatly superior or greatly inferior it is safe to say positively that it would also have been superior or inferior to stock of the same tree air dried. If, however, the differences turn out to be small and less than the probable variation of an average of the strength property, definite conclusions are not possible. This analysis is, therefore, regarded as preliminary and final conclusions are withheld until air-dry material from the same trees and parts of trees has been tested. The comparisons then possible are known to be free of some of the factors enumerated below and the rest can be adjusted for or can be reduced in importance by working with a large number of tests. Where this has been done the difference in strength properties between kiln-dried and air-dried stock and between stock dried under different kiln conditions can be stated, with considerable assurance, to be due to differences in drying conditions only.

VARIABLES AFFECTING RESULTS.

The factors which affect test results and contribute to their variability may be enumerated as follows:

(1) Defects (knots, decay, shakes, etc.).
(2) Density.
(3) Species.
(4) Moisture content and distribution.
(5) Rate of testing.
(6) Temperature at time of test.
(7) Position in tree.
(8) Tree characteristics (varying with locality of growth, soil, elevation, etc.).
(9) Unexplained variations (usually following the laws of probability).

These factors must be so handled that their effects will not be mistaken for the effect of the kiln-drying process. The effects of these factors are eliminated from comparisons in the following manner:

All pieces having visible defects which it is evident would lessen their strength are discarded at the outset. Inspection is also made after test, since some defects are likely not to be revealed until the specimen has failed.

Regarding density and position in the tree, fairly general relations have been deduced from the extensive investigations previously made. It is a general rule that the strength properties of wood of any species vary directly as some power of the density; that the density, and therefore the strength, decreases with height from ground at growth (spruce seems to be an exception to this); and that there is a considerable but unpredictable variation between strength and distance from the pith of the tree. Provided the test specimens come from the same height in the tree and the same region of annual growth, there does not seem to be much difference in strength with regard to cardinal direction in the living tree.

It is evident, then, that the influence of density, position in tree, and tree characteristics can be eliminated from comparisons, as far as the kiln-drying work is concerned, by selecting material for test in the green, kiln-dried, and air-dried conditions, not only from the same tree but also from its corresponding parts. The existence of tree characteristics also makes it desirable that several trees be represented in each kiln run. It is also found that unexplained variations are such as to necessitate that each tree be represented in each group (green, air-dried, and kiln-dried) by a considerable number of specimens.

The effect of moisture content and distribution could be eliminated by bringing the kiln and air-dried material to the same moisture content before test. This, however, requires an excessive amount of time and it is found more feasible to allow for comparatively small differences in moisture content by making adjustments of the data. These adjustments will be discussed later.

Differences in moisture content between parts of the same specimen are avoided by allowing a period of air seasoning after the kiln drying, thus bringing the moisture in the material to practically uniform distribution. Material which is air dried is not tested until it has reached a practically constant weight and the moisture content has become approximately uniform.

The effects of rate of test and temperature at time of test are cared for by properly standardized testing methods.

MECHANICAL TESTS AND THE PROPERTIES DETERMINED FROM THEM.

The standard tests made on wood at the Forest Products Laboratory and the mechanical properties determined from them are:

- Static bending.
  - Fiber stress at elastic limit.
  - Modulus of rupture.
  - Modulus of elasticity.
  - Work to elastic limit.
  - Work to maximum load.
  - Total work.
- Impact bending.
  - Fiber stress at elastic limit.
  - Modulus of elasticity.
  - Work in bending to elastic limit.
  - Height of drop to failure (50-pound hammer).
- Compression parallel to grain.
  - Fiber stress at elastic limit.
  - Crushing strength.
  - Modulus of elasticity.
- Compression perpendicular to grain.
  - Fiber stress at elastic limit.
- Shearing strength parallel to grain.
  - Radial.[1]
  - Tangential.[1]
- Cleavage.
  - Radial.[1]
  - Tangential.[1]
- Tension perpendicular to grain.
  - Radial.[1]
  - Tangential.[1]
- Hardness.
  - End.
  - Radial.
  - Tangential.

[1] The terms "radial" and "tangential" refer to the surface of failure. Radial tension is tension perpendicular to the radial surface.

It may not appear necessary to perform all of these tests on the green, kiln-dried, and air-dried material in order to get a sufficiently reliable basis for the determination of the effect of kiln drying. On the other hand, it would not do to select one kind of test on one property and assume that if the kiln dried stock proved to be superior or inferior to air-dried, all the other properties would also be superior or inferior. The several properties may very well, and do in fact, prove to be affected in different ways by the various conditions of seasoning. This phenomenon is amply illustrated by data presented later.

PROPERTIES ON WHICH ANALYSIS IS BASED AND THEIR SIGNIFICANCE.

The analysis of the effect of kiln-drying is, therefore, based on the tests which bring out the properties deemed most important in airplane construction; namely, static and impact bending and compression parallel to grain; although all of the tests are made because the tests of lesser importance can be made at a comparatively low cost and serve at times as a check on the conclusion reached from a study of the principal test data.

The properties chosen for principal attention in the analysis are five in number. They are: Modulus of rupture, modulus of elasticity, and work to maximum load, obtained from the static-bending test; height of drop, obtained from the impact-bending test; and maximum crushing strength, obtained from the compression-parallel-to-grain test.

By modulus of rupture is meant the computed fiber stress in the outermost fibers of the the beam at the maximum load. It is a measure of the ability of a beam to support a slowly applied load for a very short time. It is not a true fiber stress, since the formula by which it is computed is exactly applicable only within the elastic limit. The term is, however, universally accepted and the values are quite comparable for various species and sizes of lumber. It is, moreover, a definitely measurable quantity which does not depend to any extent on any personal factor as does, for instance, fiber stress at elastic limit.

The modulus of elasticity is a measure of the stiffness or rigidity, of a material, and is of value in computing the deflections of joists, beams, and stringers, and safe loads for columns. Although it is derived from the static bending test it is directly applicable to columns as well as beams.

Work to maximum load represents the ability of a wooden part to absorb shock with a slight permanent or semi-permanent deformation with some injury to the wood, and is a measure of the combined strength and toughness of a material under bending stresses. It is one of the most important properties as far as airplane wood is concerned.

Height of drop is the vertical fall of a 50-pound hammer causing complete failure under the impact-bending test, and represents a quality that is important in members which are occasionally stressed beyond the elastic limit. It is a very variable quantity but ranks with work to maximum load in importance as a measure of the suitability of a wood for airplane use.

The value of maximum crushing strength, as obtained from the compression-parallel-to-grain test, lies in the possibility of estimating the strength of parts used as columns. It is a very simple test and is frequently the only one used in studying the effect of a treatment or process on wood. However, it does not necessarily follow that others are affected in the same way and, particularly not with respect to the very important properties of work to maximum load and height of drop. These latter are measures of toughness, or shock resistance, which quality is not brought out by the compression-parallel-to-grain test.[1]

The manner of conducting these and the minor tests and the significance of each of the properties is discussed in various circulars and bulletins of the Forest Service of the United States Department of Agriculture.[2]

[1] See p. 37 and footnote thereto.

[2] See particularly Forest Service Circular 38 (Revised) and Bulletin 556 of the United States Department of Agriculture. See also "Working Plan for Project 124," included as an appendix in The Mechanical Properties of Wood, by S. J. Record, published by John Wiley & Sons.

PREPARATION OF MATERIAL.

SELECTING, CUTTING, AND MATCHING OF STOCK.

The necessity for having material so selected that comparisons will be only between groups which consist of material inherently alike has been pointed out. The method of cutting logs and selecting material will be illustrated for each of several species. Great care has at all times been taken to make certain that kiln-dried material is as inherently like the green and air-dried to which it is compared as possible.

In most cases the material for test was selected in the woods or from log yards and sent to the laboratory in log form. There it was stored on skids in the yard until required. In general, species which were in use or considered as substitutes for spruce in wing beams, struts, etc., were cut into 2½ or 3 inch planks, in which sizes the material was kiln-dried. Species looked upon as promising for propeller woods were sawed into 1-inch lumber and kiln-dried in this thickness.

Test specimens were 2 by 2 inches in cross section for those species dried in the 2½ or 3 inch thickness. Bending specimens were 30 inches long and were tested with center load on a span of 28 inches. Specimens from the species dried in 1-inch thickness were ⅞ by 2 inches in section. Bending specimens were 20 inches long and were tested with load at the center of an 18-inch span.

Specimens for test while green were cut and planed to size at the time of cutting material from the log. Specimens for test after air drying were at the same time cut roughly to size and stored for drying. Specimens to represent the kiln-dried material were not cut until after the kiln-drying was completed. Specimens which were to be air-dried were carefully piled in a shed where they were well up off the ground, were sheltered from the sun and from precipitation, and were subjected to very free circulation of air. Ends of these specimens were dipped in melted paraffin to retard drying from the end. The endeavor was to give them the best possible environment for air-drying.

Each shipment of a species is considered a unit. It has not been possible to get all shipments of a species uniform as to size and length of logs, etc. Logs of one species differ greatly, of course, from those of another in size and character. The method of grouping material is influenced by a number of factors, such as size of logs, number of kiln runs in which each log is to be represented, method of sawing (plain or quarter-sawed), thickness of material to be dried, and number of logs in shipment. Consequently it was impossible to adopt a single standard plan for cutting, marking, and grouping; each shipment had to be studied separately and the method best suited to it adopted.

Figure 1 (A) to (E) illustrates several of the methods of cutting logs. Figure 1 (E) shows how the logs of Sitka spruce of shipment 504 were divided. These logs were so large that it was necessary to split them before they could be sawed. They were first split into quarters. Each quarter was then split circumferentially into two pieces and the outer one of these pieces was again split radially into two pieces. The resulting 12 pieces were sawed as shown. The central flitches HL and MK were cut into sticks 2½ by 2½ inches in the rough. Matched specimens for test in the green and air-dry conditions were provided in accordance with the following scheme: With an 8-foot log or double-length bolt as a unit, two flitches extending through the tree in one direction, as in figure 1 (B), or in each of two directions, as in figure 1 (E), are cut into 2½ by 2½ inch sticks. These are numbered as in figures 1 (B) and (E), the number consisting of a letter and a figure, as H3, L6, etc. These sticks are then grouped for test as follows:

STICK NUMBERS.

Lower bolt..........	1		4, 5		8, 9 } Tested green.
Upper bolt..........		2, 3		6, 7	etc. }
Lower bolt..........		2, 3		6, 7	} Tested after air-drying.
Upper bolt..........	1		4, 5		8, 9 }

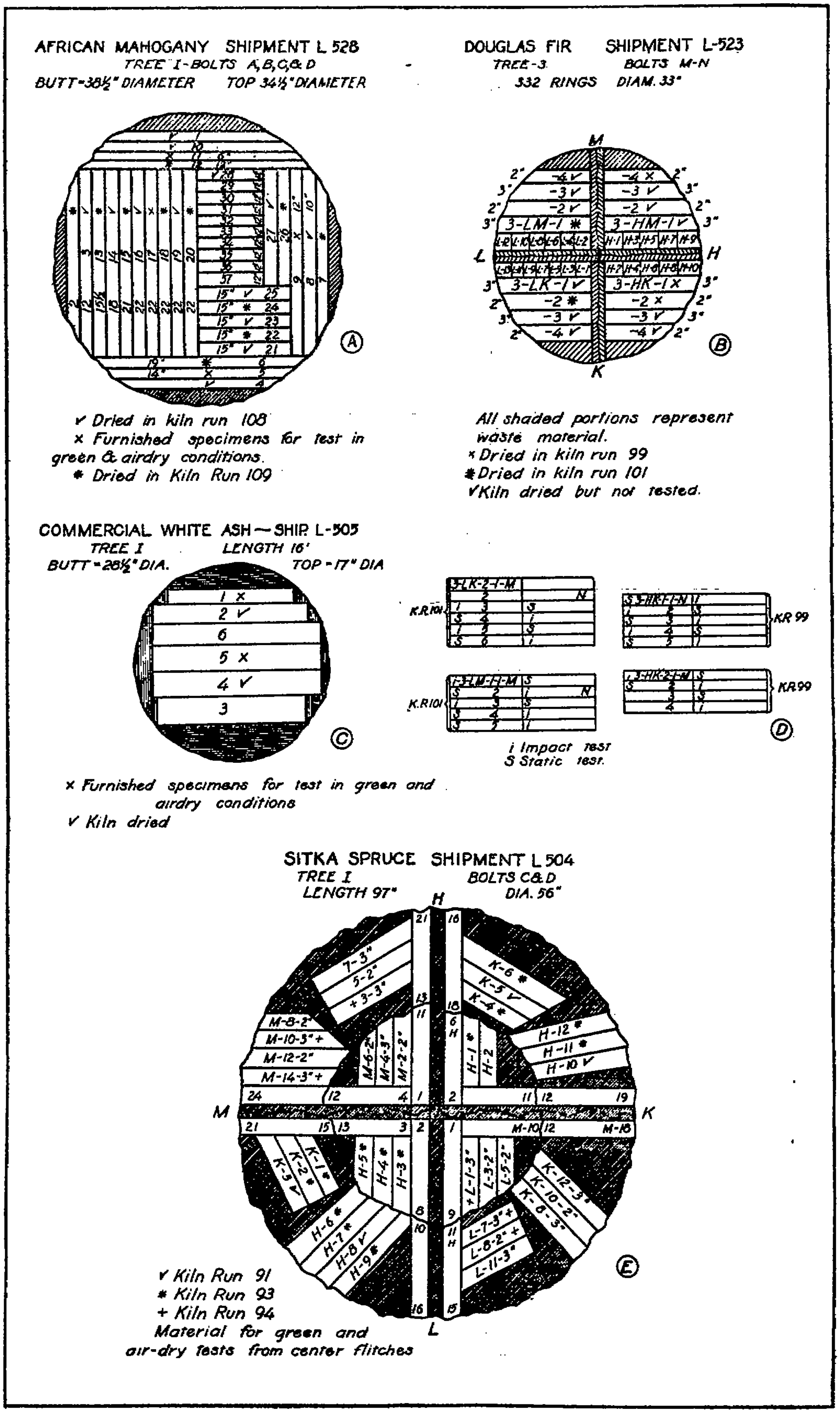

FIG. 1.—Method of cutting logs into lumber for kiln drying and into test specimens.

That is, two composite bolts are formed, each including half the sticks from the upper bolt and half those from the lower bolt. The sticks of one of these composite bolts are tested green and those from the other after air-drying.

Figure 1 (D) shows how planks are divided into sticks for static and impact-bending tests after having been dried in the kilns. In general, half of the sticks of any given group—green, air-dried, or from any kiln run—are tested in static bending and half in impact. One specimen from each stick is tested in compression parallel to grain. One-half of the static-bending sticks furnish smaller specimens for compression-perpendicular-to-grain tests; the other half give specimens for hardness tests. Shear, cleavage, and tension-perpendicular-to-grain specimens are taken from impact-bending sticks.

Figure 1 (A) and (C) are cutting diagrams as used for African mahogany and white ash, and are typical of diagrams for logs which were cut into 1-inch material or were not sufficiently large to be cut as in figure 1 (B) or (E).

INSPECTION OF STOCK.

Immediately previous to being placed in the kiln all material is very carefully inspected and any defects and imperfections noted and marked on the piece or made a matter of record. On removal from the kiln it is again inspected and record made of any increase in the previously noted defects, such as extension of shakes, increase of checks, or loosening of knots; also of warping and cupping, the development of new checks, etc. It is also examined for case-hardening.

KILN DRYING AND TESTING.

Following the initial inspection the material is placed in experimental kilns and dried. On removal from the kilns it is stored for a brief period, after which the standard tests as previously enumerated are made.

METHODS OF ANALYSIS.

We come now to a discussion of the actual comparison of the test data on material dried under different kiln conditions and in the air. Because of the several influencing factors which have been enumerated, this comparison can not be made directly from a table of properties in which these properties are grouped according to the seasoning conditions. The reason is that in the case of the preliminary analysis the air-dried stock used for comparison was not inherently like that kiln-dried. The trees and the parts of the trees are necessarily different and the localities of growth are, in general, different also. In the final analysis the tests of the several kiln runs and the air-dried were on matched stock; that is, on stock inherently the same. Thus the source of possible error in making a direct comparison introduced by unlike stock falls away. However, differences in moisture content still usually exist at the time of test.

IMPROVEMENT RATIOS.

In attempting to find for use in the preliminary analysis some basis of comparison which would, as far as possible, avoid the errors resulting from inherently different material in the groups compared, study of the available data showed that the *change* in properties which is produced by drying is in general somewhat less variable than the strength values. Accordingly, it was believed that the effect of kiln drying could be better judged by comparing the change which it produced with the corresponding change produced by air drying than by comparing strength values of the kiln-dried and air-dried material. The mathematical measure of this change is defined as an "improvement ratio."

$$\text{Improvement ratio} = \frac{\text{Strength value for kiln or air dried material}}{\text{Same strength value for matched green material}}$$

Early tests of the effect of moisture on the strength properties had shown that in one species, at least, the effect of moisture change was practically independent of the specific gravity of the wood. On the other hand, the strength properties are very largely influenced by the specific gravity. Although the relation of specific gravity to strength has been the subject of considerable study and important principles have been deduced, it is not possible to make adjustment of strength figures for differences in specific gravity with sufficient exactness for the present purpose. Hence, it seems that comparisons are likely to be less affected by differences in specific gravity if based on improvement ratios than if based on the strength properties themselves.

ADJUSTMENT FOR DIFFERENCES OF MOISTURE CONTENT.

In some instances the strength properties of wood change very rapidly with changes in moisture. Some strength properties of some species are nearly tripled in drying from the green condition to about 8 per cent moisture. In other instances, however, the strength properties are decreased in drying. After wood has passed the fiber-saturation point,[1] a change of 1 per cent in the moisture content may produce as much as 7 or 8 per cent change in the strength value. Consequently, since it is impracticable to bring the various groups of material which are to be compared to the same moisture content before test, it is essential to the accuracy of comparisons that careful attention be given to adjustment of strength values for differences of moisture content.

Several years ago a rather comprehensive study of the relation of moisture content to the strength of wood was carried out by the Forest Service at laboratories then maintained at Yale University.[2] This investigation, however, covered comparatively few species, and not all the strength properties of these. In taking up the analysis of the data on the effect of kiln drying on strength, the need of a general moisture-strength law which would be applicable to all species and all properties became apparent. For the purpose of developing such a law the existing data were very carefully reviewed.

Figure 2, taken from Forest Service Bulletin 70, illustrates the relation between moisture and several strength properties of red spruce. The graph for modulus of rupture is seen to be a curve from zero to about 30.5 per cent moisture, beyond which it is a straight horizontal line. This shows that as moisture increases strength decreases until a point is reached where there is no further decrease. This point (30.5 per cent in this case) is termed the fiber-saturation point. At this point the cell walls are completely saturated, but there is no free or excess water in the pores of the cells.

In studying data as given in Forest Service Circular 108 and Forest Service Bulletin 70 on the several species and properties, it was found that when the logarithm of the strength property was plotted against the percentage moisture the points could be averaged, with but comparatively little error, by a straight line. This was so consistently true that the application of the principle involved to other species and to other properties was thought to be justified. The relation as found may be stated mathematically as follows:

$$S = C \times 10^{AM}$$

where S is the strength value at any moisture content, M, below the fiber-saturation point, and C and A are empirical factors. It has been assumed that the type of curve represented by the above equation is applicable to all properties, to all species, and to all drying conditions. The differences between these various curves are represented by the constants (C and A) which adapt the type equation to specific instances. These constants for any specific case are derived from the data to which the equation is to be applied. The following equation, derived from that given above, is conveniently applicable to improvement ratios:

$$\text{Log } R_2 = \frac{M_s - M_2}{M_s - M_1} \times \text{Log } R_1$$

where M_s = moisture content at fiber-saturation point.
M_1 = moisture content of air-dried or kiln-dried material at time of test.
M_2 = moisture content to which it is desired to adjust improvement ratios.
R_1 = improvement ratio of dry material at moisture content of M_1.
R_2 = improvement ratio adjusted to moisture content M_2.

The factor C has been eliminated in the derivation of this equation. The fraction $\frac{\text{Log } R_1}{M_s - M_1}$ is the value of A. In other words, the value of A for use in the adjustment of a set of data is derived from the data.

[1] See second paragraph following. [2] Results and discussion of these tests are given in Forest Service Circular 108 and Forest Service Bulletin 70.

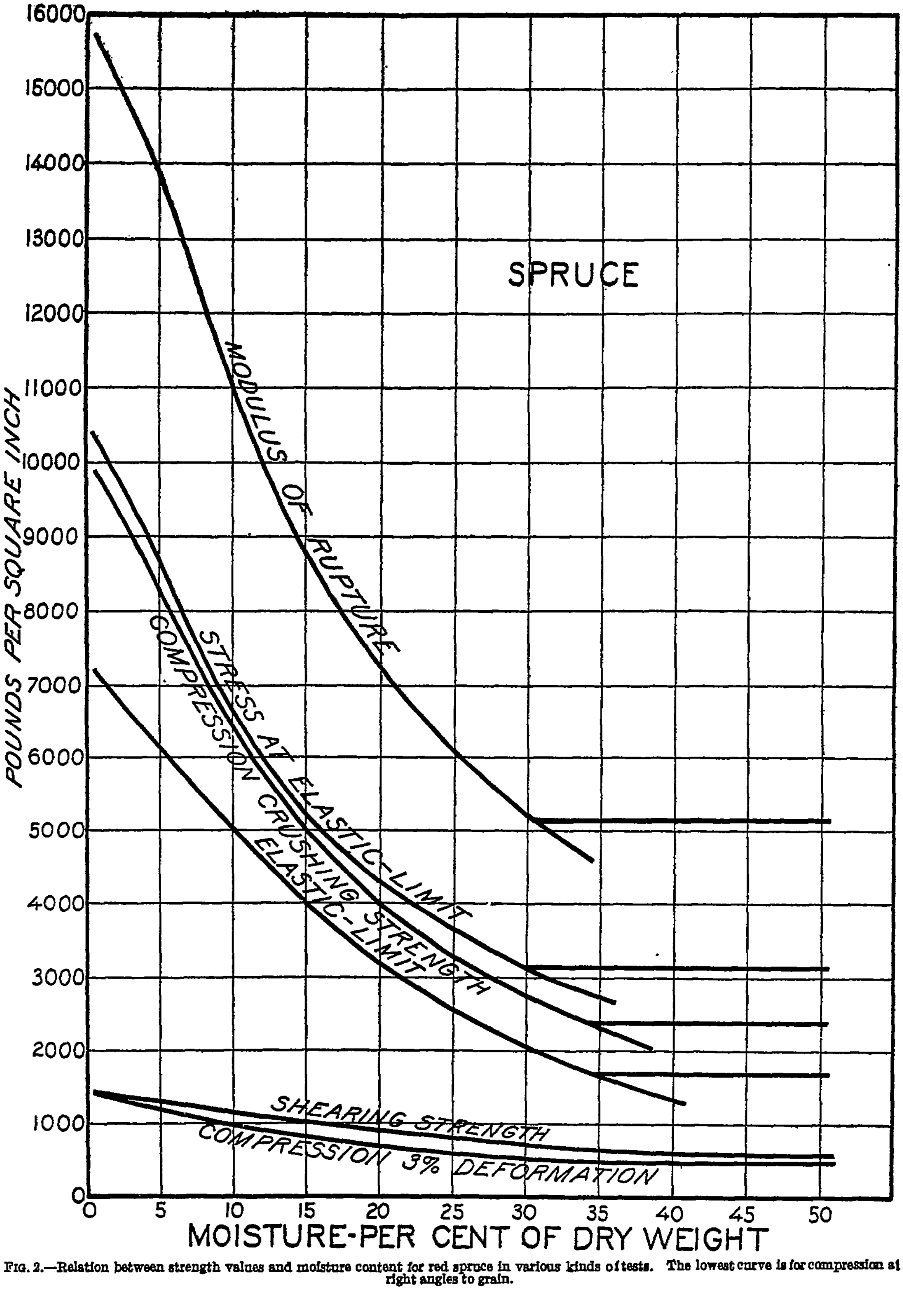

FIG. 2.—Relation between strength values and moisture content for red spruce in various kinds of tests. The lowest curve is for compression at right angles to grain.

The use of this formula is illustrated by the following example:

The average modulus of rupture of a certain group of material tested at 9.0 per cent moisture was 10,240 pounds per square inch. The modulus of rupture of the corresponding green material was 4,890 pounds per square inch. The fiber-saturation point is 23 per cent. What would be the improvement ratio adjusted to 11 per cent moisture?

$$M_s = 23$$
$$M_2 = 11$$
$$M_1 = 9.0$$
$$R_1 = \frac{10240}{4890} = 2.095$$
$$\text{Log } R_2 = \frac{23-11}{23-9.0} \times \log 2.095$$
$$= \frac{12}{14} \times .321 = .275 \quad \text{and}$$
$$R_2 = 1.88$$

Also, modulus of rupture at 11 per cent = 4,890 × 1.88 = 9,400 pounds per square inch.

As stated above, improvement ratios and methods of adjusting them for moisture are made use of in preliminary analyses where it is necessary to compare kiln-dried material with air-dried material from a different source. They are also found very convenient in comparing kiln-dried material with the air-dried material actually matching it. These latter groups are seldom at the same moisture content when tested; consequently adjustment for moisture is necessary. This adjustment is made a trifle more easily on improvement ratios than on the strength properties themselves.

DISCUSSION BY SPECIES.[1]

The various species on which tests have been made will now be discussed individually. This discussion will be divided into two parts, corresponding to two groups as follows:

Group 1.—Species on which data are available from tests on matched groups of green, air-dried, and kiln-dried material.

Group 2.—Species on which data are not yet available on air-dried material matching that tested green and after kiln drying.

Group 1 consists of Sitka spruce, Douglas fir, western white pine, and white ash.

Group 2 includes white pine, Norway pine, western hemlock, white fir, Port Orford cedar, bald cypress, Central American mahogany, African mahogany (*khaya* sp.), northern and southern white oak, southern red oak, black walnut, sugar maple, and yellow birch.

The kiln-dried material of the first three species of group 1 will be compared directly to air-dried material matching it. Western white pine will be used as an example of the two methods of analysis. It will first be discussed and analyzed as if tests on the air-dried material matching that which was tested after kiln drying were not available. It will then be discussed on the basis of comparison of kiln-dried material with air-dried which is matched to it. This plan will afford a comparison of the two methods of analysis.

Since group 2 consists of those species in which data from tests of air-dried material matched to that kiln dried are not yet available, conclusions must necessarily be made by the method first illustrated under the discussion of western white pine. Data on the various species of this group are not included. Only conclusions reached and recommendations based thereon are given.

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[1] The species names used herein are those official in the United States Forest Service except the following: Central American mahogany (*Swietenia mahagoni*), which is officially termed "mahogany;" African mahogany (*Khaya* sp.), for which no official name has been adopted by the Forest Service; and "commercial white ash," concerning which see footnote, p. 53.

The official common and botanical names for the other species are: Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga taxifolia*), western white pine (*Pinus monticola*), Port Orford cedar (*Chamaecyparis lawsoniana*), bald cypress (*Taxodium distichum*), western hemlock (*Tsuga heterophylla*), white pine (*Pinus strobus*), Norway pine (*Pinus resinosa*), white fir (*Abies concolor*), black walnut (*Juglans nigra*), sugar maple (*Acer saccharum*), yellow birch (*Betula lutea*). Other common and botanical names applied to the various species are given in Forest Service Bulletin 17, "Check List of the Forest Trees of the United States."

It is not the function of this monograph to discuss kiln-drying schedules; consequently only such data concerning the drying in these experimental runs as is essential to an understanding and interpretation of the results of the strength tests are included. Neither is it intended that the various graphs of kiln conditions should furnish comparisons of the various processes with respect to rate of drying. For such discussions and comparisons the reader is referred to a monograph by H. D. Tiemann entitled "The Kiln Drying of Wood for Airplanes" and published as one of this series. It is also desired to emphasize the fact that the runs described herein were experimental and are not presented as models, nor necessarily as recommended practice.

SITKA SPRUCE.

Because of the importance of Sitka spruce as an airplane material, more experimental kiln drying has been done on this species than on any other. The results of 13 kiln runs made with different combinations of temperature, humidity, circulation, and other factors which may affect strength properties are available for analysis. The first three runs are those which have been previously mentioned as preliminary. These runs were made on partially air-dried rough plank. Because of the fact that the material tested was quite limited in amount, and the further fact that the other runs have furnished much more comprehensive data, it is unnecessary to present the data on these preliminary runs.

SOURCE OF MATERIAL.

The other 10 runs, on which full data are available, were made on material sent to the laboratory in the log form, in three different shipments.

Shipment 504 consisted of six 8-foot logs from four trees grown in Clatsop County, Oreg. They ranged in diameter from 53 to 77 inches. Trees 1 and 2 were each represented by two 8-foot logs, namely, bolts *c–d* [1] and *i–j* for tree 1, bolts *a–b* and *i–j* for tree 2. Trees 3 and 4 were represented by the *e–f* bolts only. Material from trees 2 and 3 was used in kiln runs 88 and 89, while trees 1 and 4 supplied stock for runs 91, 93, and 94.

Shipment 563 came from Portland, Oreg. Much of the material was used for special drying tests which it is not the purpose to consider here. The shipment furnished material for runs 147 and 148, data and discussion of which are included in this publication.

Shipment 578 consisted of six logs, from as many trees, and varying in diameter from 60 to 66 inches. Trees 1, 4, 5, and 6 were represented by the *a–b* bolts, tree 2 by the *c–d* bolts, and tree 3 by the *e–f* bolts. Trees 2 and 3 furnished material for kiln run 163, while material from the other trees was equally divided between runs 171 and 172.

Previously tested green and air-dried material, with which comparison is made, was secured from one tree from Chehalis County, Wash.

CUTTING AND MARKING.

The cutting and marking of Sitka spruce has been previously described (see pp. 15 and 17) is illustrated in figure 1 (E).

DESCRIPTION OF KILN-DRYING CONDITIONS.

Figure 3 shows graphically the kiln conditions and moisture contents of samples of the stock for runs 88, 89, 91, 93, and 94. Similar data for runs 147, 148, 163, 171, and 172 are shown in figure 4.

Kiln runs 88 and 89.—Kiln runs 88 and 89 were made on stock in the form of planks 3 inches thick and of various widths. The planks were piled flat and open as indicated in figure 5. This figure shows the piling, arrangement of heating coils, condenser coils, spray line, and regulating and measuring instruments for kiln run 89, but those for kiln run 88 were not essentially different. Both of these runs were made in a water-spray kiln. Two-inch stickers were used, and openings of an inch left between the planks of each tier. Kiln run 89 had much the milder

[1] This lettering of bolts is in accordance with the following scheme: Beginning at the stump, each 4 feet of length of the tree is assigned a letter. The 4-foot bolt above the stump is then *a*, the second *b*, etc. The first and second taken together are called *a–b*, the eighth and ninth together *h–i*, etc.

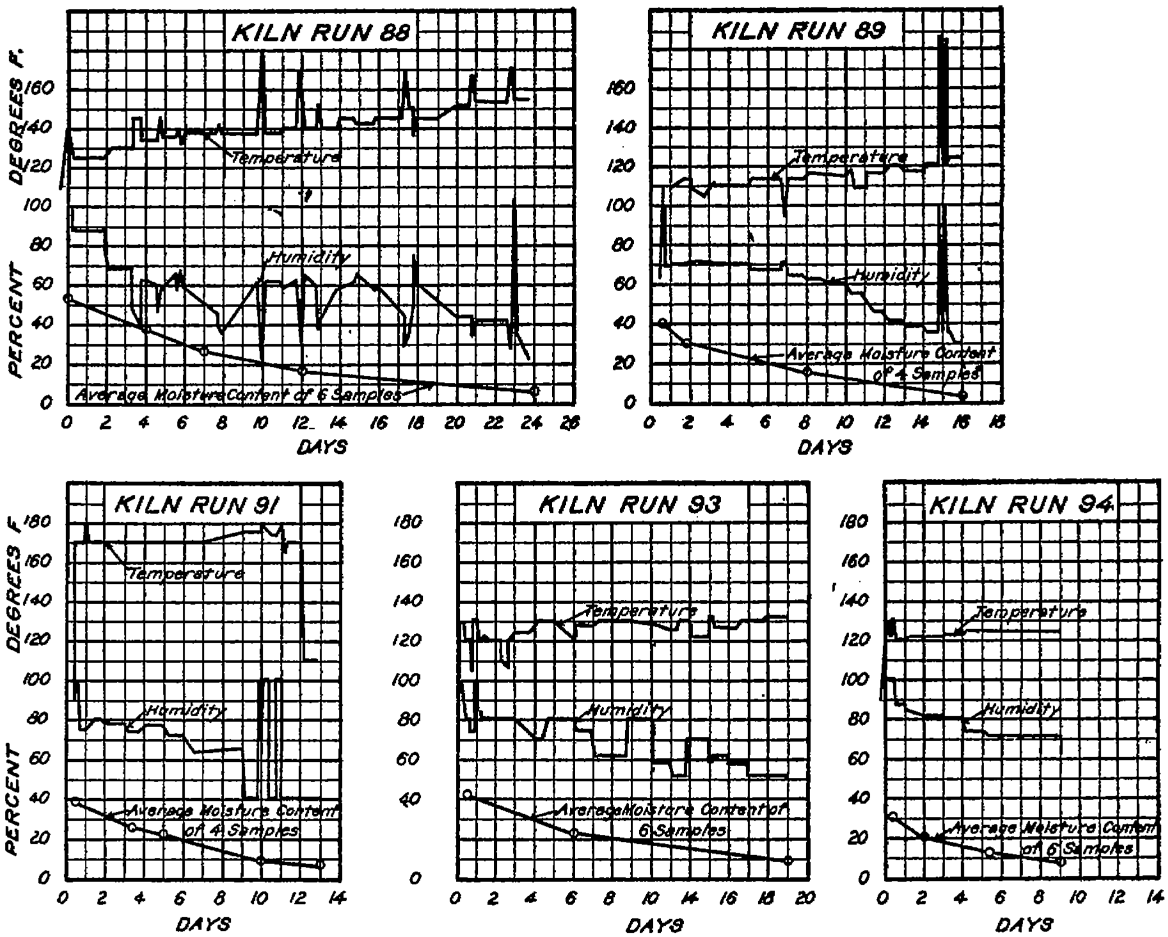

FIG. 3.—Kiln conditions for Sitka spruce, kiln runs 88, 89, 91, 93, 94 (shipment 504).

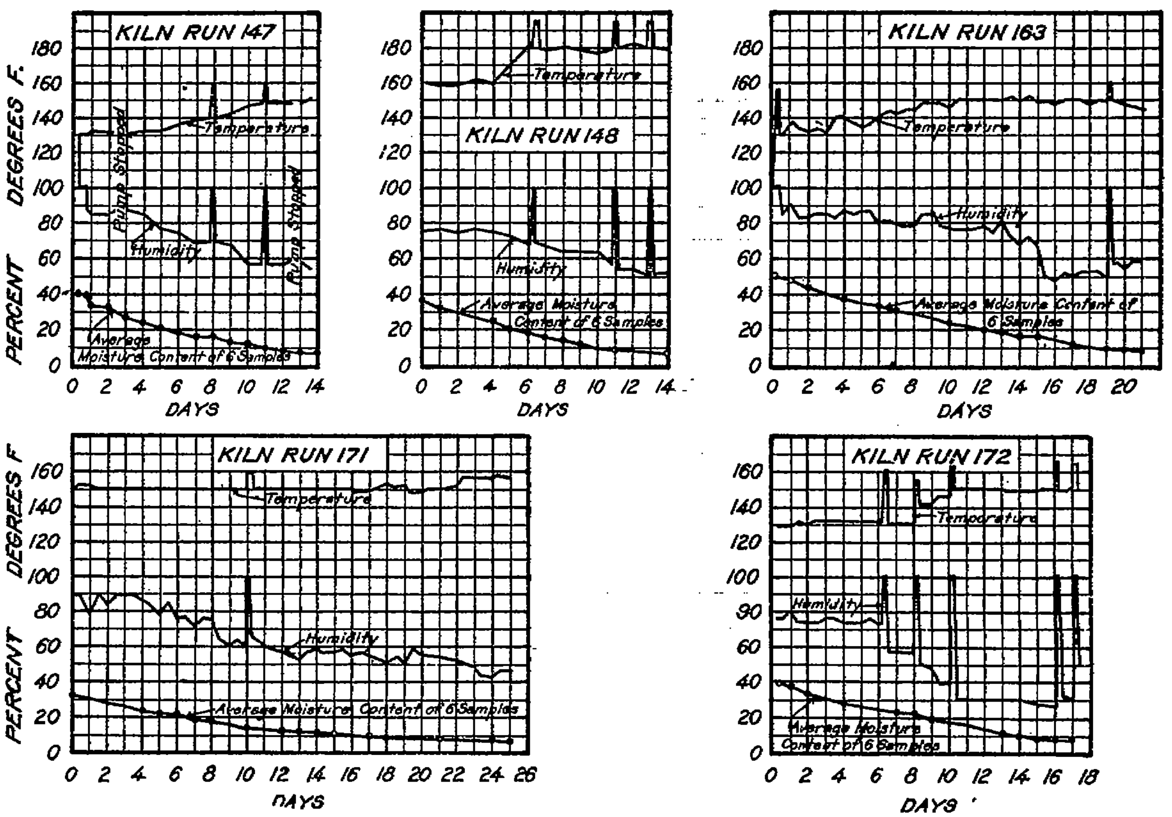

FIG. 4.—Kiln conditions for Sitka spruce, kiln runs 147 and 148 (shipment 568), and runs 163, 171, and 172 (shipment 578).

drying conditions of the two runs, as the temperatures were lower by about 30° F. all through the run and the humidities were higher. (See fig. 3.) In order to get uniform temperatures quickly throughout the planks, runs 88 and 89 were begun with an initial steaming of four or five hours at temperatures of 130° and 150° F., respectively. The very frequent rises in temperature in kiln run 88 (see fig. 3) were due to faulty control apparatus. The stock from both runs appeared to be in excellent condition at the close of the drying, and there was no degrade due to checking, warping, or casehardening. Casehardening had developed during the latter part of the drying

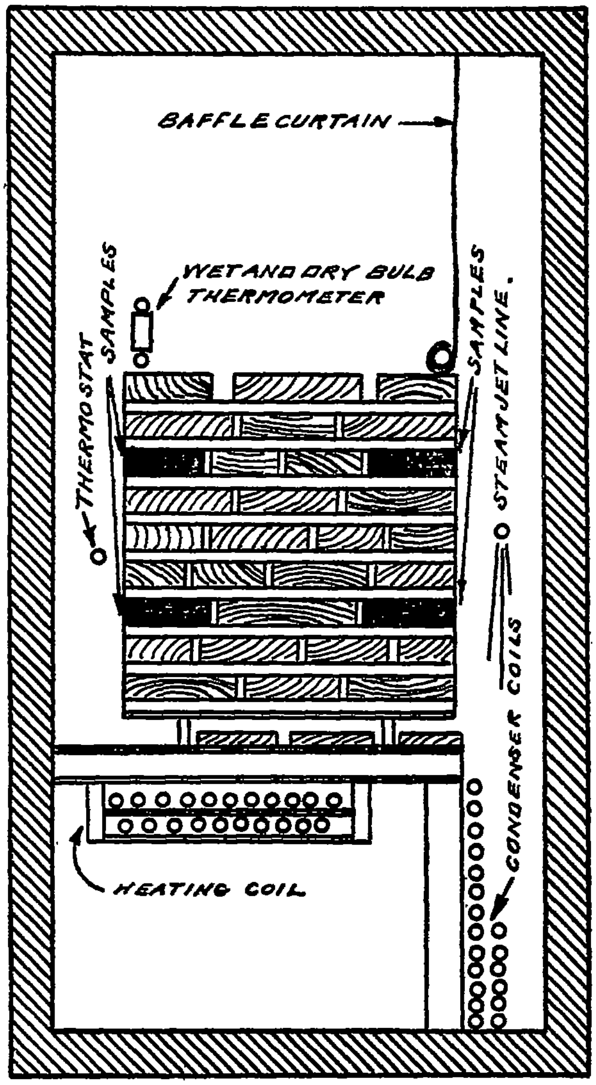

FIG. 5.—Section of kiln and piling diagram, Sitka spruce, kiln run 89.

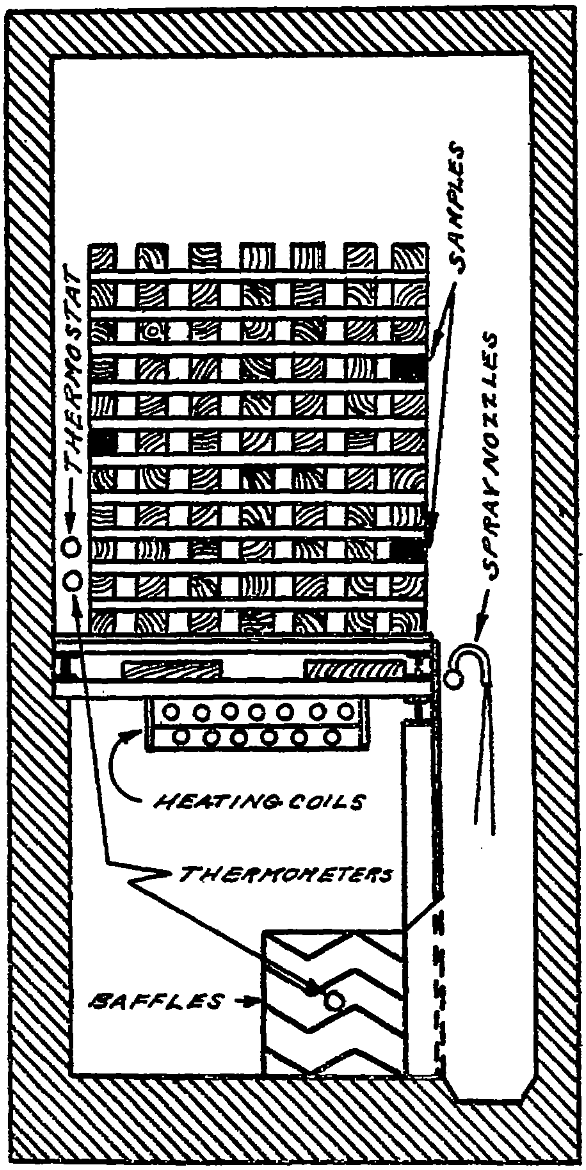

FIG. 6.—Section of kiln and piling diagram, Sitka spruce, kiln run 194.

in both the runs. In run 88 it was relieved by steaming for two hours at 170° F., while in run 89 two steamings at 185° F. were required to do away with the stresses, one of two hours and one of one hour duration.[1]

Kiln runs 91 and 93.—Kiln runs 91 and 93 were made in the same kiln as run 89, so that figure 5, which illustrates the piling and the arrangement of kiln parts for run 89, will suffice for these runs. The stock was of 3-inch thickness, and 1¾-inch stickers were used. The kiln loads were small, as only 600 board feet were dried in each.

[1] H. D. Tiemann's monograph, The Kiln Drying of Wood for Airplanes, includes a discussion of the stresses which are formed during drying.

The material in run 91 was steamed twice to relieve casehardening. These steamings were made at 180° F. for two and one-half hours and for one hour.

No casehardening was found at any time in the material dried in run 93, and therefore steaming was unnecessary.

Kiln run 94.—The kiln arrangement and method of piling used in kiln run 94 are shown in figure 6. In this run the stock was dried, not in the form of 3-inch planks, but in sizes suitable for airplane beam planks. The load consisted of 3 by 4, 2 by 3, 2 by 4, and 2 by 5 inch pieces, all 8 feet in length. The 3 by 4 inch pieces were piled as shown in the diagram, using 1¾-inch stickers and leaving about 3 inches between the sticks of each tier. The 2-inch material was similarly arranged in a separate pile behind that shown in the figure, the kiln being twice as long as the sticks to be dried. The same size stickers and spaces were used. The run was mild and practically a repetition of the temperatures and humidities of run 93 (see fig. 3). The final moisture content was 9.6 per cent, and there was no visible degrade nor any casehardening at any time during the run.

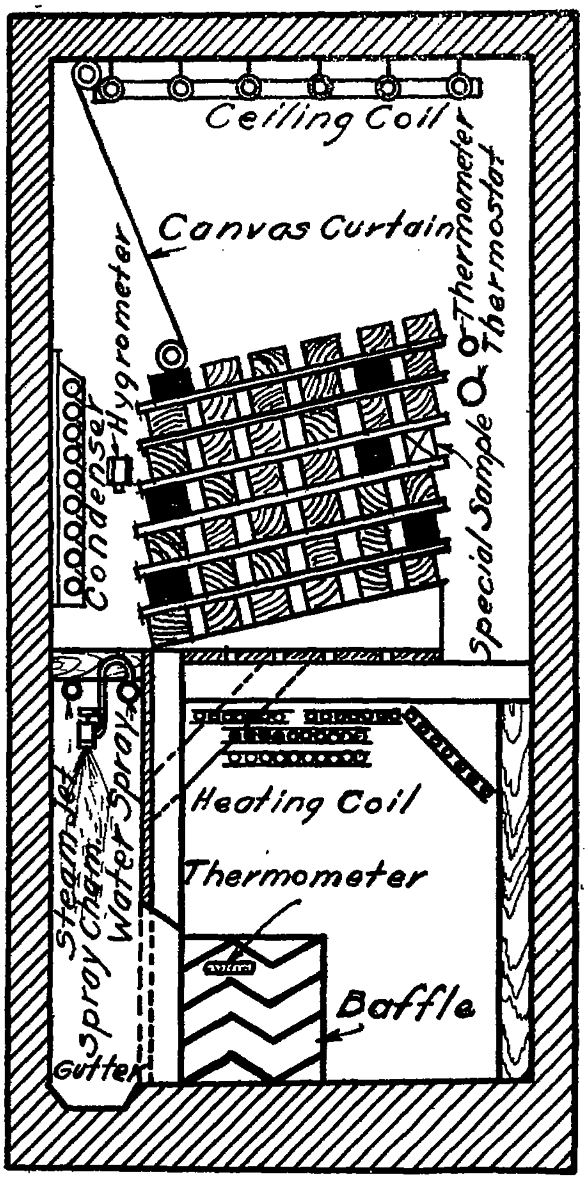

FIG. 7.—Section of kiln showing method of piling Sitka spruce, kiln run 147.

Kiln run 147.—Run 147 was also made on pieces of small size. These were rough-sawed sticks 2½ inches square and 4 feet long. The ends were dipped in an asphalt paint to prevent drying from the ends. The piling was open and on a slant, as shown in figure 7. The material developed slight casehardening, which was relieved by steaming twice at a temperature of 160°, as shown on the temperature and humidity curves of figure 4.

Kiln run 148.—The other kiln run on stock of shipment 563 was numbered 148. This was made for the explicit purpose of finding the effect, on both appearance and strength, of high temperature drying with moderate humidities. The load was a large one for the size of kiln, consisting of 2,400 board feet of 3-inch planks, which were flat-piled with no spaces between the planks. The kiln was of the type shown in figure 6. The kiln conditions and average moisture contents of the samples are shown in figure 4.

Kiln runs 163, 171, and 172.—Of the three kiln runs on stock from shipment 578 the two runs numbered 163 and 172 were practically the same with respect to piling and the temperatures used. Both runs were made in water-spray kilns. The arrangements of the kilns and the locations of the measuring and controlling instruments were practically the same as is shown in figure 6. The stock was in the form of 2½-inch planks, 8 feet long, and varied in width from 6 to 18 inches. The piling was flat, with 1½-inch stickers and with 2-inch spaces between the planks of each tier.

The stock of run 163 was given a preliminary steaming of two hours at 155° F. in order to warm the planks through before drying conditions were established. The temperatures, humidities, and the average moistures for the six samples varied from day to day according to the curves of figure 4. There was a 2 per cent degrade in this run, due to warping and to surface checking in the sapwood of some of the planks.

Run 171 was a constant-temperature run, the temperature being 150° F. except during the last three days, when it was 156° F.

THE AIR DRYING.

Material of shipment 504, matching that kiln dried in runs 88, 89, 91, 93, and 94, was air dried in the form of sticks 2½ by 2½ inches by 4 feet, the ends being carefully paraffined to prevent end drying. It was dried for about one year, from midsummer 1917 to midsummer 1918 in a shed without artificial heat. The shed was open on the north and closed on the other three sides. The specimens were piled about 7 feet above the ground, midway between the ground and the roof of the shed. The conditions thus secured were considered as favorable for perfect air drying as are obtainable. When stored for drying the average moisture content of the group of sticks matching two of the kiln runs (88 and 89) was about 49.1 per cent, and for another group of sticks matching kiln runs 91, 93, and 94 about 41.5 per cent. The final moisture contents, after the material appeared to have reached constant weight, as indicated by periodic weighing of samples, were found to be very uniform and somewhat higher than was anticipated.[1] For six samples they were 14.0, 14.3, 14.2, 14.3, 14.3, and 14.5 per cent, giving an average of 14.3 per cent. The moisture at the time of test was nearly 2 per cent less, since some time necessarily elapsed from the time of removal from the drying shed, during which time the sticks were stored indoors in a warmer and drier atmosphere.

STRENGTH DATA.

The conclusions which are to be drawn regarding the effect, on the strength of Sitka spruce, of the various conditions of seasoning just described are based on the study of a series of tables giving both the mechanical properties of the various groups of material and the improvement ratios. The ratios are further presented in graph form for the sake of ready intercomparison.

TABLE 1.—*Mechanical properties of Sitka spruce. Tabulation of test data. No adjustment for moisture.*

Properties.	Tree 186. Shipment 325. From Chehalis County, Wash.		Shipment 504. From Clatsop County, Oreg.								
	Green.	Air-dry.	Green matching kiln runs 88, 89.	Air-dry matching kiln runs 88, 89.	Kiln run 88.	Kiln run 89.	Green matching kiln runs 91, 93, 94.	Air-dry matching kiln runs 91, 93, 94.	Kiln run 91.	Kiln run 93.	Kiln run 94.
STATIC BENDING.											
Moisture (per cent)[2]	54.4	8.8	49.1	12.4	9.1	10.7	41.5	12.5	10.7	11.1	9.4
Specific gravity[3]	.329	.353	.346	.377	.380	.369	.338	.367	.362	.366	.368
Fiber stress at elastic limit (lbs. per sq. in.)	2,730	6,520	3,060	5,910	6,870	6,090	3,240	5,780	5,820	6,160	7,320
Fiber stress at maximum load (lbs. per sq. in.)	5,200	10,500	5,040	8,470	10,440	9,110	4,820	8,430	9,220	8,890	10,200
Modulus of elasticity (1,000 lbs. per sq. in.)	1,050	1,410	1,163	1,352	1,551	1,418	1,065	1,394	1,373	1,478	1,517
Work to elastic limit (inch-lbs. per cu. in.)	.43	1.74	.47	1.56	1.71	1.50	.57	1.33	1.43	1.43	2.01
Work to maximum load (inch-lbs. per cu. in.)	5.7	9.2	5.4	7.44	8.3	7.7	5.4	7.34	9.5	6.7	7.6
Work, total (inch-lbs. per cu. in.)	17.9	19.9	17.1	....	14.6	13.4	13.1	....	15.4	....	....
IMPACT BENDING, 50-POUND HAMMER.											
Moisture (per cent)[2]	73.2	9.0	46.1	13.0	9.1	11.7	44.1	12.2	10.8	10.6	9.2
Specific gravity[3]	.33	.37	.352	.377	.375	.366	.339	.378	.360	.365	.374
Fiber stress at elastic limit (lbs. per sq. in.)	7,220	12,680	8,020	10,120	11,590	10,900	7,690	9,940	10,380	10,710	12,140
Modulus of elasticity (1,000 lbs. per sq. in.)	1,366	1,845	1,307	1,618	1,702	1,650	1,244	1,663	1,696	1,731	1,930
Work to elastic limit (inch-lbs. per cu. in.)	2.2	4.8	2.8	3.5	4.4	4.1	2.7	3.4	3.6	3.7	4.3
Inches drop 50-pound hammer to failure	24.0	29.0	21.0	22.4	24	22	19	19.5	23	21	25
COMPRESSION PARALLEL TO GRAIN.											
Moisture (per cent)[2]	54.4	8.9	49.0	12.5	9.2	10.5	41.6	12.9	10.4	11.7	8.2
Specific gravity[3]	.32	.35	.343	.374	.378	.371	.337	.363	.362	.363	.373
Rings per inch	6.1	8.9	14.8	6.9	16.6	17.4	13.9	7.4	18.4	13.8	14.9
Summerwood (per cent)	20	16	24	34	....	....	....	35	....	66	55
Fiber stress at elastic limit (lbs. per sq. in.)	1,680	4,930	1,860	....	5,010	4,530	1,950	....	4,600	....	....
Fiber stress at maximum load (lbs. per sq. in.)	2,280	5,070	2,200	4,680	5,530	5,100	2,190	4,580	5,120	5,400	6,400

[1] Very probably material which is air dried even in such small sizes does not reach its absolute minimum of moisture for several years.
[2] Per cent moisture based on oven-dry weight.
[3] Specific gravity based on oven-dry weight and volume as tested.

TABLE 1.—*Mechanical properties of Sitka spruce. Tabulation of test data. No adjustment for moisture*—Continued.

Properties.	Shipment 563. From Multnomah County, Oreg.				Shipment 578.					
	Green matching kiln run 147.	Kiln run 147.	Green matching kiln run 148.	Kiln run 148.	Green matching kiln run 163.	Kiln run 163.	Green matching kiln run 171.	Kiln run 171.	Green matching kiln run 172.	Kiln run 172.
STATIC BENDING.										
Moisture (per cent) [1]	40.5	10.3	37.9	11.5	46.2	12.6	41.8	9.9	40.0	10.6
Specific gravity [2]	.400	.425	.397	.424	.338	.364	.362	.382	.368	.381
Fiber stress at elastic limit (lbs. per sq. in.)	3,279	7,582	3,750	7,333	3,410	5,160	3,210	6,910	3,180	7,220
Fiber stress at maximum load (lbs. per sq. in.)	5,967	10,756	6,084	10,942	5,180	8,720	5,160	10,580	5,120	10,520
Modulus of elasticity (1,000 lbs. per sq. in.)	1,444	1,503	1,474	1,635	1,088	1,248	1,063	1,448	1,061	1,403
Work to elastic limit (inch-lbs. per cu. in.)			.62	1.91	.66	1.66	.52	1.87	.55	1.10
Work to maximum load (inch-lbs. per cu. in.)	6.30	10.01	6.28	9.09	6.86	8.66	5.70	8.75	6.41	9.13
Work, total (inch-lbs. per cu. in.)										12.50
IMPACT BENDING, 50-POUND HAMMER.										
Moisture (per cent) [1]	40.3	10.7	37.1	11.8	44.1	10.7	42.0	10.7	42.8	9.8
Specific gravity [2]	.397	.432	.396	.424	.346	.375	.370	.373	.372	.385
Fiber stress at elastic limit (lbs. per sq. in.)			9,654	11,843	7,300	11,420	7,870	11,880	7,840	9,780
Modulus of elasticity (1,000 lbs per sq. in.)			1,556	1,804	1,278	1,724	1,181	1,623	1,168	1,653
Work to elastic limit (inch-lbs. per cu. in.)			3.4	4.2	2.4	4.2	2.9	4.9	3.0	3.8
Inches drop 50-pound hammer to failure	23.7	32.0	24.7	25.4	27.5	26.6	26.7	24.3	23.8	24.2
COMPRESSION PARALLEL TO GRAIN.										
Moisture (per cent) [1]	40.9	11.3	38.2	12.3	48.8	12.2	40.1	9.6	40.8	10.7
Specific gravity [2]	.401	.427	.393	.427	.345	.370	.357	.378	.356	.384
Rings per inch			13.4	9.04	8.4	7.2	6.2	6.6	6.8	8
Summerwood (per cent)			44	38	42	32	35	38	38	34
Fiber stress at elastic limit (lbs. per sq. in.)										
Fiber stress at maximum load (lbs. per sq. in.)	2,875	5,973	2,840	6,234	2,390	4,240	2,410	6,060	2,380	5,920

[1] Per cent moisture based on oven-dry weight. [2] Specific gravity based on oven-dry weight and volume as tested.

The mechanical properties of all the groups of material for all conditions of seasoning are given in the single Table 1. An additional special table of data for comparing runs 147 and 148 is Table 9. These properties are average values of the average for all tests from each double bolt, or 8-foot log. For example: It has already been mentioned that kiln run 88 was made on material from three logs of shipment 504. They were the *a–b* and *i–j* bolts of tree 2 and bolt *e–f* of tree 3. The average property was determined for each bolt separately and the values given in the table are the averages of the bolt averages.

The four succeeding tables (Tables 2 to 5 inclusive) tabulate improvement ratios. They are obtained by different groupings of the data according to the points to be brought out. The first three of these tables (2, 3, and 4) pertain only to shipment 504, for which the air-dry tests completing the work have been made.

TABLE 2.—*Improvement ratio, Sitka spruce, air-dried and kiln-dried, with and without adjustment to 11 per cent moisture.*[1]

$$\text{Improvement ratio} = \frac{\text{Dry strength}}{\text{Green strength}}$$

Properties.	Air-dry shipment 325.		Shipment 504.													
			Air-dry to match kiln runs 88 and 89.		Kiln run 88.		Kiln run 89.		Air-dry to match kiln runs 91, 93, and 94.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.
STATIC BENDING.																
Fiber stress at elastic limit	2.39	2.09	1.93	2.10	2.24	2.00	1.98	1.95	1.78	1.93	1.80	1.78	1.90	1.91	2.26	2.05
Modulus of rupture	2.02	1.81	1.68	1.80	2.08	1.88	1.81	1.78	1.75	1.90	1.91	1.88	1.84	1.85	2.12	1.94
Modulus of elasticity	1.36	1.30	1.16	1.18	1.34	1.29	1.22	1.21	1.31	1.36	1.29	1.28	1.39	1.39	1.42	1.36
Work to maximum load	1.63	1.52	1.38	1.48	1.54	1.45	1.48	1.42	1.36	1.42	1.76	1.74	1.24	1.24	1.41	1.35
Total work	1.05	1.04			.85	.87	.78	.78			1.18	1.18				
IMPACT BENDING, 50-POUND HAMMER.																
Fiber stress at elastic limit	1.76	1.62	1.26	1.32	1.44	1.37	1.36	1.39	1.29	1.33	1.35	1.34	1.39	1.38	1.58	1.49
Modulus of elasticity	1.35	1.29	1.24	1.30	1.30	1.25	1.25	1.27	1.34	1.38	1.36	1.35	1.39	1.38	1.55	1.46
Height of drop	1.21	1.18	1.07	1.08	1.14	1.12	1.05	1.05	1.03	1.03	1.21	1.21	1.11	1.11	1.32	1.27
COMPRESSION PARALLEL TO GRAIN.																
Fiber stress at elastic limit					2.70	2.37	2.44	2.35			2.35	2.25				
Fiber stress at maximum load	2.22	1.97	2.12	2.37	2.50	2.22	2.32	2.24	2.07	2.37	2.34	2.25	2.47	2.61	2.92	2.38

[1] Fiber-saturation point=23 per cent. I. R.=Improvement ratio.

Table 2 presents ratios derived from the properties of material of shipments 325 and 504 as presented in Table 1. Ratios are given both with and without adjustment for moisture content. The next table (Table 3) was made up for the reason that the original data showed a consistent variation in the strength properties according as the test specimens came from near the central or the outer portions of the tree. It was thought that better comparisons between kiln-dried, green, and air-dried material would be had by using smaller units of matching—that is, by groups more inherently alike. Table 3 gives by inner and outer portions the properties of each bolt. ("Outer" and "inner" portions are divided by the circumferential splitting lines as illustrated in fig. 1 (E).) The improvement ratios included are based on average values of properties of bolts.

TABLE 3.—*Properties of Sitka spruce, shipment 504 (also improvement ratios with and without adjustment to 11 per cent moisture).*

SUMMARY OF INNER PORTION OF TREES ONLY.

	Tree and bolt.	Seasoning.	Static bending.					Impact bending, 50-pound hammer.			Compression parallel to grain.			
			Number of tests.	Moisture.	M. of R.	M. of E.	Work.	Number of tests.	Moisture.	Ht. of drop.	Number of tests.	Moisture.	Sp. gr. test.	M. C. S.
				Per cent.	*Pounds per square inch.*	*1,000 pounds per square inch.*	*Inch-pounds per cubic inch.*		*Per cent.*	*Inches.*		*Per cent.*		*Pounds per square inch.*
	2 a-b	Green to match kiln runs 88 and 89.	17		4,670	1,185	5.8	8		26	35		0.336	2,100
	2 i-j		14		4,640	1,140	4.9	9		18	28		.326	2,050
	3 e-f		19		5,370	1,270	5.3	8		21	40		.377	2,440
Average					4,890	1,198	5.3			21.7			.346	2,200
	2 a-b	Air dry to match kiln runs 88 and 89.	15	12.4	8,240	1,266	7.50	9	12.8	22.7	33	12.7	.367	4,590
	2 i-j		15	12.1	8,220	1,347	7.41	7	13.1	22.7	31	12.2	.358	4,740
	3 e-f		18	12.6	8,830	1,589	7.54	9	12.9	25.5	43	12.3	.411	4,890
Average				12.4	8,430	1,401	7.48		12.9	23.6		12.4	.379	4,740
I. R. at test					1.72	1.17	1.41			1.09				2.16
I. R.$_{11}$					1.85	1.20	1.48			1.11				2.39
	2 a-b	Kiln run 88	6	9.5	10,100	1,585	8.1	5	9.7	27	11	9.5	.378	5,780
	2 i-j		3	9.8	9,730	1,515	8.5	4	9.5	25	8	9.0	.368	5,140
	3 e-f		6	7.6	10,890	1,650	8.7	8	7.8	26	12	7.8	.408	6,440
Average				9.0	10,240	1,583	8.4		9.0	26.0		8.8	.383	5,790
I. R. at test					2.09	1.32	1.58			1.20				2.63
I. R.$_{11}$					1.89	1.27	1.48			1.17				2.26
	2 a-b	Kiln run 89	7	11.0	8,530	1,460	6.4	7	10.7	20	14	10.0	.308	5,460
	2 i-j		3	10.5	11,000	1,720	9.6	8	8.7	29	6	9.3	.361	5,500
	3 e-f		4	12.1	9,020	1,555	8.0	6	13.2	23	12	11.4	.401	5,180
Average				11.2	9,520	1,578	8.0		10.9	24.0		10.2	.357	5,380
I. R. at test					1.95	1.32	1.51			1.11				2.44
I. R.$_{11}$					1.97	1.33	1.52			1.11				2.31
	1 c-d	Green to match kiln runs 91, 93, and 94.	18		4,710	1,130	4.5	8		15	36		.340	2,220
	1 i-j		18		5,130	1,140	6.0	9		19	39		.341	2,210
	4 e-f		22		4,620	1,094	5.6	5		21	49		.327	2,140
Average					4,820	1,121	5.4			18.3			.336	2,190
	1 c-d	Air dry to match kiln runs 91, 93, and 94.	19	12.0	8,220	1,450	7.85	8	11.8	13.8	38	12.8	.368	4,590
	1 i-j		23	12.1	9,030	1,503	8.22	8	11.4	22.8	41	12.6	.369	4,930
	4 e-f		23	12.8	8,180	1,414	7.58	9	13.0	21.1	46	12.8	.355	4,250
Average				12.1	8,477	1,456	7.88		12.1	19.2		12.7	.364	4,590
I. R. at test					1.76	1.29	1.46			1.05				2.09
I. R.$_{11}$					1.86	1.32	1.52			1.06				2.36
	1 c-d	Kiln run 91												
	1 i-j		6	11.4	9,110	1,366	12.4	6	11.6	28	12	10.8	.370	5,410
	4 e-f		3	11.4	9,180	1,690	7.8	4	11.5	22	8	11.4	.366	5,470
Average				11.4	9,140	1,528	10.1		11.6	25		11.1	.368	5,440
I. R. at test					1.90	1.36	1.87			1.36				2.48
I. R.$_{11}$					1.94	1.38	1.91			1.38				2.50
	1 c-d	Kiln run 93	4	11.2	7,780	1,620	5.2	3	10.2	21	8	12.0	.378	5,710
	1 i-j		2	12.4	9,480	1,552	7.5	2	11.0	24	4	12.8	.376	5,590
	4 e-f		2	10.0	9,610	1,450	8.8	2	9.6	24	4	10.3	.355	5,960
Average				11.2	8,960	1,541	7.2		10.3	23.0		11.7	.370	5,750
I. R. at test					1.86	1.37	1.33			1.26				2.63
I. R.$_{11}$					1.88	1.38	1.34			1.24				2.79
	1 c-d	Kiln run 94	1	6.8	11,090	1,255	13.1	1	7.7	31	2	7.1	.379	7,620
	1 i-j		3	9.4	9,120	1,436	7.2	4	8.9	32	6	7.7	.377	7,170
	4 e-f		1	10.9	9,560	1,426	6.6	1	10.0	29	2	9.3	.374	5,760
Average				9.0	9,920	1,372	9.0		8.9	30.7		8.0	.377	6,850
I. R. at test					2.06	1.22	1.67			1.68				3.13
I. R.$_{11}$					1.85	1.19	1.55			1.55				2.49

TABLE 3.—*Properties of Sitka spruce, shipment 504 (also improvement ratios with and without adjustment to 11 per cent moisture*—Continued.

SUMMARY OF OUTER PORTION OF TREES ONLY.

	Tree and bolt.	Seasoning.	Static bending.					Impact bending, 50-pound hammer.			Compression parallel to grain.			
			Number of tests.	Moisture.	M. of R.	M. of E.	Work.	Number of tests.	Moisture.	Ht. of drop.	Number of tests.	Moisture.	Sp. gr. test.	M. C. S.
				Per cent.	*Pounds per square inch.*	*1,000 pounds per square inch.*	*Inch-pounds per cubic inch.*		*Per cent.*	*Inches.*		*Per cent.*		*Pounds per square inch.*
	2 a-b..	Green to match kiln runs 88 and 89.	23		5,360	1,285	5.7	8		23	36		0.347	2,380
	2 i-j...		19		5,250	1,189	5.8	7		20	29		.337	2,300
	3 e-f...		22		4,750	974	5.0	5		19	43		.335	1,970
Average					5,120	1,133	5.5			20.7			.340	2,217
	2 a-b..	Air dry to match kiln runs 91, 93, and 94.	20	12.1	8,854	1,381	8.02	7	12.7	24	28	12.6	.380	4,860
	2 i-j...		19	12.0	8,550	1,374	8.01	9	12.5	21.5	27	12.3	.364	4,850
	3 e-f...		21	12.5	8,060	1,166	6.13	6	13.2	17.7	36	13.0	.365	4,130
Average				12.2	8,485	1,307	7.39		12.8	21.1		12.6	.370	4,613
I. R. at test					1.66	1.15	1.34			1.02				2.08
I. R.$_{11}$					1.76	1.17	1.38			1.02				2.33
	2 a-b..	Kiln run 88...	19	9.9	10,580	1,565	8.7	20	9.8	24	37	10.3	.388	5,480
	2 i-j...		9	8.7	11,620	1,706	9.5	9	8.9	26	19	9.0	.375	5,740
	3 e-f...		17	8.8	9,230	1,344	6.5	18	8.8	20	39	8.7	.369	5,170
Average				9.1	10,480	1,538	8.2		9.2	23.3		9.3	.377	5,460
I. R. at test					2.05	1.36	1.49			1.12				2.46
I. R.$_{11}$					1.86	1.30	1.41			1.10				2.20
	2 a-b..	Kiln run 89...	16	11.8	9,520	1,442	8.4	16	12.1	22	31	10.2	.386	5,560
	2 i-j...		15	8.8	10,400	1,528	8.9	13	9.2	23	30	9.1	.358	5,630
	3 e-f...		17	13.9	7,270	1,177	5.8	16	14.8	17	37	12.6	.360	4,090
Average				11.5	9,060	1,382	7.7		12.0	20.7		10.6	.368	5,090
I. R. at test					1.77	1.22	1.40			1.00				2.29
I. R.$_{11}$					1.81	1.23	1.42			1.00				2.23
	1 c-d..	Green to match kiln runs 91, 93, 94.	17		4,700	945	5.2	7		18	35		.334	2,180
	1 i-j...		18		4,920	1,095	5.2	7		17	32		.333	2,230
	4 e-f...		26		4,830	990	5.8	11		21	45		.345	2,190
Average					4,820	1,010	5.4			18.7			.337	2,200
	1 c-d..	Air dry to match kiln runs 91, 93, and 94.	16	12.6	8,440	1,441	7.10	7	12.1	20.0	29	12.8	.362	4,520
	1 i-j...		16	12.2	8,500	1,387	7.72	8	12.1	21.5	32	12.9	.360	4,640
	4 e-f...		29	12.9	8,110	1,199	6.84	5	12.6	17.2	41	13.3	.365	4,200
Average				12.6	8,350	1,342	7.22		12.3	19.6		13.0	.362	4,453
I. R. at test		93 and 94			1.73	1.33	1.33			1.05				2.02
I. R.$_{11}$					1.88	1.39	1.39			1.06				2.33
	1 c-d..	Kiln run 91...	12	10.9	9,800	1,425	11.6	11	11.1	23	25	10.3	.352	5,190
	1 i-j...		8	9.6	9,620	1,315	8.9	8	8.5	21	16	9.3	.355	5,110
	4 e-f...		14	12.0	8,300	1,288	6.1	11	11.6	19	31	10.7	.367	4,810
Average				10.8	9,240	1,343	8.9		10.4	21.0		10.1	.360	5,040
I. R. at test					1.92	1.33	1.65			1.12				2.29
I. R.$_{11}$					1.90	1.33	1.64			1.11				2.16
	1 c-d..	Kiln run 93...	4	10.2	8,930	1,458	6.6	4	10.6	20	8	12.0	.350	5,040
	1 i-j...		6	11.8	9,210	1,600	7.4	6	11.2	25	10	11.7	.363	5,710
	4 e-f...		6	11.1	8,840	1,265	6.2	5	10.5	17	11	11.4	.360	4,770
Average				11.0	8,990	1,441	6.7		10.8	20.7		11.7	.358	5,170
I. R. at test					1.86	1.43	1.24			1.11				2.35
I. R.$_{11}$					1.86	1.43	1.24			1.11				2.48
	1 c-d..	Kiln run 94...	6	9.5	10,020	1,530	7.3	9	9.2	24	18	7.8	.366	6,200
	1 i-j...		6	9.8	10,800	1,720	8.1	5	9.7	28	12	9.0	.379	6,880
	4 e-f...		8	9.4	10,280	1,435	6.9	8	9.1	21	13	8.3	.374	5,910
Average				9.6	10,370	1,562	7.4		9.3	24.3		8.4	.373	6,330
I. R. at test					2.15	1.55	1.37			1.30				2.88
I. R.$_{11}$					1.99	1.48	1.33			1.26				2.39

Explanation of terms, etc.:
- Moisture content based on oven-dry weight
- M. of R.=Modulus of rupture—pounds per square inch.
- M. of E.=Modulus of elasticity—1,000 pounds per square inch.
- Wk.=Work to maximum load—inch-pounds per cubic inch.
- M. C. S.=Maximum crushing strength—pounds per square inch.
- Ht. of drop=Height of drop of 50-pound hammer to complete failure—inches.
- I. R.=Improvement ratio $= \frac{\text{dry strength}}{\text{green strength}}$
- I. R.$_{11}$=Improvement ratio—adjusted to 11 per cent moisture.
- Sp. gr. test=Specific gravity based on oven-dry weight and volume as tested.

Improvement ratios based on a still further subdivision of the unit for matching are shown in Table 4. These are derived from some of the values shown in the preceding table. Only the extreme lower and upper bolts from among those available are included, so that the trees 2 and 3, having only the bolts *e–f*, are not represented. Tables 3 and 4 serve the purpose of detecting differences, if any exist, between the effect of drying on material from different parts of the trees, and are useful in supporting the conclusions reached from the study of ratios based on the general properties shown in Table 2.

TABLE 4.—*Summary of improvement ratios according to bolts—Sitka spruce—shipment 504. Kiln runs 88, 89, 91, 93, and 94 and air dry to match.*

Property.	Seasoning.	Tree No.	Bolts.	Inner portion. Lower bolt, A–B or C–D. I. R. as tested.	Inner portion. Lower bolt, A–B or C–D. I. R. adjusted.	Inner portion. Upper bolt, I–J. I. R. as tested.	Inner portion. Upper bolt, I–J. I. R. adjusted.	Outer portion. Lower bolt, A–B or C–D. I. R. as tested.	Outer portion. Lower bolt, A–B or C–D. I. R. adjusted.	Outer portion. Upper bolt, I–J. I. R. as tested.	Outer portion. Upper bolt, I–J. I. R. adjusted.
				1	2	3	4	5	6	7	8
M. of R.	Air dry to match kiln runs 88 and 89.	2	A–B, I–J	1.76	1.90	1.77	1.87	1.65	1.74	1.63	1.71
	Kiln run 88	2	A–B, I–J	2.16	1.98	2.09	1.96	1.97	1.86	2.22	1.95
	Kiln run 89	2	A–B, I–J	1.82	1.82	2.37	2.29	1.78	1.86	1.98	1.78
	Air dry to match kiln runs 91, 93, and 94.	1	C–D, I–J	1.74	1.83	1.76	1.86	1.80	1.97	1.78	1.84
	Kiln run 91	1	C–D, I–J	...	...	...	...	2.08	2.07	1.95	1.82
	Kiln run 93	1	C–D, I–J	1.65	1.67	1.85	2.00	1.90	1.83	1.87	1.96
	Kiln run 94	1	C–D, I–J	2.35	1.86	1.78	1.66	2.14	1.97	2.19	2.04
M. of E.	Air dry to match kiln runs 88 and 89.	2	A–B, I–J	1.07	1.08	1.18	1.20	1.08	1.09	1.21	1.23
	Kiln run 88	2	A–B, I–J	1.34	1.30	1.33	1.30	1.22	1.20	1.50	1.41
	Kiln run 89	2	A–B, I–J	1.23	1.23	1.51	1.48	1.12	1.11	1.34	1.28
	Air dry to match kiln runs 91, 93, and 94.	1	C–D, I–J	1.28	1.31	1.32	1.36	1.52	1.62	1.27	1.30
	Kiln run 91	1	C–D, I–J	...	...	...	...	1.51	1.51	1.20	1.18
	Kiln run 93	1	C–D, I–J	1.43	1.44	1.36	1.42	1.54	1.50	1.46	1.50
	Kiln run 94	1	C–D, I–J	1.11	1.08	1.26	1.23	1.62	1.54	1.57	1.51
Work	Air dry to match kiln runs 88 and 89.	2	A–B, I–J	1.29	1.34	1.51	1.57	1.41	1.46	1.38	1.42
	Kiln run 88	2	A–B, I–J	1.40	1.35	1.73	1.65	1.53	1.48	1.64	1.52
	Kiln run 89	2	A–B, I–J	1.10	1.10	1.96	1.91	1.47	1.51	1.53	1.41
	Air dry to match kiln runs 91, 93, and 94.	1	C–D, I–J	1.74	1.83	1.37	1.41	1.36	1.43	1.48	1.55
	Kiln run 91	1	C–D, I–J	...	...	...	...	2.23	2.22	1.71	1.62
	Kiln run 93	1	C–D, I–J	1.15	1.15	1.25	1.29	1.27	1.25	1.42	1.46
	Kiln run 94	1	C–D, I–J	2.91	2.20	1.20	1.17	1.40	1.35	1.56	1.50
M. C. S.	Air dry to match kiln runs 88 and 89.	2	A–B, I–J	2.19	2.48	2.31	2.54	2.04	2.28	2.11	2.31
	Kiln run 88	2	A–B, I–J	2.75	2.46	2.50	2.19	2.30	2.20	2.49	2.18
	Kiln run 89	2	A–B, I–J	2.60	2.42	2.68	2.37	2.34	2.22	2.45	2.17
	Air dry to match kiln runs 91, 93, and 94.	1	C–D, I–J	2.06	2.34	2.28	2.52	2.07	2.35	2.08	2.39
	Kiln run 91	1	C–D, I–J	...	...	...	...	2.38	2.29	2.30	2.07
	Kiln run 93	1	C–D, I–J	2.57	2.80	2.52	2.97	2.31	2.49	2.36	2.71
	Kiln run 94	1	C–D, I–J	3.42	2.53	3.24	2.52	2.84	2.28	8.08	2.62
Ht. of drop	Air dry to match kiln runs 88 and 89.	2	A–B, I–J	.87	.85	1.26	1.32	1.04	1.05	1.07	1.08
	Kiln run 88	2	A–B, I–J	1.038	1.03	1.39	1.34	1.04	1.04	1.30	1.25
	Kiln run 89	2	A–B, I–J	.77	.78	1.61	1.49	.96	.96	1.15	1.13
	Air dry to match kiln runs 91, 93, and 94.	1	C–D, I–J	.92	.92	1.20	1.21	1.11	1.12	1.25	1.28
	Kiln run 91	1	C–D, I–J	...	...	...	...	1.28	1.28	1.24	1.20
	Kiln run 93	1	C–D, I–J	1.40	1.37	1.26	1.26	1.11	1.11	1.47	1.48
	Kiln run 94	1	C–D, I–J	2.06	1.76	1.68	1.56	1.33	1.28	1.64	1.56

Explanation of terms
M. of R.—Modulus of rupture, static bending.
M. of E.—Modulus of elasticity, static bending.
Work—Work to maximum load, static bending.
M. C. S.—Maximum crushing strength, compression parallel to grain.
Ht. of drop—Height of drop, impact bending.
I. R.—Improvement ratio.
Improvement ratios adjusted to 11 per cent moisture.
Fiber-saturation point—23 per cent.

The improvement ratios for material from shipments 563 and 578 (Table 5), for which the air-dried material is not yet ready for test, are obtained in a somewhat different manner. The ratios are computed for individual double bolts, but without subdivision into inner and outer portions for each kiln run. The averages for the ratios for the several bolts are then regarded as the improvement ratios corresponding to the kiln run. The ratios were so derived for kiln runs 147, 148, 163, 171, and 172, and are shown in Table 5.

TABLE 5.—*Improvement ratios according to bolts (adjusted to 11 per cent moisture).*

[Sitka spruce: Kiln runs 147 and 148, shipment 563, and kiln runs 163, 171, and 172, shipment 578.]

Seasoning.	Tree and bolt.	Static bending.							Impact bending, 50-pound hammer.			Compression parallel to grain.		
		Moisture.	M. of R.		M. of E.		Work to maximum load.		Moisture.	Height of drop.		Moisture.	Max. cr. strength.	
			I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.
		Per ct.							*Per ct.*			*Per ct.*		
	1 a-b......	11.6	1.85	1.91	1.40	1.43	1.84	1.90	12.7	1.21	1.25	12.5	2.10	2.34
	1 c-d......	11.2	1.87	1.89	1.01	1.01	....	....	10.5	1.36	1.35	11.1	2.07	2.08
Kiln run 147 (ship. 563).	2 a-b......	10.5	1.65	1.62	.76	.77	1.52	1.49	10.0	1.46	1.42	10.8	2.01	1.99
	2 c-d......	10.2	1.78	1.72	.93	.93	....	....	9.7	1.55	1.49	11.5	2.19	2.27
	5 c-d......	9.9	1.85	1.76	1.26	1.24	1.30	1.27	10.4	1.25	1.24	10.5	1.93	1.88
Average........	....	....	1.80	1.78	1.07	1.07	1.55	1.53	....	1.37	1.36	....	2.06	2.10
	1 a-b......	12.6	1.64	1.77	1.16	1.19	1.55	1.66	13.1	.89	.87	13.8	1.95	2.39
	1 c-d......	11.1	1.75	1.75	1.10	1.10	1.71	1.72	11.0	1.05	1.05	12.7	2.09	2.36
Kiln run 148 (ship. 563).	2 a-b......	10.1	1.94	1.85	1.29	1.27	1.29	1.27	11.5	1.19	1.20	11.0	2.42	2.42
	2 c-d......	9.7	2.04	1.90	1.24	1.22	1.50	1.44	11.2	1.19	1.19	12.3	2.49	2.79
	5 c-d......	10.9	1.64	1.64	.93	.93	1.17	1.17	12.0	.85	.84	11.8	2.03	2.13
Average........	....	....	1.80	1.78	1.14	1.14	1.44	1.45	....	1.03	1.03	....	2.20	2.42
Kiln run 163 (ship. 578).	2 c-d......	12.8	1.76	1.95	1.14	1.17	1.34	1.41	10.0	.94	.94	12.9	1.81	2.02
	3 e-f......	12.4	1.61	1.71	1.15	1.17	1.17	1.19	11.4	1.00	1.00	11.5	1.74	1.78
Average........	....	....	1.68	1.82	1.14	1.16	1.25	1.29	....	.97	.97	....	1.77	1.89
	1 a-b......	10.6	2.06	2.01	1.17	1.16	1.65	1.63	10.7	.85	.85	10.0	2.41	2.25
Kiln run 171 (ship. 578).	4 a-b......	10.6	1.93	1.89	1.39	1.37	1.44	1.42	13.0	.84	.81	10.0	2.67	2.47
	5 a-b......	9.2	2.10	1.91	1.34	1.29	1.42	1.36	9.4	.84	.86	9.0	2.46	2.16
	6 a-b......	9.1	2.12	1.91	1.44	1.37	1.67	1.56	9.7	1.19	1.17	9.2	2.54	2.25
Average........	....	....	2.05	1.93	1.33	1.30	1.54	1.49	....	.93	.93	....	2.52	2.27
	1 a-b......	9.9	2.08	1.96	1.29	1.27	1.29	1.27	9.7	.82	.84	11.7	2.36	2.49
Kiln run 172 (ship. 578).	4 a-b......	10.0	2.04	1.93	1.25	1.23	1.43	1.39	8.5	.83	.86	10.6	2.41	2.35
	5 a-b......	10.3	2.06	2.00	1.40	1.37	1.48	1.45	10.8	.70	.70	10.2	2.49	2.35
	6 a-b......	12.1	2.03	2.18	1.35	1.39	1.53	1.60	10.2	1.19	1.18	10.1	2.66	2.48
Average........	....	....	2.06	2.01	1.32	1.31	1.43	1.41	....	.89	.90	....	2.48	2.41

M. of R.=Modulus of rupture.
M. of E.=Modulus of elasticity.
Max. cr. strength=Maximum crushing strength.
I. R.=Improvement ratio.
Fiber-saturation point=23 per cent.

The improvement ratios as given in Tables 2, 3, 4, 5, and 10 are put into graphical form in figures 8, 9, and 10. Figure 8 also shows ratios for air seasoning of a closely allied species, red spruce, based on data from a bulletin of the Forest Service.[1] In figure 8 the values plotted for previous air-dry tests of shipment 325 and the values of improvement ratios shown by dotted lines (shipment 504, kiln runs 88, 89, 91, 93, 94) are from Table 2. The last five ratios under each property are the average values taken from Table 5. Ratios from Table 3 are also graphed in this figure.

The ratios of Table 4 are plotted in figure 9. Figure 10 shows the ratios, by individual bolts, for runs 147 and 148, from Table 10. This figure is included because of the bearing of these ratios on the question of the effect of high temperature.

DISCUSSION.

COMPARISON OF KILN-DRIED WITH MATCHED AIR-DRIED MATERIAL.

The outstanding fact indicated by figure 9 and by that part of figure 8 pertaining to material for which air-dry tests are available (shipment 504) is the very general excellence of the material which has been kiln dried, as compared in each case with the corresponding air-dried stock. Irrespective of the unit of matching, whether matched by units of three whole bolts, by the inner and outer portions for three bolts, or by inner and outer portions for individual bolts,

[1] Forest Service Bulletin 70, The Effect of Moisture on the Strength and Stiffness of Wood.

the excellence of the kiln-dried material is general with respect to all of the five properties.

The conclusions as to the relative merits of the various kiln runs are:

(1) Of the two runs 88 and 89 made on the same group of material, 89 is the poorer, although it is better than the corresponding air-dry except in compression parallel, and possibly also in height of drop.

(2) In the other group of material (including runs 91, 93, and 94) kiln run 94 shows, with most consistency, the highest improvement ratio. Taking all the properties into consideration, it is difficult to choose between runs 91 and 93. If, however, we base a decision on the highly important properties of work to maximum load and height of drop, it would be concluded that run 91 is the better, in spite of the higher temperature used throughout the run.

It will be noticed that the air-dried material of the group matching runs 88 and 89 shows about the same improvement over green as does that of the group matching runs 91, 93, and 94, and that they differ considerably less from each other than they do from the air-dry of the previous shipment, 325. The property which is an exception to this statement is the very variable and less important one of modulus of elasticity. This brings out the point that, while the relative suitability of the several kiln runs can be determined by intercomparison of the improvement ratios, it is not possible to state positively that any of them give improvements equal or superior to those to be obtained by air drying until *matched* air-dried material has actually been tested. To illustrate: If tests on the air-dried groups matching kiln runs 88, 89, 91, 93, and 94 were not available, and judgment of these runs had to be based on a comparison of their improvement ratios with those of the previously tested air-dry of shipment 325, and without any allowance for variability, the conclusion would be reached that of these runs 94 alone had yielded stock equal or superior to air-dry. It is now evident that such a comparison would be misleading. It so happens that in this instance this method of comparison is safe, in that it does not give a false idea concerning the safety of kiln-drying. On the other hand, it might happen that such a comparison would lead to the conclusion that a given drying process was entirely safe, when such was not the case. However, in making such comparisons careful consideration must be given to the variations to be expected. This was done in the first analysis of the effect of runs 88, 89, 91, 93, and 94, and the conclusion was reached that, with the possible exception of run 89, all had given satisfactory results. That all the runs, 89 included, have given satisfactory results is indicated by the data presented herein.

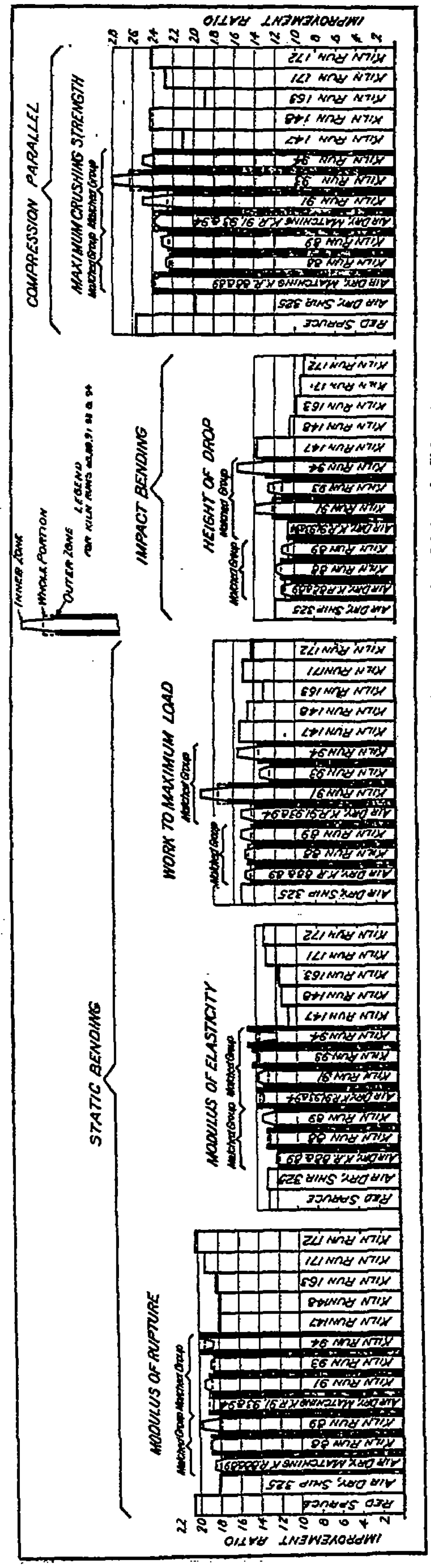

FIG. 8.—Improvement ratios for comparison of ten groups of kiln-dried and three of air-dried stock, Sitka spruce.

The above conclusions have been arrived at by a consideration of the ratios shown in figures 8 and 9, mentally balancing a deficiency in one property against superior excellence in another. While it is necessary to exercise care in any attempt to reduce comparisons to an exact mathematical basis, it is interesting to note how comparisons on such a basis lead to practically the same conclusions as given. Table 6[1] gives the results of a computation of the "efficiencies" of the various runs.

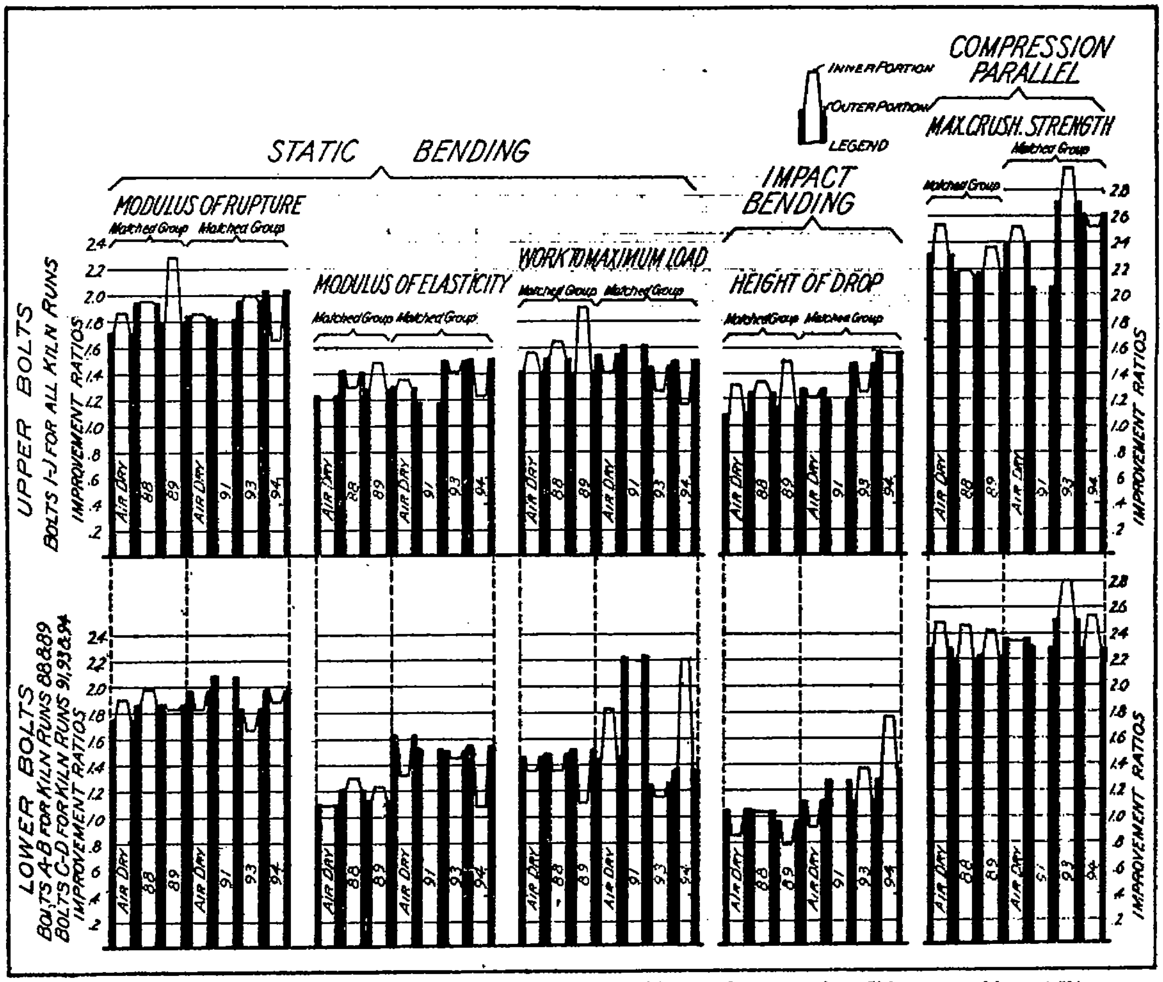

FIG. 9.—Improvement ratios for comparing upper and lower bolts and inner and outer portions, Sitka spruce, shipment 504.

TABLE 6.—*Efficiencies of various kiln runs—Sitka spruce—Shipment 504.*

Property.	F	Kiln run 88.		Kiln run 89.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	104.3	208.6	98.9	197.8	98.9	197.8	97.4	194.8	102.3	204.3
Modulus of elasticity	4	109.0	436.0	102.5	410.0	94.1	376.4	102.3	409.2	100.0	400.0
Work to maximum load	3	102.2	306.6	99.3	297.9	122.6	367.8	87.4	262.2	95.0	285.0
Drop	3	103.8	311.4	97.3	291.9	114.1	342.3	104.8	314.4	119.9	359.7
Maximum crushing strength	2	93.7	187.4	94.5	189.0	95.0	190.0	110.5	221.0	100.5	201.0
ΣE		513.0		492.5		524.7		502.4		517.7	
ΣE÷5=Average E		102.6		98.5		104.9		100.5		103.5	
Σ(E×F)			1,450.0		1,876.6		1,474.3		1,401.6		1,449.9
Σ(E×F)÷ΣF=Weighted average E			103.6		98.3		105.3		100.1		103.6

F=Weighting factor.

$$E = \text{Efficiency} = \frac{\text{Improvement ratio for property of kiln-dry}}{\text{Improvement ratio for same property of corresponding air-dry}}$$

[1] The weighting factors *F* used in this and other tables are those which have been used in computing a composite figure to measure the suitability of various species for aircraft use. The relative importance of the various properties and the applicability of such factors in the present instance might be subject to some question. However, the facts that the "average efficiencies" and "weighted average efficiencies" as given in Table 6 do not differ significantly, and that both methods put the various kiln runs in the same order, indicates that, in the present instance at least, any reasonable weighting scheme would bring approximately the same results.

Table 6 is derived from figure 8 and with its footnotes is self-explanatory. The arrangement of kiln runs in order of descending weighted average efficiencies as obtained from Table 6 is as follows:

	Efficiency (percent).
Air drying	100.0
Kiln run 91	105.3
Kiln run 88	103.6
Kiln run 94	103.6
Kiln run 93	100.1
Kiln run 89	98.3

Comparison with figure 3 shows that the above list puts the kiln runs approximately in descending order with respect to temperatures. It is also notable that, measured by this method, all runs except 89 gave results superior to air drying.

TABLE 7.—*Efficiencies of various kiln runs—Sitka spruce—Shipment 504—Upper bolts.*

(A)—OUTER PORTION.

Property.	F	Kiln run 88.		Kiln run 89.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	113.4	226.8	104.0	208.0	98.9	197.8	106.5	213.0	113.0	226.0
Modulus of elasticity	4	115.3	461.2	104.0	416.0	90.8	363.2	115.2	460.8	116.9	467.6
Work	3	107.0	321.0	99.3	297.9	104.8	314.4	94.1	282.3	96.9	290.7
Drop	3	116.0	348.0	104.5	313.5	93.5	280.5	115.8	347.4	121.6	364.8
Compression	2	94.2	188.4	94.0	188.0	86.6	173.2	113.5	227.0	109.7	219.4
Σ(E×F)			1,545.4		1,423.4		1,329.1		1,530.5		1,568.5
Σ(E×F)÷ΣF=weighted average E			110.4		101.7		94.9		109.3		112.0

(B)—INNER PORTION.

Property.	F	Kiln run 88.		Kiln run 89.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	104.9	209.8	122.3	244.6			107.5	215.0	89.2	178.4
Modulus of elasticity	4	108.2	432.8	124.0	496.0			104.3	417.2	90.5	362.0
Work	3	105.9	317.7	121.6	364.8			89.5	268.5	82.4	247.2
Drop	3	101.5	304.5	113.0	339.0			105.0	315.0	128.0	384.0
Compression	2	86.2	172.4	93.4	186.8			118.0	236.0	100.0	200.0
Σ(E×F)			1,437.2		1,631.2				1,451.7		1,371.6
Σ(E×F)÷ΣF=weighted average E			102.7		116.5				103.7		97.9

F=Weighting factor

$$E = \text{Efficiency} = \frac{\text{Improvement ratio for property of kiln dry}}{\text{Improvement ratio for same property of corresponding air dry}}$$

TABLE 8.—*Efficiencies of kiln runs—Sitka spruce—Shipment 504—Lower bolts.*

(A)—OUTER PORTION.

Property.	F	Kiln run 88.		Kiln run 89.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	106.9	213.8	106.9	213.8	105.0	210.0	92.9	185.8	100.0	200.0
Modulus of elasticity	4	110.0	440.0	101.9	407.6	93.8	375.2	92.5	370.0	95.0	380.0
Work	3	101.2	303.6	103.3	309.9	155.0	465.0	87.4	262.2	94.4	283.2
Drop	3	98.1	294.3	90.6	271.8	114.2	342.6	100.0	300.0	114.2	342.6
Compression	2	96.5	193.0	97.4	194.8	92.6	185.2	105.5	211.0	96.5	193.0
Σ(E×F)			1,444.7		1,397.9		1,578.0		1,329.0		1,398.8
Σ(E×F)÷ΣF=weighted average E			103.2		99.7		112.7		94.7		99.0

(B)—INNER PORTION.

Property.	F	Kiln run 88.		Kiln run 89.		Kiln run 91.		Kiln run 93.		Kiln run 94.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	104.1	208.2	95.7	191.4			91.1	182.2	103.1	206.2
Modulus of elasticity	4	120.2	480.8	114.9	459.6			119.0	476.0	88.5	354.0
Work	3	100.9	302.7	82.0	246.0			62.8	188.4	120.1	360.3
Drop—impact	3	121.0	363.0	91.7	275.1			148.9	446.7	191.2	573.6
Compression	2	99.1	198.2	97.5	195.0			119.7	239.4	108.0	216.0
Σ(E×F)			1,552.9		1,367.1				1,532.7		1,710.1
Σ(E×F)÷ΣF=weighted average E			111.0		97.5				109.5		122.1

F=Weighting factor

$$E = \text{Efficiency} = \frac{\text{Improvement ratio for property of kiln dry}}{\text{Improvement ratio for same property of corresponding air dry}}$$

Tables 7 and 8 present data similar to those of Table 6, but derived from figure 9. They show efficiency figures for various smaller groups of material. Tables 7 and 8, as would be expected, disclose considerably greater variations than are shown in Table 6. The averages naturally show variations from those of Table 6. In no case, however, is the drop of these averages below 100 per cent serious. Some rather low "efficiencies" for individual properties are found among these figures for smaller groups of material. It is notable, however, that there are few cases in which both work to maximum load and drop, or both modulus of rupture and maximum crushing strength, fall low. It is doubtful also whether such variations as are found in these tables can be supposed to be the result of the kiln processes. It is more probable that they result from actual inherent differences between the kiln-dried and air-dried material. Such differences are more likely to occur between small groups than between large ones. In other words, the differences between small groups of tests are likely to have little meaning, and conclusions as to the effect of the kiln processes can best be reached from consideration of the larger groups.

Table 6, then, leads to the following conclusions, which are practically the same as those previously stated:

1. Runs 88, 91, 93, and 94 have produced material equal or superior to material that was air-dried.

2. Run 89 is probably the poorest of the runs, but may be considered practically equal to the air-dry.

From Nos. 1 and 2 would follow:

3. Within the limits used, 115° to 180° F., the strength properties of Sitka spruce are independent of the temperature of drying (but see following paragraph).

As has been mentioned, it is to be expected that a given process or set of drying conditions will have a different effect on different groups of material from the same species, and that it may be possible for a process to be safe for one group and very damaging to another. This expectation has been fulfilled in this series of tests, and consideration of some of the runs yet to be discussed necessitates a considerable modification of conclusion No. 3 above.

DISCUSSION OF RUNS FOR WHICH DATA ON MATCHED AIR-DRIED MATERIAL ARE NOT YET AVAILABLE.

Consideration is now to be given to material from additional kiln runs. Air-dried material matched to that dried in these runs and tested is not yet available for test.

Runs 147 and 148.—Two of these runs (147 and 148) are particularly worthy of attention.

Run 147 was made on pieces 2¼ by 2¼ inches in section, by 4 feet long. The temperature was 130° F. at the beginning and 150° F. at the end. The humidity and steaming treatments were so regulated as to keep casehardening at a minimum. Run 148 was on material from the same logs as run 147; material was in the form of wide planks 2¼ inches thick and the temperatures were 160° F. initial and 180° F. final.

Strength data for these runs are given in Tables 1 and 9. Improvement ratios are shown in Table 5 and in figure 8. These improvement ratios are based on all the material in each run as compared to corresponding green material, and serve for a general comparison of these two with other runs.

TABLE 9.—*Mechanical properties of Sitka spruce.*

[Special table for comparing kiln runs 147 and 148, shipment 563.]

Kiln runs.	Tree and bolt.	Static bending.									
		Moisture.[1]		Specific gravity.[2]		Modulus of rupture.		Modulus of elasticity.		Work to maximum load.	
		Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.
		Per cent.	*Per cent.*			*Pounds per square inch.*	*Pounds per square inch.*	*1,000 pounds per square inch.*	*1,000 pounds per square inch.*	*Inch-pounds per cubic inch.*	*Inch-pounds per cubic inch.*
147	1 c-d	11.2	40.0	0.446	0.423	11,900	6,370	1,760	1,745	....	....
	2 a-b	10.5	36.4	.404	.382	9,460	5,728	1,323	1,738	7.4	4.90
	2 c-d	10.2	32.2	.410	.392	10,000	5,630	1,302	1,398	....	....
	5 c-d	9.9	37.4	.390	.365	9,930	5,355	1,436	1,135	7.7	5.90
Average		10.4	36.5	.412	.391	10,322	5,771	1,455	1,504	7.6	5.40
148 (outer portion)	1 c-d	12.3	36.0	.445	.411	10,914	6,579	1,671	1,604	....	....
	2 a-b	9.8	32.4	.409	.389	11,360	5,980	1,803	1,405	8.6	6.49
	2 c-d	10.0	51.2	.418	.352	11,741	5,709	1,677	1,358	....	....
	5 c-d	11.5	34.3	.375	.359	9,300	5,904	1,220	1,392	6.9	6.23
Average		10.9	38.5	.412	.378	10,829	6,043	1,593	1,440	7.8	6.36

Kiln runs.	Tree and bolt.	Impact bending, 50-pound hammer.						Compression parallel to grain.					
		Moisture.[1]		Specific gravity.[2]		Height of drop.		Moisture.[1]		Specific gravity.[2]		Maximum crushing strength.	
		Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.	Kiln run 147 or 148.	Green.
		Per cent.	*Per cent.*			*Inches.*	*Inches.*	*Per cent.*	*Per cent.*			*Pounds per square inch.*	*Pounds per square inch.*
147	1 c-d	10.5	40.2	0.445	0.410	38.0	28.0	11.1	39.0	0.430	0.403	6,515	3,138
	2 a-b	10.0	35.0	.421	.377	28.0	19.2	10.8	37.2	.410	.384	5,270	2,622
	2 c-d	9.7	32.8	.421	.384	31.0	20.0	11.5	34.0	.415	.389	6,230	2,845
	5 c-d	10.4	36.2	.390	.363	25.5	20.4	10.5	37.5	.394	.364	5,490	2,850
Average		10.1	36.1	.419	.385	30.6	21.9	10.9	36.9	.412	.386	5,876	2,864
148 (outer portion)	1 c-d	11.2	37.8	.440	.402	29.0	28.0	13.9	34.6	.437	.410	6,176	3,038
	2 a-b	10.8	31.8	.409	.389	25.0	21.0	10.5	32.4	.407	.389	6,850	2,827
	2 c-d	10.3	35.4	.414	.395	24.0	20.0	12.4	37.8	.418	.378	6,670	2,693
	5 c-d	12.0	31.5	.388	.362	16.0	20.0	12.5	32.0	.383	.368	5,170	2,747
Average		11.1	34.1	.413	.387	24.0	22.0	12.3	34.2	.411	.386	6,217	2,826

[1] Per cent moisture based on oven-dry weight.
[2] Specific gravity based on oven-dry weight and volume as tested.

Figures better suited to the comparison of runs 147 and 148 are given in Table 9. Improvement ratios derived from them are given in Table 10 and graphed in figure 10. These data differ from those of Tables 1 and 5 and figure 8 chiefly in that run 147 included no material from the central portions of the various bolts, so that in making Tables 9 and 10 and figure 10 tests on material from such central portions dried in run 148 were excluded in order to get the best possible comparison of the two runs.

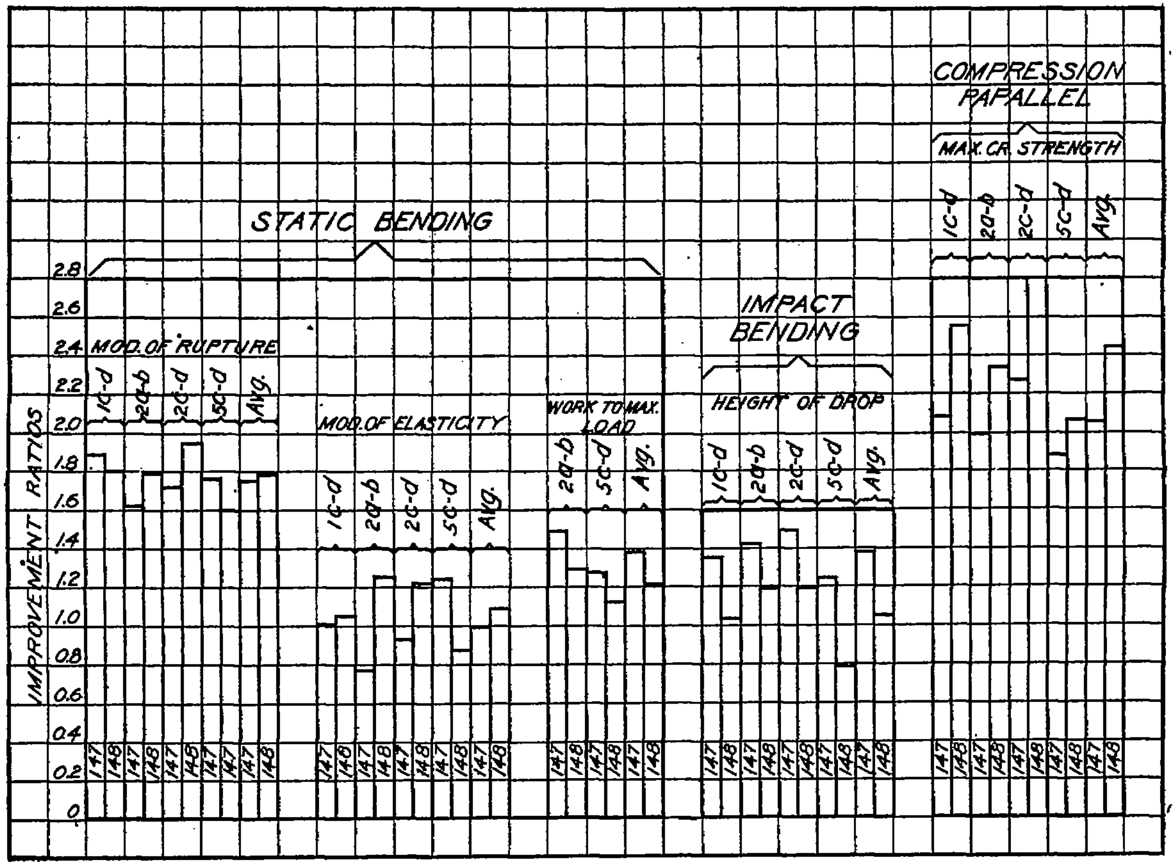

FIG. 10.—Improvement ratios for comparing kiln runs 147 and 148, Sitka spruce.

TABLE 10.—*Improvement ratios according to bolts (adjusted to 11 per cent moisture).*

[Sitka spruce: Kiln runs 147 and 148, shipment 563.]

Seasoning.	Tree and bolt.	Static bending: Moisture.	Static bending: Modulus of rupture, I. R. as tested.	Modulus of rupture, I. R. adjusted.	Modulus of elasticity, I. R. as tested.	Modulus of elasticity, I. R. adjusted.	Work to maximum load, I. R. as tested.	Work to maximum load, I. R. adjusted.	Impact bending, 50-pound hammer: Moisture.	Height of drop, I. R. as tested.	Height of drop, I. R. adjusted.	Compression parallel to grain: Moisture.	Maximum crushing strength, I. R. as tested.	Maximum crushing strength, I. R. adjusted.
		Per ct.							Per ct.			Per ct.		
Kiln run 147 (ship. 563)	[1] 1 a-b													
	1 c-d	11.2	1.87	1.89	1.01	1.01			10.5	1.36	1.35	11.1	2.07	2.08
	2 a-b	10.5	1.65	1.62	.76	.77	1.52	1.49	10.0	1.46	1.42	10.8	2.01	1.99
	2 c-d	10.2	1.78	1.72	.93	.93			9.7	1.55	1.49	11.5	2.19	2.27
	5 c-d	9.9	1.85	1.76	1.26	1.24	1.30	1.27	10.4	1.25	1.24	10.5	1.93	1.88
Average		10.5	1.79	1.75	.99	.99	1.41	1.38	10.2	1.41	1.38	11.0	2.06	2.05
Kiln run 148[2] (ship. 563)	1 a-b													
	1 c-d	12.3	1.66	1.80	1.04	1.05	(1)	(1)	11.2	1.03	1.03	13.9	2.03	2.55
	2 a-b	9.8	1.90	1.79	1.28	1.25	1.32	1.29	10.8	1.19	1.19	10.5	2.42	2.34
	2 c-d	10.0	2.06	1.95	1.24	1.22	(1)	(1)	10.8	1.20	1.19	12.4	2.48	2.80
	5 c-d	11.5	1.57	1.60	.87	.87	1.11	1.12	12.0	.80	.78	12.4	1.88	2.06
Average		10.9	1.80	1.78	1.11	1.09	1.22	1.21	11.1	1.06	1.05	12.3	2.20	2.44

[1] Data not used since corresponding data for other kiln run are missing.
[2] Material from outer portion only—to match kiln run 147.
I. R.=Improvement ratio.

Comparisons of runs 147 and 148 (see fig. 10) in modulus of rupture, modulus of elasticity, and maximum crushing strength are erratic when individual bolts are considered, but 148 *averages* better than 147 in each of these properties. In work to maximum load and height of drop, the results are (contrary to those for small groups from the runs previously considered) consistent and quite largely in favor of run 147. This leads to the conclusion that run 148 damaged the material in work to maximum load and height of drop [1] as compared to similar material tested after drying in run 147.

That the results of run 147 are in all probability entirely satisfactory is concluded from comparison with the groups of air-dried material (fig. 8)[2].

Runs 163, 171, and 172.—Runs 171 and 172 compare very favorably with the other runs and with groups of air-dried material, except in height of drop, where they seem to be quite low.

Run 163 seems to fall below runs 171 and 172, and, in fact, below a number of the groups of material graphed in figure 8. No definite conclusions concerning these runs can be drawn until the corresponding air-dried material has been tested.

GENERAL COMPARISON OF RUNS.

Table 11 affords a means of comparing all runs. It is made up in a manner similar to Table 5, except that it gives for each run a weighted average improvement ratio instead of a weighted average "efficiency." "Efficiency" figures can not, of course, be obtained in advance of tests on corresponding air-dried material.

Table 11 indicates practically the same thing as has been brought out previously with respect to the relative merits of several of the kiln runs. It does not, however, indicate an appreciable difference between runs 147 and 148. It indicates that 163 is the poorest of all, and rather distinctly inferior to air-dried material. Very probably the apparently very poor results on run 163 are only an example of variability explainable through the fact that run 163 was on different material from the other runs. Runs 163, 171, and 172 were made on material from the same shipment, but 171 and 172 involved other trees than 163. Figures such as are given in Table 11 furnish quite accurate comparisons between two or more groups of material from the same trees. Comparisons between groups of material from different trees must, however, be modified to take into account the variations which are likely to occur.

TABLE 11.—*Sitka spruce—Average improvement ratios for all kiln runs and several groups of air-dried material.*

	Air-dry shipment 325.			Air-dry matching kiln runs 88 and 89.		Kiln run 88.		Kiln run 89.		Air-dry matching kiln runs 91, 93, and 94.		Kiln run 91.		Kiln run 93.	
	F	R	F×R	R	F×R	R	F×R	R	F×R	R	F×R	F×R	F×R	R	F×R
Modulus of rupture	2	1.81	3.62	1.80	3.60	1.88	3.76	1.78	3.56	1.90	3.80	1.88	3.76	1.85	3.70
Modulus of elasticity	4	1.30	5.20	1.18	4.72	1.29	5.16	1.21	4.84	1.36	5.44	1.28	5.12	1.39	5.56
Work to maximum load	3	1.52	4.56	1.43	4.39	1.45	4.35	1.42	4.26	1.42	4.26	1.74	5.22	1.24	3.72
Drop	3	1.18	3.54	1.08	3.24	1.12	3.36	1.05	3.15	1.03	3.09	1.21	3.63	1.11	3.33
Maximum crushing strength	2	1.97	3.94	2.37	4.74	2.22	4.44	2.24	4.48	2.37	4.74	2.25	4.50	2.61	5.22
ΣR	....	7.78	....	7.86	....	7.96	....	7.70	....	8.08	....	8.36	....	8.20	....
ΣR÷5=Average R	....	1.56	....	1.57	....	1.59	....	1.54	....	1.62	....	1.67	....	1.64	....
Σ(F×R)	....	....	20.86	....	20.59	....	21.07	....	20.29	....	21.13	....	22.23	....	21.53
Σ(F×R)÷ΣF= Weighted average R	....		1.49	....	1.47	....	1.51	....	1.45	....	1.52	....	1.59	....	1.54
Ave. R (kiln dry) / Ave. R (air dry)	....	....	....	....	....	....	1.02	....	.986	....	....	....	1.046	....	1.013

	Kiln run 94.			Kiln run 147.		Kiln run 148.		Kiln run 163.		Kiln run 171.		Kiln run 172.	
	F	R	F×R	R	F×R	R	F×R	R	F×R	R	F×R	R	F×R
Modulus of rupture	2	1.94	3.88	1.78	3.56	1.78	3.56	1.82	3.64	1.93	3.86	2.01	4.02
Modulus of elasticity	4	1.36	5.44	1.07	4.28	1.14	4.56	1.16	4.64	1.30	5.20	1.31	5.24
Work to maximum load	3	1.35	4.05	1.53	4.59	1.45	4.35	1.29	3.87	1.49	4.47	1.41	4.23
Drop	3	1.27	3.81	1.36	4.08	1.03	3.09	.97	2.91	.93	2.79	.90	2.70
Maximum crushing strength	2	2.38	4.76	2.10	4.20	2.42	4.84	1.89	3.78	2.27	4.54	2.47	4.82
ΣR	....	8.30	....	7.84	....	7.82	....	7.13	....	8.02	....	8.10	....
ΣR÷5=Average R	....	1.66	....	1.57	....	1.56	....	1.43	....	1.60	....	1.62	....
Σ(F×R)	....	....	21.94	....	20.71	....	20.40	....	18.84	....	20.86	....	21.01
Σ(F×R)÷ΣF= Weighted average R	....	....	1.57	....	1.48	....	1.46	....	1.35	....	1.49	....	1.50
Ave. R (kiln dry) / Ave. R (air dry)	....	....	1.035	....	....	....	....	....	....	....	....	....	....

R=Improvement ratio adjusted to 11 per cent moisture.
F=Weighting factor.

[1] This falling down in these properties, while excellent results were secured in modulus of rupture and maximum crushing strength, is in accordance with results previously obtained from tests on the effect of other treatments and of incipient decay. It has been found in such tests that quite severe damage to shock resisting ability (as indicated by work and drop values) may occur without any detectable effect on static strength as indicated by modulus of rupture and maximum crushing strength.

[2] It is notable that run 148 might be looked upon as fairly satisfactory were it compared to the data of figure 8, exclusive of run 147.

PHOTOGRAPHS OF FAILURES.

Plates I to IX, inclusive, show failures of impact-bending sticks from various kiln runs and from some air-dried material. Plates I, II, and III, pertaining to run 148, are of particular interest. The possible value and interest of such photographs was not suggested until the time of the testing of these sticks. It is unfortunate that similar photographs from earlier runs, particularly 147, are not available.

Of the failures shown in Plate I more than one-third would be judged to be of the highest type and in no way indicative of the brashness shown by the data of Tables 9 and 10 and figure 10. In Plate II but one or two of the failures are at all indicative of brashness, and it is difficult to believe that this material has been injured. That such is the case, however, seems to be very definitely shown by the test results. All but one, or possibly two, of the failures shown in Plate III are indicative of very poor material.

Plates IV to VII show failures of sticks from runs 171 and 172, and of corresponding green sticks. Failures of air-dried sticks corresponding to kiln runs 88 and 89 are shown in Plate VIII, and to runs 91, 93, and 94 in Plate IX. Comparison of these various photographs fails to indicate any difference between the air-dried and kiln-dried material with respect to types of failure.

Plates I, II, and III as brought out by the comment on them and comparison with the strength data show that reliable conclusions as to the effect of kiln drying can not be attained by inspection of failures.

RÉSUMÉ FOR SITKA SPRUCE.

Because of the importance of Sitka spruce as an airplane material, and in order to set forth the methods of analysis used and to illustrate the difficulties met and the caution necessary in making such an analysis, the data on Sitka spruce have been discussed in greater detail than is considered necessary for the other species.

Data concerning 10 kiln runs are presented. These 10 runs include 5 runs, material from which is compared to matched material tested after air drying, and 5 for which data on matched air-dried material are not available.

It is shown conclusively that Sitka spruce can be kiln dried without loss of strength as compared to air drying.

In connection with this and other conclusions stated in this report it is desired to call attention to the fact that the material which was kiln dried is compared to material air dried under conditions probably much more favorable to good results than is ordinarily the case. This material was also air dried in small sticks ($2\frac{1}{2}$ by $2\frac{1}{2}$ inches in cross-section). This procedure is undoubtedly more favorable to the retention of maximum strength than is air drying in wider planks, as is ordinarily done. In fact, casehardening of sticks of this size was purposely attempted in one kiln run (not discussed herein) but without success.

Data on the first five runs fail to disclose any consistent relation between the temperatures used in drying and the strength of the resulting material, and taken by themselves would lead to the conclusion that temperatures up to 180° F. can be safely used. There is, however, quite conclusive evidence of damage to material dried in one of the other runs made with temperatures between 160° and 180° F. Taken as a whole, therefore, the data presented do not justify the use of temperatures as high as 160° F. Definite evidence as to what is the critical temperature which should never be exceeded is not afforded.

It is believed, however, that the data presented justify the conclusion that the temperatures of specification 20500–A (120° F. initial to 145° F. final) are entirely safe.

There is no evidence of the extreme brashness which has been claimed to result from kiln drying.

RECOMMENDATIONS.

Because of the possibility of damage from higher temperature and the fact that as the scheduled temperature is increased the danger of damage through accidental departure from schedule increases, it is recommended that the temperatures of Table 1 of Specification 20500–A (see Appendix A of Report No. 65, "Kiln Drying of Wood for Airplanes") be not exceeded in the drying of Sitka spruce for airplane stock.

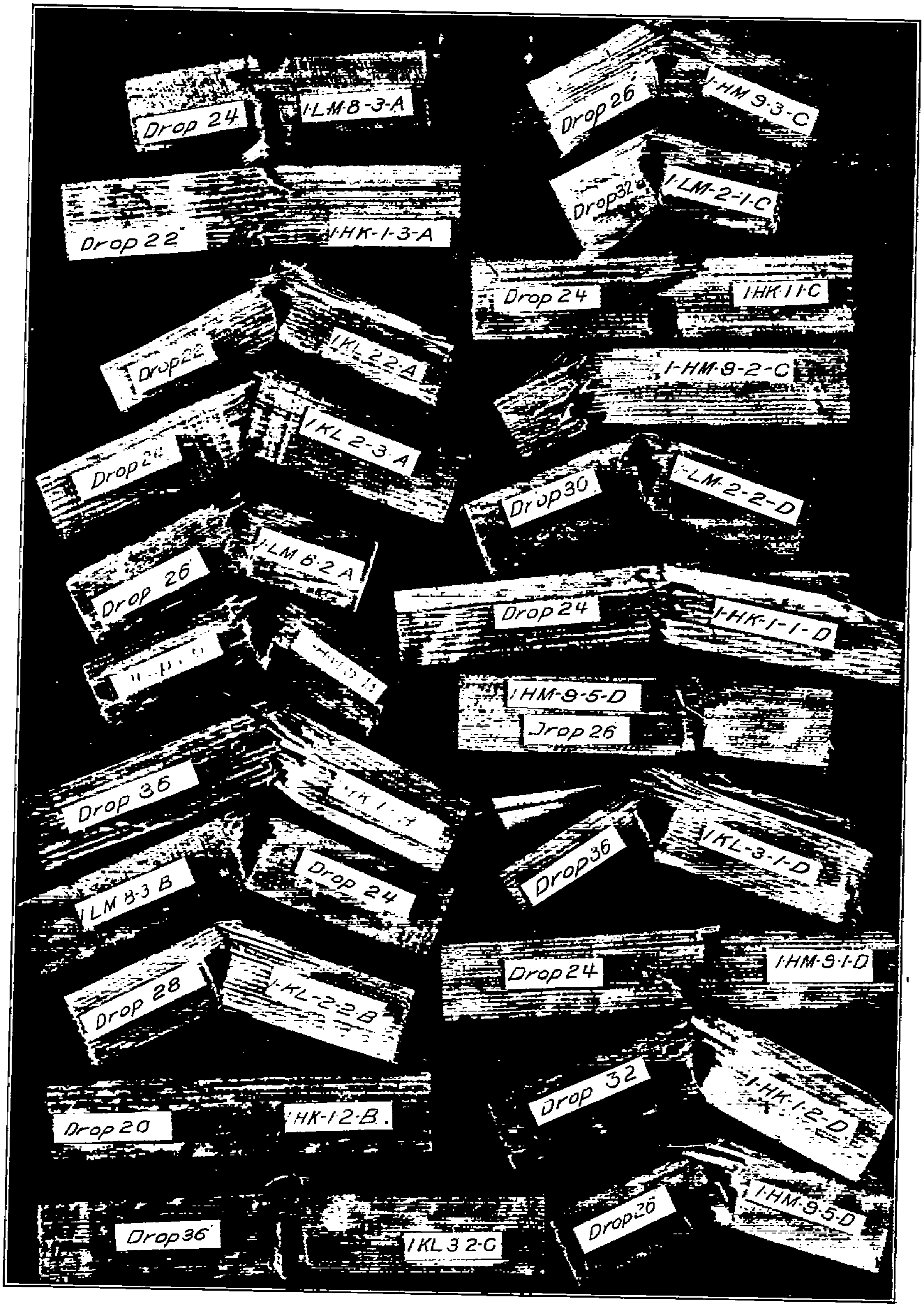

PLATE I.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, KILN RUN 148.

PLATE II.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, KILN RUN 148.

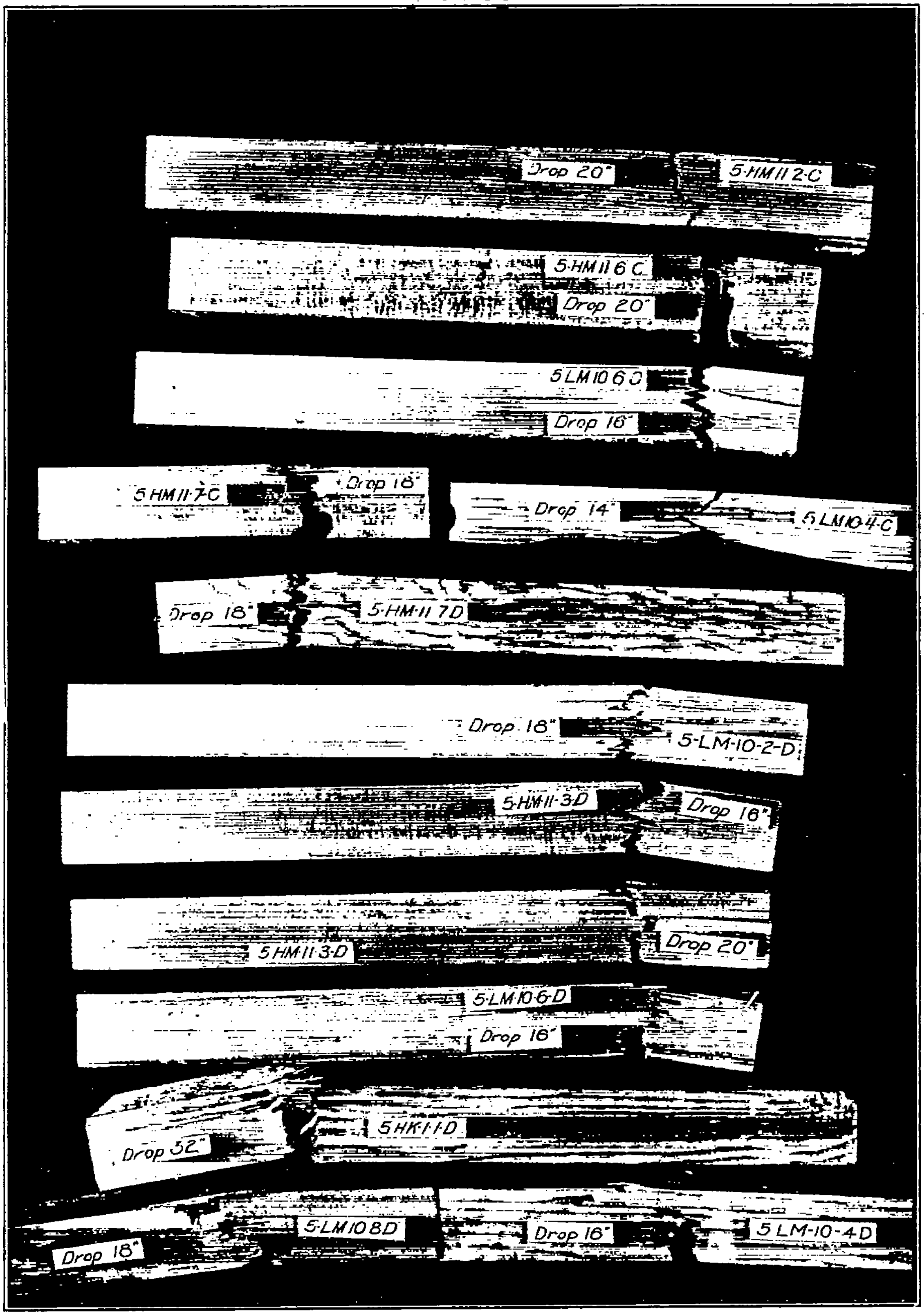

PLATE III.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, KILN RUN 148.

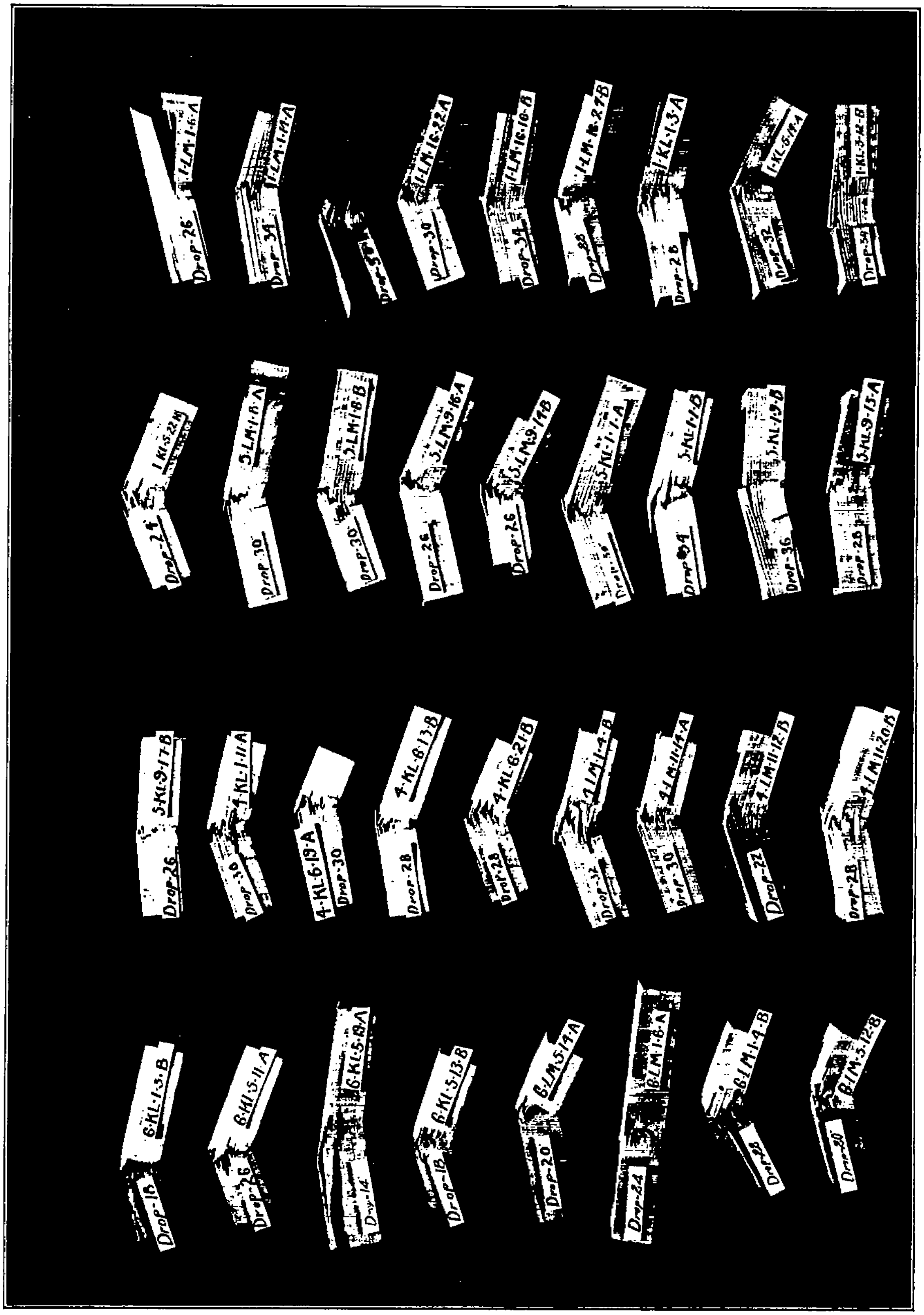

PLATE IV.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, GREEN, MATCHING KILN RUN 171.

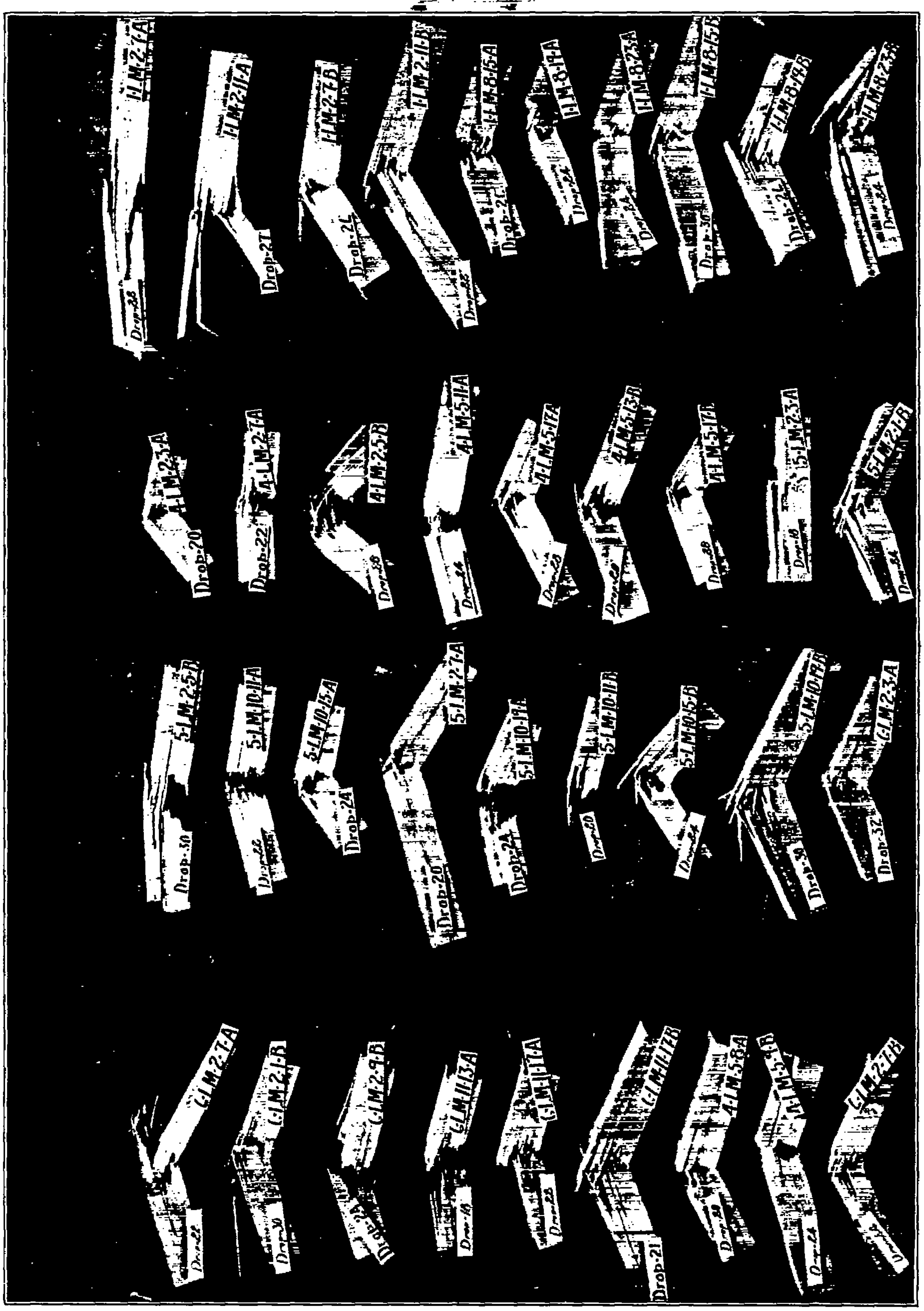

PLATE V.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, KILN RUN 171.

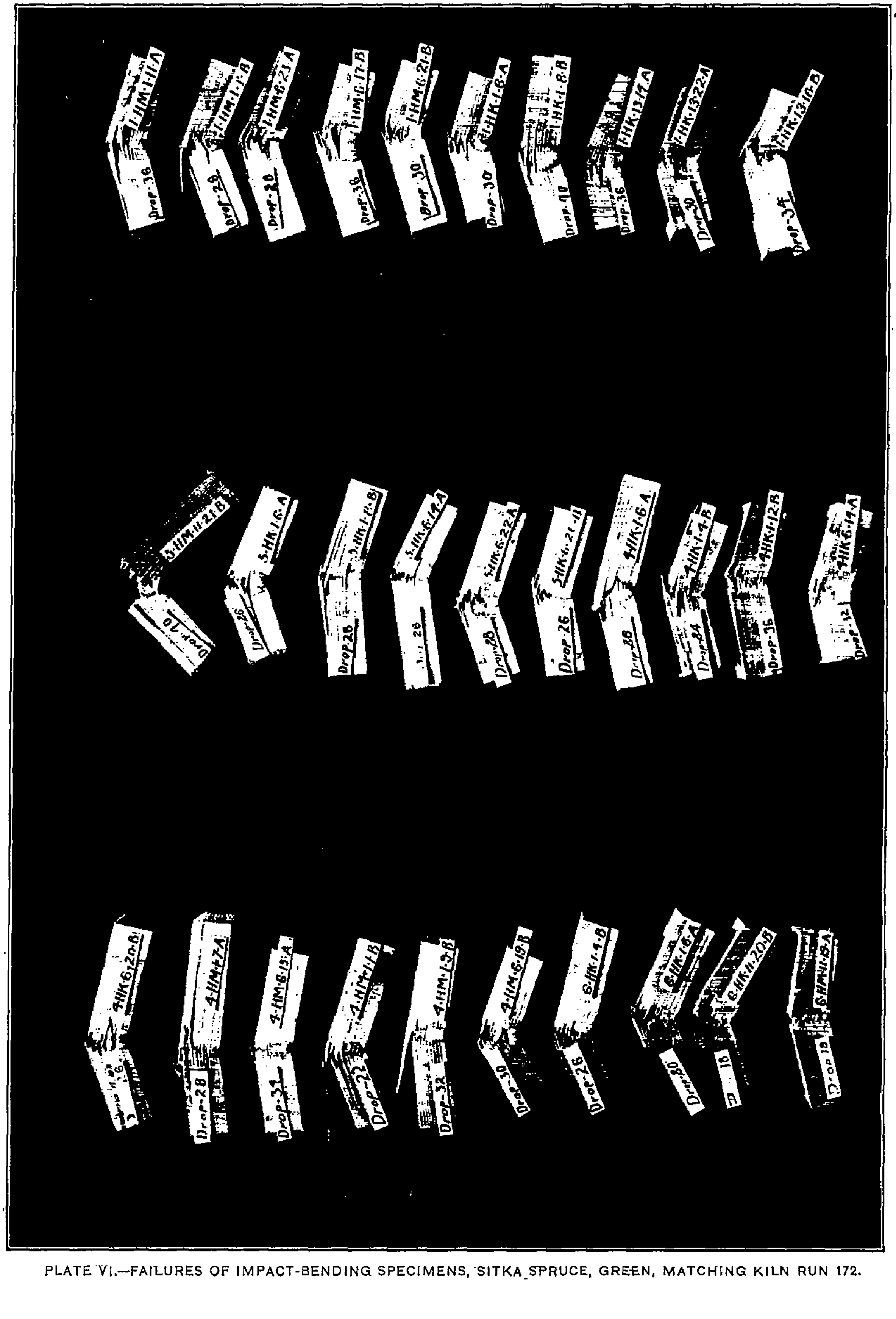

PLATE VI.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, GREEN, MATCHING KILN RUN 172.

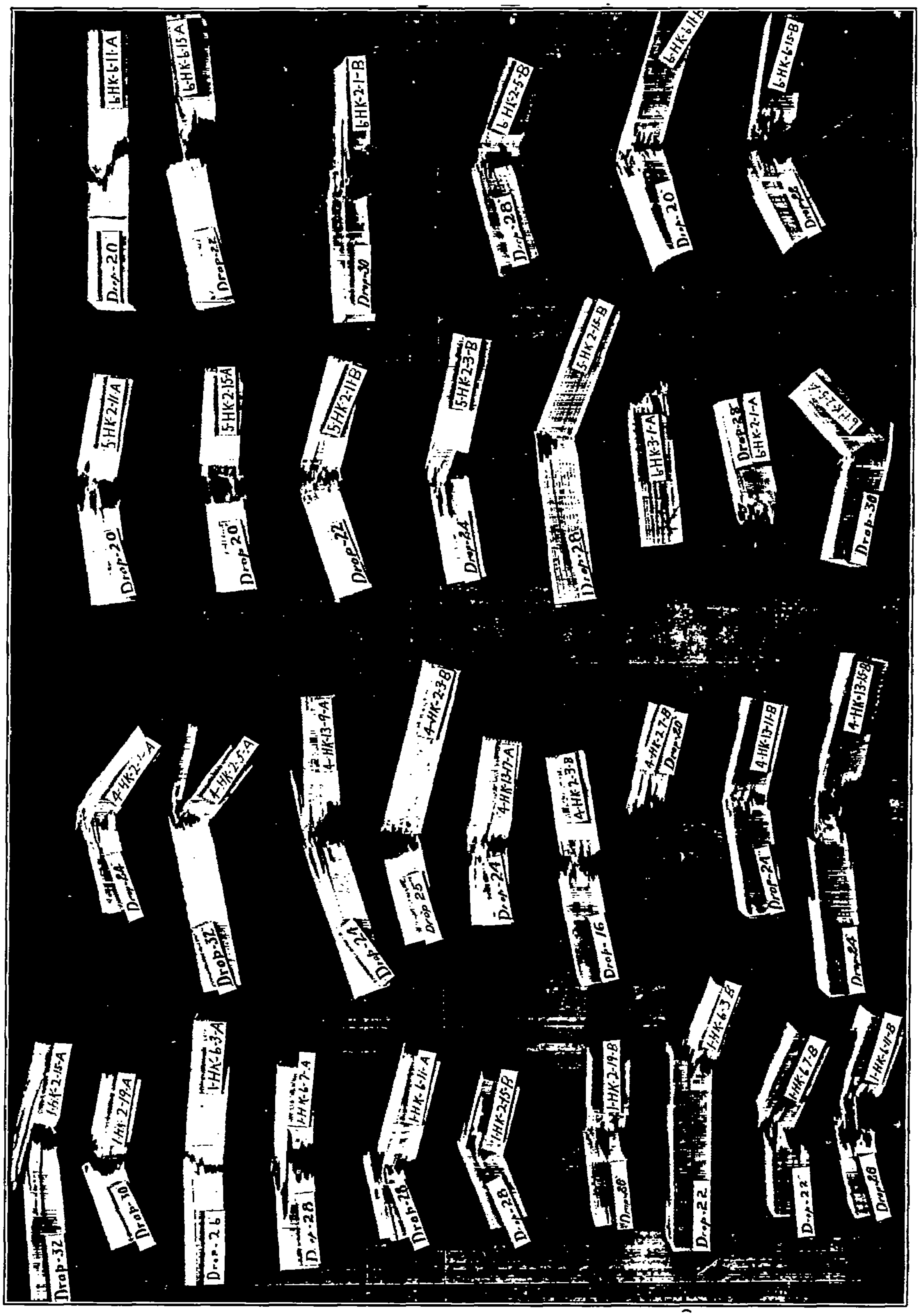

PLATE VII.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, KILN RUN 172.

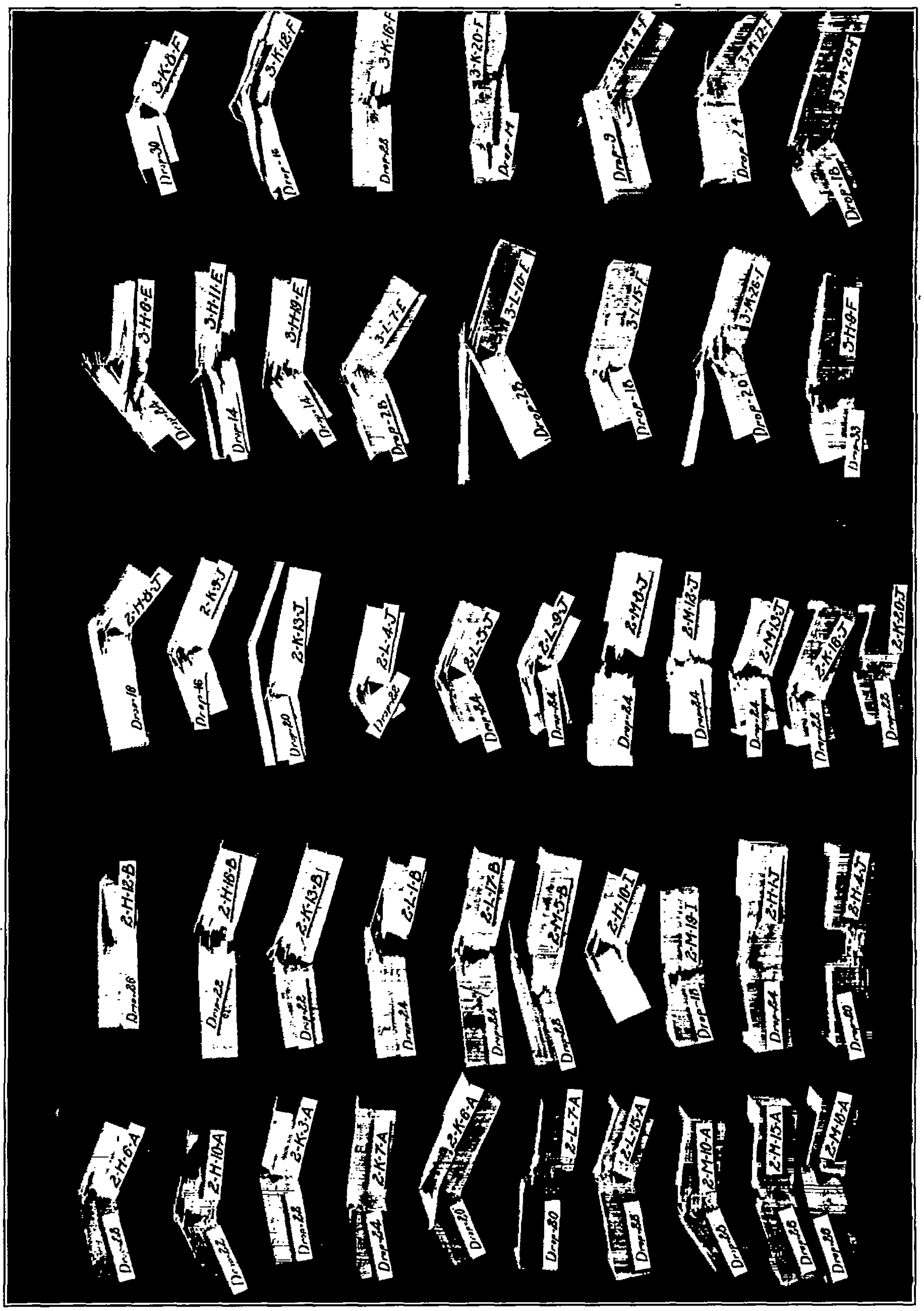

PLATE VIII.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, AIR-DRIED, MATCHING KILN RUNS 88 AND 89.

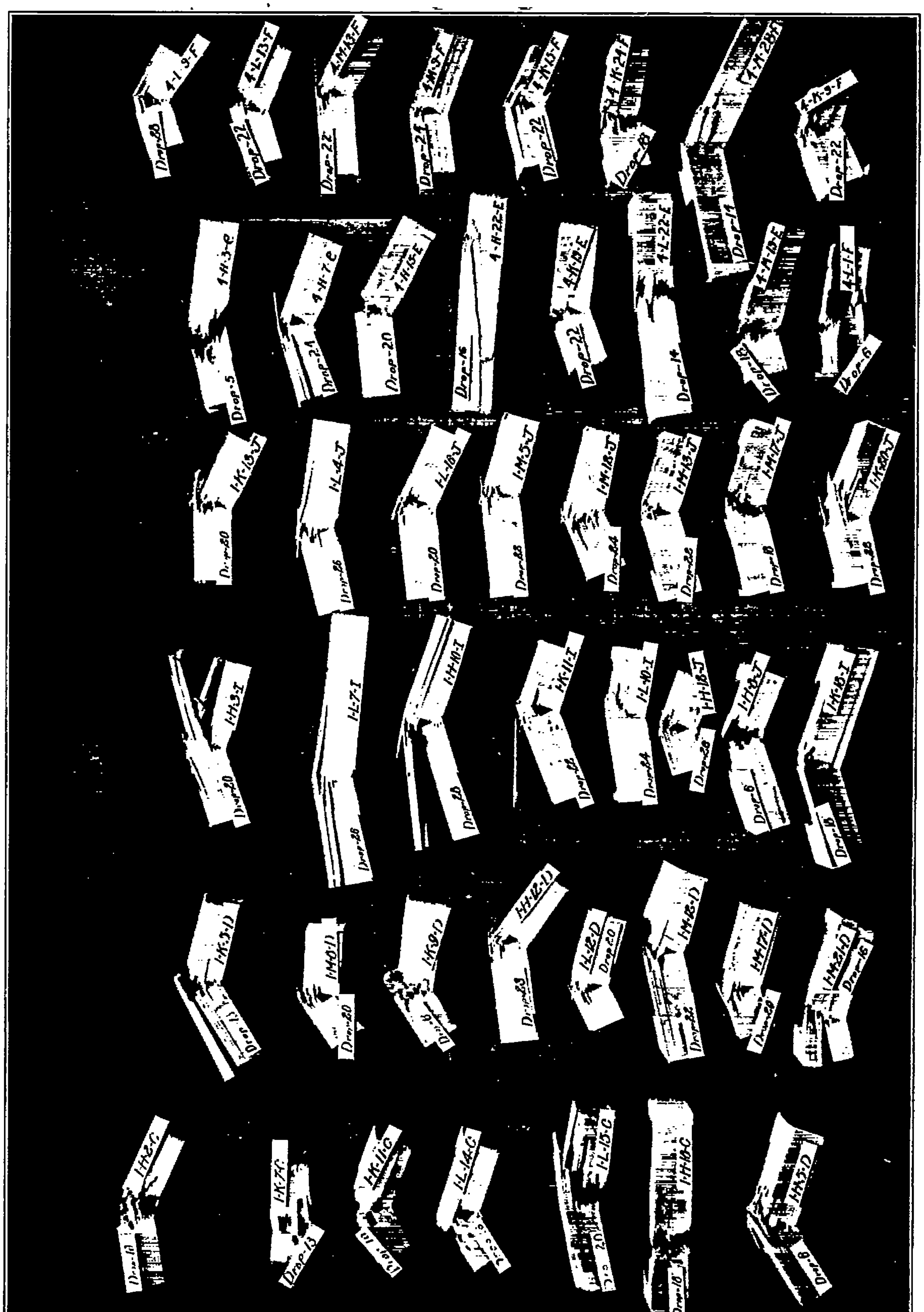

PLATE IX.—FAILURES OF IMPACT-BENDING SPECIMENS, SITKA SPRUCE, AIR-DRIED, MATCHING KILN RUNS 91, 93, AND 94.

DOUGLAS FIR.

SOURCE OF MATERIAL.

The material for the four experimental runs on Douglas fir was derived from 10 trees which were grown along the lower Columbia River, in Clatsop County, Oregon, at an elevation of about 1,500 feet. Each tree was represented by two 8-foot logs, an upper bolt (*h-i*, *i-j*, or *m-n*) and a lower bolt (*a-b*), making in all twenty 8-foot bolts. The logs varied in size from 31 inches to 39 inches in diameter and were from 300 to 350 years old. This material constituted shipment 523.

The logs were sawed into 2-inch and 3-inch planks of various widths. Specimens for test in the green and air-dried conditions were obtained from two flitches extending from side to side and nearly through the center of each 8-foot log. (See fig. 1 (B).) The sticks from each 8-foot bolt were grouped as outlined on page 15.

The remaining material was divided among the four kiln runs. Figure 1 (B) is an example showing how planks for test after kiln drying were selected. Figure 1 (D) shows how these planks were divided into test specimens and how the latter were marked. Table 12 is a schedule showing the distribution of material from these 10 trees among the four kiln runs. Previously tested green and air-dried material, with which comparisons are made, was secured from two trees from shipment 315, two from shipment 318, and one from shipment 354. These shipments were from Lewis County, Wash., Lane County., Oreg., and Humboldt County, Calif., respectively.

TABLE 12.—*Douglas fir. Shipment 523. List of trees and bolts to show which bolts were represented in the various kiln runs.*

Tree and bolt.	Kiln run 99.	Kiln run 101.	Kiln run 102.	Kiln run 103.
1 a-b	*	*		
1 i-j	*	*		
2 a-b	*	*		
2 k-l			*	*
3 a-b			*	*
3 m-n	*	*		
4 a-b	*	*		
4 h-i			*	*
5 a-b			*	*
5 h-i	*	*		
6 a-b	*	*		
6 i-j			*	*
7 a-b			*	*
7 i-j	*	*		
8 a-b	*	*		
8 h-i			*	*
9 a-b			*	*
9 k-l	*	*		
10 a-b			*	*
10 h-i			*	*

* Indicates that material from the bolt listed at the left was included in the kiln run whose number appears at the top of the column.

DESCRIPTION OF KILN-DRYING CONDITIONS.

Figure 11 is a graphical representation of the kiln conditions and of the moisture contents of samples of the stock for the four runs 99, 101, 102, and 103.

In every case material went into the kiln soon after cutting from the log and before any appreciable drying had occurred.

Kiln run 99.—The charge for run 99 consisted of two hundred twenty-nine 2 by 3 inch, 4 by 5 inch, and 3 by 4 inch pieces. Arrangement of the kiln was practically the same as shown in figure 7 (kiln run 147), except that the stock was flat-piled with 2 to 3 inches between the pieces in each layer. Two-inch stickers were used.

After a preliminary steaming at 130° F. for four hours, drying was started at 120° F. and about 90 per cent relative humidity. Temperature and humidity were gradually changed, as shown by the curves, to about 125° F. and 55 per cent humidity at the end of the run.

Casehardening, though not apparent at the close of the run, was discovered after removal of the material from the kiln. It was accordingly reloaded, steamed for two and one-half hours at 150° F. for the removal of casehardening, and then redried.

Inspection showed that less than 1 per cent degrade occurred in this run.

Kiln run 101.—Run 101 was made in a curtain kiln the arrangement of which is shown in figure 12.

The charge consisted of 2-inch and 3-inch material of various widths and derived from the same bolts as that for run 99.

After a preliminary steaming at 120° F. drying was begun at 105° F. and 80 per cent relative humidity. These conditions were gradually changed, as shown by figure 20, to 120°

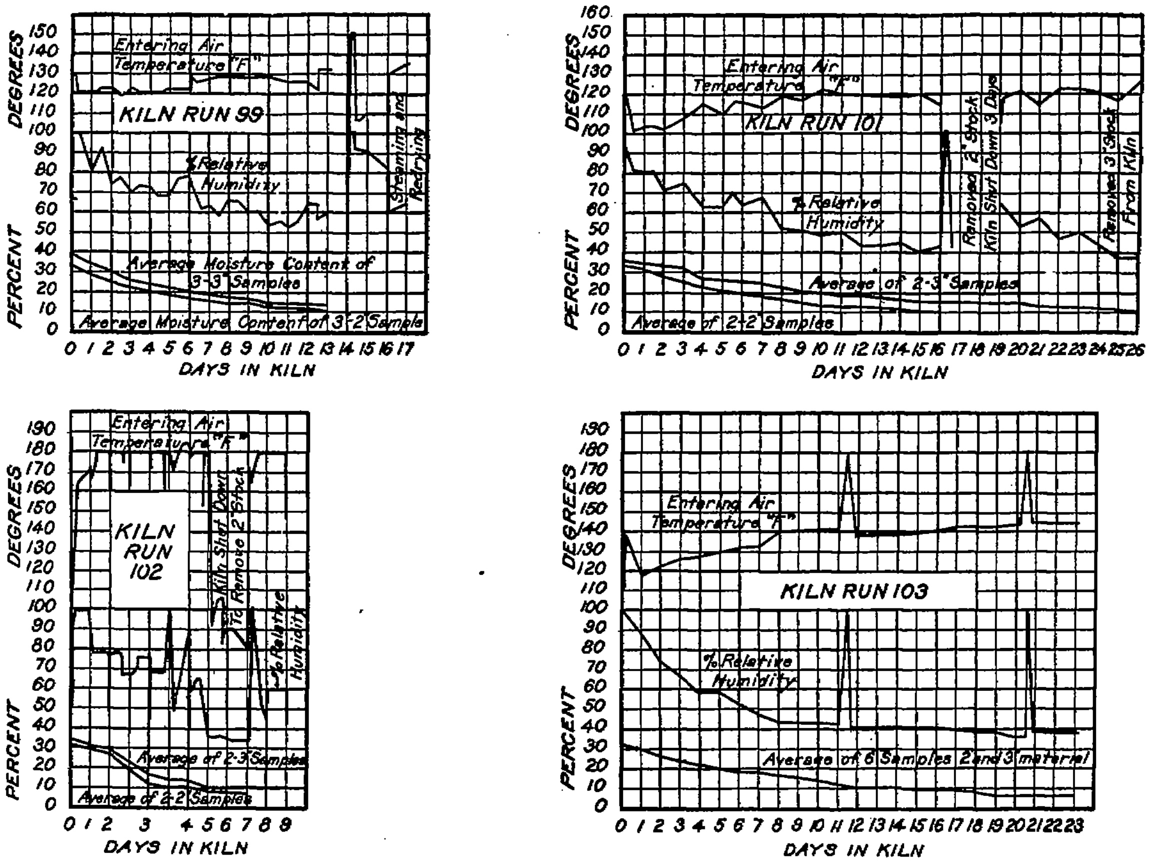

FIG. 11.—Kiln conditions for Douglas fir, kiln runs 99, 101, 102, and 103 (shipment 523).

F. and 40 per cent relative humidity at the end of the run. Steaming at 133° F. was used on the sixteenth day to remove casehardening.

Less than 1 per cent degrade occurred, as shown by inspection before and after kiln drying.

Kiln run 102.—The arrangement of the kiln for run 102 was practically as shown in figure 5 (run 89). The stock consisted of 2-inch and 3-inch planks of various widths. After preliminary steaming at about 165° F. the temperature was raised to about 180° F., where it was kept for the remainder of the run. The initial humidity (after steaming) was 80 per cent. Steaming at 180° F. was used once to remove casehardening.

Kiln run 103.—Figure 13 shows the kiln arrangement for run 103. The stock was 2-inch and 3-inch planks of various widths. After preliminary steaming at 138° F. drying was begun with a temperature of 117° F. and relative humidity of 85 per cent. These conditions were gradually changed to 142° F. and about 37 per cent relative humidity at the close of the run.

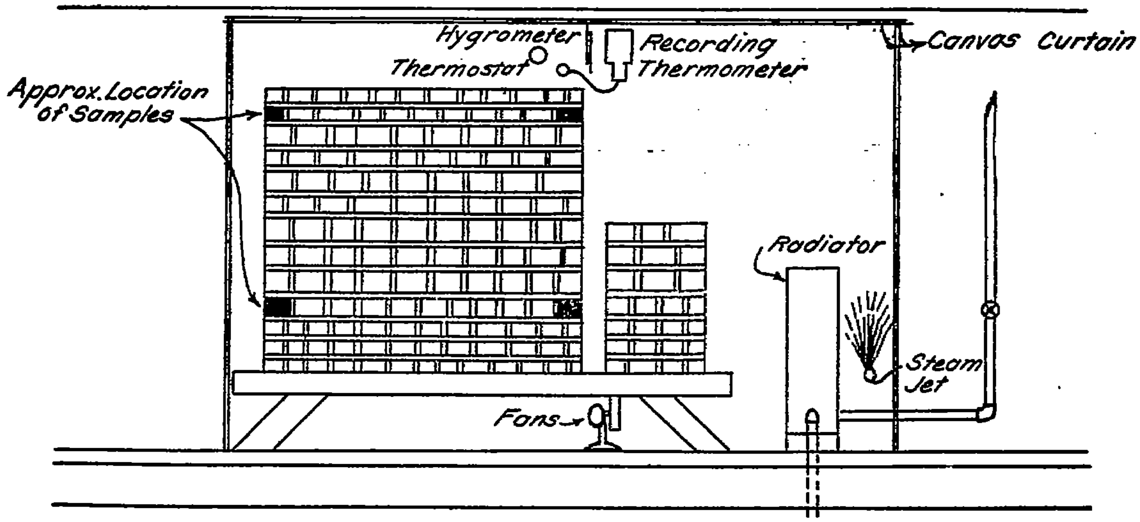

FIG. 12.—Cross section of kiln and piling diagram, Douglas fir kiln run 101.

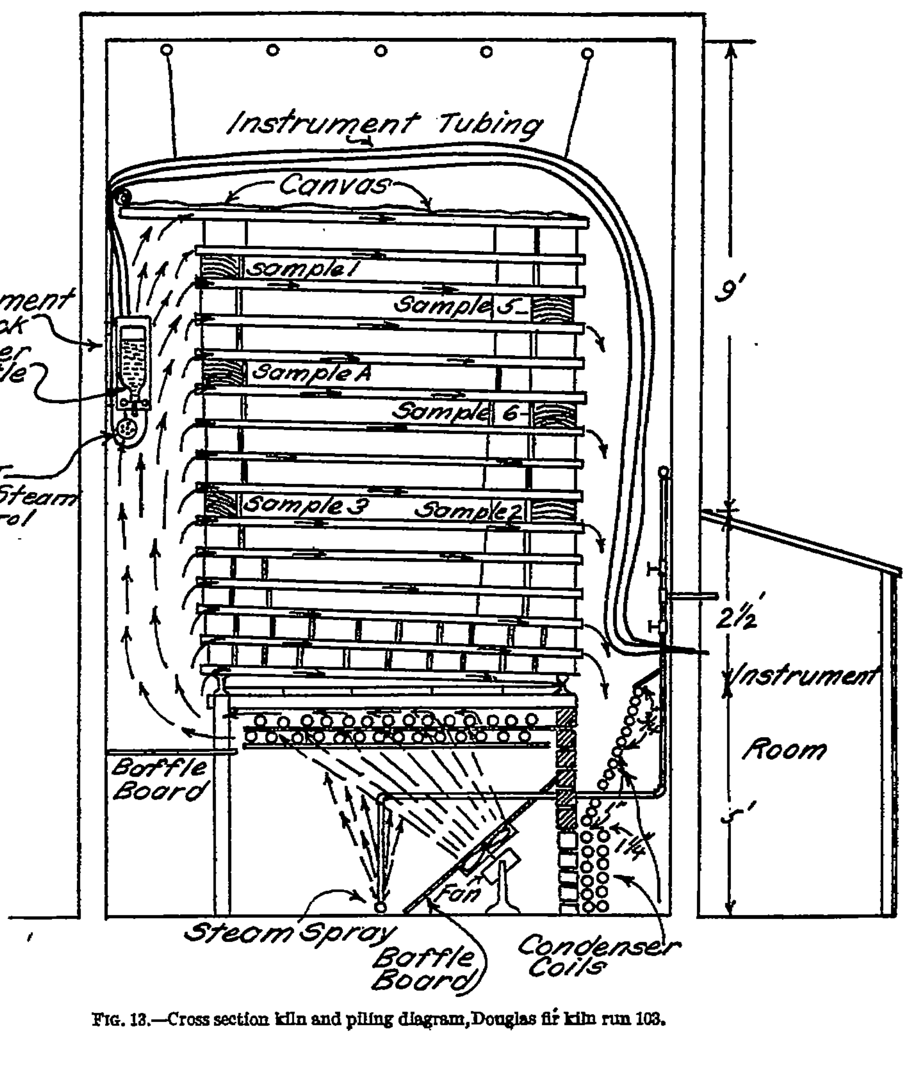

FIG. 13.—Cross section kiln and piling diagram, Douglas fir kiln run 103.

THE AIR DRYING.

Test specimens 2½ by 2½ inches by 4 feet, matching the various kiln runs, were air dried for about eight months, from February, 1918, to October, 1918, under practically the same conditions as similar Sitka spruce specimens (see p. 25), when they were found to have reached practically constant weight. The average moisture content at time of storing was about 31 per cent. The moisture contents of the samples at the end of the air-drying periods were about 12 per cent.

STRENGTH DATA.

Table 13 gives the average mechanical properties of the green and air-dried Douglas fir previously tested (shipments 315, 318, and 354); and also—by butt and upper bolt classes—of material from kiln runs 99 and 101, and from runs 102 and 103, with green and air-dry to match each pair of kiln runs.

TABLE 13.—*Average mechanical properties of Douglas fir.* (*Tabulations of test results without moisture adjustment.*)

Property.	Various shipments.		Shipment 523.							
			Lower bolts.							
	Ship. 315 315 318 318 354	Tree. 1 6 6 8 3	Green, to match kiln runs 99 and 101.	Air dry, to match kiln runs 99 and 101.	Kiln run 99.	Kiln run 101.	Green, to match kiln runs 102 and 103.	Air dry, to match kiln runs 102 and 103.	Kiln run 102.	Kiln run 103.
	Green.	Air dry.								
STATIC BENDING.										
Moisture (per cent)[1]	39.8	6.4	36.9	12.0	11.0	11.5	33.7	12.2	13.3	9.1
Specific gravity[2]	.467	.526	.465	.494	.500	.518	.459	.484	.501	.487
Fiber stress at elastic limit (lbs. per sq. in.)	7,825	11,437	4,810	8,540	9,720	9,491	4,910	8,230	8,072	10,450
Modulus of rupture (lbs. per sq. in.)	5,100	15,242	7,860	12,510	13,360	3,6091	7,980	12,270	11,105	13,550
Modulus of elasticity (1,000 lbs. per sq. in.)	1,684	2,184	1,550	1,859	1,922	2,039	1,535	1,791	1,842	1,704
Work to elastic limit (inch-lbs. per cu. in.)	....	....	.87	2.21	2.73	2.53	.91	2.16	2.0	3.79
Work to maximum load (inch-lbs. per cu. in.)	6.6	9.1	8.2	9.5	10.4	9.9	8.2	9.1	7.7	9.0
IMPACT BENDING: 50-POUND HAMMER.										
Moisture (per cent)[1]	41.4	6.4	33.5	12.1	10.8	11.5	33.1	12.2	12.3	9.6
Specific gravity[2]	.463	.528	.490	.499	.498	.517	.455	.480	.499	.489
Fiber stress at elastic limit (lbs. per sq. in.)	10,103	15,605	10,140	13,730	12,387	13,930	9,120	13,360	13,122	13,050
Modulus of elasticity (1,000 lbs. per sq. in.)	1,817	2,371	1,788	2,106	2,158	2,503	1,547	1,967	2,327	2,250
Work to elastic limit (inch-lbs. per cu. in.)	3.2	6.1	3.2	5.0	3.9	4.4	13.0	5.0	4.2	41.
Drop causing complete failure (inches)	23.9	34.9	24	28.2	27.4	29.0	22.0	28.1	25.0	30.4
COMPRESSION PARALLEL TO GRAIN.										
Moisture (per cent)[1]	37.9	6.4	33.5	12.3	10.9	11.7	32.5	11.9	10.9	8.8
Specific gravity[2]	.459	.504	455	.491	.497	.514	.451	.482	.498	.483
Maximum crushing strength (lbs. per sq. in.)	4,060	11,283	3,850	7,540	7,921	8,250	3,850	7,320	7,220	8,610

[1] Per cent moisture based on oven-dry weight.

[2] Specific gravity based on oven-dry weight and volume as tested.

TABLE 13.—*Average mechanical properties of Douglas fir*—Continued.

Property.	Shipment 523. Upper bolts. Green, to match kiln runs 99 and 101.	Air dry, to match kiln runs 99 and 101.	Kiln run 99.	Kiln run 101.	Green, to match kiln runs 102 and 103.	Air dry, to match kiln runs 102 and 103.	Kiln run 102.	Kiln run 103.
STATIC BENDING:								
Moisture (per cent) [1]	30.3	12.3	10.4	10.9	29.4	11.7	12.4	9.3
Specific gravity [2]	.411	.452	.433	.436	.435	.474	.476	.490
Fiber stress at elastic limit (lbs. per sq. in.)	4,320	7,590	8,811	8,917	4,880	7,930	7,544	9,540
Modulus of rupture (lbs. per sq. in.)	7,070	11,380	11,563	11,860	7,560	11,820	10,520	12,562
Modulus of elasticity (1,000 lbs. per sq. in.)	1,421	1,738	1,697	1,763	1,522	1,761	1,765	1,631
Work to elastic limit (inch-lbs. per cu. in.)	.76	1.87	2.59	2.55	.91	2.03	1.84	3.27
Work to maximum load (inch-lbs. per cu. in.)	6.6	8.6	8.6	8.2	6.8	8.6	7.5	7.9
IMPACT BENDING: 50-POUND HAMMER.								
Moisture (per cent) [1]	31.1	12.0	10.4	10.5	30.1	11.9	11.2	9.1
Specific gravity [2]	.407	.435	.429	.435	.432	.481	.479	.483
Fiber stress at elastic limit (lbs. per sq. in.)	9,560	11,880	11,814	12,520	8,850	13,260	12,970	12,730
Modulus of elasticity (1,000 lbs. per sq. in.)	1,713	1,796	2,012	2,135	1,509	1,966	2,243	2,282
Work to elastic limit (inch-lbs. per cu. in.)	3.0	4.4	3.9	4.2	2.9	5.0	4.2	4.0
Drop causing complete failure (inches)	20.0	22.7	23.9	24.0	19.0	26.2	23.0	28.1
COMPRESSION PARALLEL TO GRAIN.								
Moisture (per cent) [1]	29.9	12.1	9.8	11.0	30.9	11.9	9.9	8.8
Specific gravity [2]	.409	.440	.432	.432	.432	.475	.472	.481
Maximum crushing strength (lbs. per sq. in.)	3,630	6,810	7,358	7,496	3,900	7,230	7,440	8,710

[1] Per cent moisture based on oven-dry weight. [2] Specific gravity based on oven-dry weight and volume as tested.

Table 14 presents the average improvement ratios for the more important properties of the various groups of air-dried and kiln-dried material. These ratios are derived from Table 13 and are given both with and without adjustment to a uniform moisture content (11 per cent).

TABLE 14.—*Average improvement ratios of Douglas fir (with and without adjustment to 11 per cent moisture).*

[Shipment 523.]

Seasoning.	Bolt.	Static bending. Moisture.	Modulus of rupture. I. R. as tested.	Modulus of rupture. I. R. adjusted.	Modulus of elasticity. I. R. as tested.	Modulus of elasticity. I. R. adjusted.	Work to maximum load. I. R. as tested.	Work to maximum load. I. R. adjusted.	Impact bending. Moisture.	Height of maximum drop. I. R. as tested.	Height of maximum drop. I. R. adjusted.	Compression parallel to grain. Moisture.	Maximum crushing strength. I. R. as tested.	Maximum crushing strength. I. R. adjusted.
		P. ct.							*P. ct.*			*P. ct.*		
Air dry to match kiln runs 99 and 101	a–b	12.0	1.59	1.66	1.20	1.22	1.16	1.17	12.1	1.18	1.20	12.3	1.96	2.13
Kiln run 99	a–b	11.0	1.70	1.70	1.24	1.24	1.27	1.27	10.8	1.14	1.14	10.9	2.06	2.05
Kiln run 101	a–b	11.5	1.74	1.79	1.32	1.33	1.21	1.22	11.5	1.21	1.22	11.7	2.14	2.25
Air dry to match kiln runs 102 and 103	a–b	12.2	1.54	1.61	1.17	1.19	1.11	1.12	12.2	1.28	1.31	11.9	1.90	2.00
Kiln run 102	a–b	13.3	1.39	1.51	1.20	1.25	.94	.93	12.3	1.14	1.15	10.9	1.88	1.87
Kiln run 103	a–b	9.1	1.70	1.58	1.11	1.09	1.10	1.09	9.6	1.38	1.34	8.8	2.24	1.98
Air dry [1]	Upper.	6.4	1.95	1.62	1.30	1.21	1.38	1.26	6.4	1.46	1.32	6.4	2.77	2.08
Air dry to match kiln runs 99 and 101	...do...	12.3	1.61	1.71	1.22	1.25	1.30	1.35	12.0	1.14	1.15	12.1	1.88	2.00
Kiln run 99	...do...	10.4	1.64	1.60	1.19	1.18	1.30	1.29	10.4	1.20	1.19	9.8	2.03	1.90
Kiln run 101	...do...	10.9	1.68	1.67	1.25	1.24	1.24	1.24	10.5	1.20	1.19	11.0	2.06	2.06
Air dry to match kiln runs 101 and 102	...do...	11.7	1.56	1.61	1.16	1.17	1.27	1.28	11.9	1.38	1.42	11.9	1.85	1.95
Kiln run 102	...do...	12.4	1.39	1.45	1.16	1.18	1.10	1.12	11.2	1.21	1.21	9.9	1.91	1.81
Kiln run 103	...do...	9.3	1.66	1.56	1.07	1.06	1.16	1.14	9.1	1.48	1.40	8.8	2.24	1.98

[1] Average of 5 trees of previously tested air-dried material, contained in the (c–d), (d–e), and (e–f) bolts, shipments 315, 318, and 354.
I. R.—Improvement ratio.

The improvement ratios from Table 13 are graphed in figure 14.

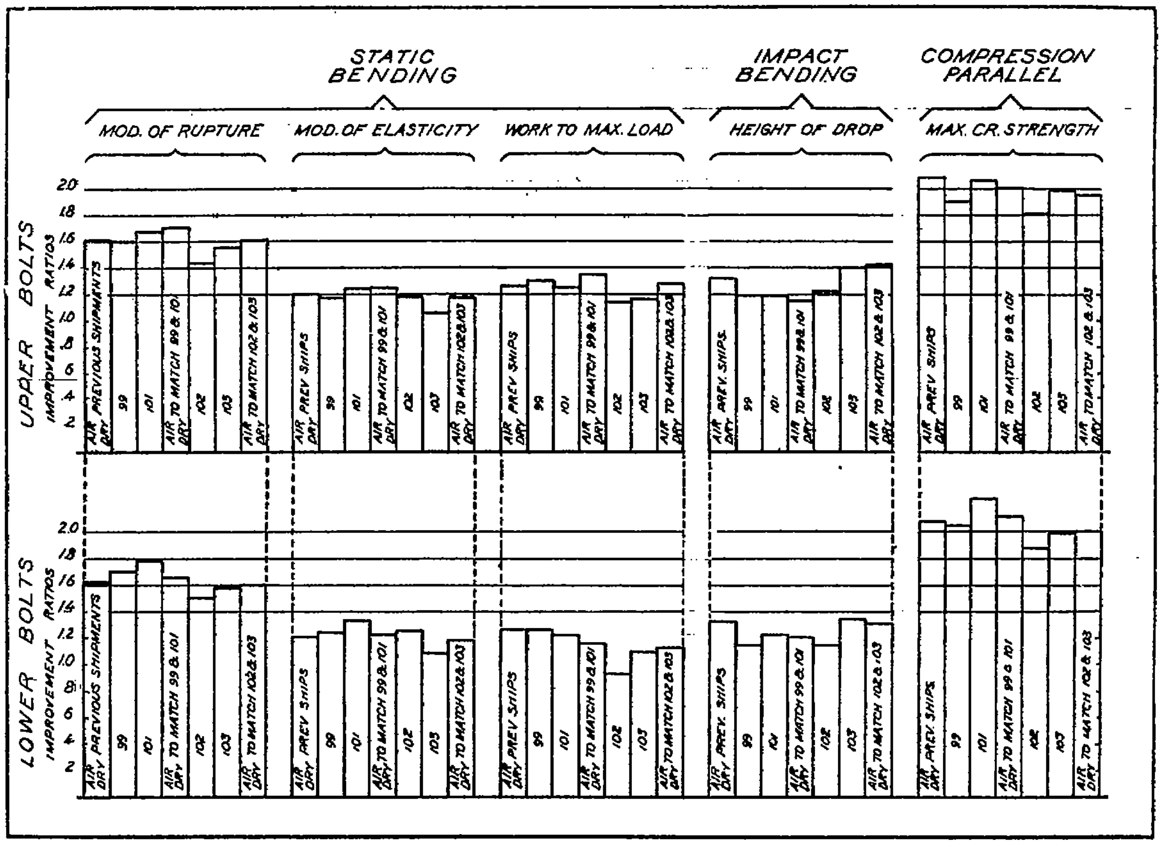

FIG. 14.—Improvement ratios for comparison of kiln-dried and air-dried stock, Douglas fir.

Table 15, similar to Tables 6, 7, and 8 for Sitka spruce, give efficiencies for upper and lower bolts, respectively.

TABLE 15.—*Efficiencies for kiln runs on Douglas fir.*

(A)—UPPER BOLTS.

Property.	F.	Kiln run 99.		Kiln run 101.		Kiln run 102.		Kiln run 103.	
		E.	E×F.	E.	E×F.	E.	E×F.	E.	E×F.
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	93.6	187.2	97.4	194.8	89.4	178.8	97.0	194.0
Modulus of elasticity	4	93.6	374.4	99.2	396.8	100.9	403.6	90.6	362.4
Work to maximum load	3	88.9	266.7	91.8	275.4	89.0	267.0	90.6	271.8
Drop	3	103.6	310.8	103.6	310.8	86.6	259.8	98.5	295.5
Compression	2	95.0	190.0	103.0	206.0	93.4	186.8	97.9	195.8
Σ(E×F)			1,329.1		1,383.8		1,296.0		1,319.5
Σ(E×F)÷ΣF=Weighted average E			94.9		98.8		92.6		94.2

(B)—LOWER BOLTS.

Property.	F.	Kiln run 99. E.	Kiln run 99. E×F.	Kiln run 101. E.	Kiln run 101. E×F.	Kiln run 102. E.	Kiln run 102. E×F.	Kiln run 103. E.	Kiln run 103. E×F.
Modulus of rupture	2	102.4	204.8	107.2	214.4	93.7	187.4	98.6	197.2
Modulus of elasticity	4	101.7	406.8	109.0	436.0	104.2	416.8	91.5	366.0
Work to maximum load	3	108.7	326.1	105.2	315.6	83.0	249.0	97.3	291.9
Drop	3	93.3	279.9	101.7	305.1	87.8	263.4	97.0	291.0
Compression	2	96.3	192.6	106.2	212.4	93.5	187.0	99.0	198.0
Σ(E×F)			1,410.2		1,483.5		1,303.6		1,344.1
Σ(E×F)÷ΣF=Weighted average E			100.7		106.0		93.1		96.0
Average of upper and lower bolts			97.8		102.4		92.8		95.1

F=Weighting factor

$$E = \text{Efficiency} = \frac{\text{Improvement ratio for property of kiln dry}}{\text{Improvement ratio for same property of corresponding air dry}}$$

DISCUSSION.

Inspection of figure 14 indicates that of the four kiln runs, 101 alone has given results which can be considered fully equal to air drying. This run falls below the corresponding air-dried material in three instances: Modulus of rupture, modulus of elasticity, and work to maximum load, all for material from upper bolts. The deficiencies in these instances are so small that they are entirely offset by superior excellence in other respects.

Further inspection shows that run 102 is very consistently, modulus of elasticity being the only exception, inferior to the corresponding air-dry, and is, upon the whole, the poorest of the four runs. These conclusions are supported by the figures presented in Table 15. Air drying is taken as the standard of efficiency, or 100 per cent. The efficiencies of air drying and of the several kiln runs, the latter as obtained by averaging the figures of Table 15 (A) with those of Table 15 (B), are as follows:

	Per cent.
Air drying	100.0
Kiln run 101	102.4
Kiln run 99	97.8
Kiln run 103	95.1
Kiln run 102	92.7

Reference to figure 11 shows that the above list is in order of increasing temperatures; i. e., as temperature increases, efficiency decreases.

If the values for efficiency with respect to work to maximum load and maximum drop only, as given in Table 15 (A) and (B), be averaged (without weighting) we get—

	Per cent.
Air drying	100.0
Kiln run 101	100.6
Kiln run 99	98.6
Kiln run 103	95.8
Kiln run 102	86.6

The order is as before, and the deficiency is less in runs 99 and 103, but somewhat greater in run 102.

These figures all point to a rather definite relation between strength properties and the temperatures used in drying. In no case is the deficiency sufficient to be considered an obstacle to the use of such material for ordinary purposes. However, any failure to equal air-dried material must be looked upon with considerable suspicion when stock is to be used for aircraft construction.

Tests of the effect of various steps of preservative treatment on Douglas fir have shown that this species is especially susceptible to injury by high temperatures. Data on such tests, together with those given herein, furnish the following for correlation of temperature and strength:

Temperature.[1]	Reference.	Modulus of rupture.[2]		
Degrees F.		*Per cent.*		
110	Kiln run 101	102.3		
120	Kiln run 99	98.0		
130	Kiln run 103	97.8		
180	Kiln run 102	90.5		
200	Bull. No. 286[3]	[5] 89.0	[6] 93.5	[7] 91.2
259	Bull. No. 286[4]	[5] 78.3	[6] 91.7	[7] 85.0

[1] This is the temperature applied to green wood.
[2] In percentages of control material.
[3] U. S. Department of Agriculture Bull. No. 286: Strength Tests of Structural Timbers Treated by Commercial Wood Preserving Processes. (Table 3—Creosoted at atmospheric pressure and 200 °F. for 27 hours.)
[4] Bull. No. 286: Steamed at 20-pound pressure for five hours.
[5] Bull. No. 286: Results from specimens treated green and tested soon after treatment.
[6] Bull. No. 286: Results from tests made after thorough air drying following treatment.
[7] Results of 5 and 6 averaged.

These data are plotted in figure 15. While the tests of Bulletin No. 286 are probably not exactly comparable to those described herein, they furnish basis for an estimate of the effect of still higher temperatures than those used in the kiln runs herein discussed.

The data on the four kiln runs as given in Table 15 (A) and (B) and as presented in figure 15 indicate that 120° F. is about the critical temperature for Douglas fir in the green state. The data drawn from Bulletin No. 286 by showing a continual decrease of strength properties with increase in temperature support this indication.

CONCLUSIONS.

In view of the points brought out in the above discussion these conclusions are reached: (1) There is a quite definite relation between the strength properties of Douglas fir and the temperatures used in drying it. (2) About 120° F. is the critical temperature above which damage is likely to result. (3) The decrease of strength properties with increase in temperature is gradual. (4) The maximum damage to be expected from the use of Table 1 of Specification

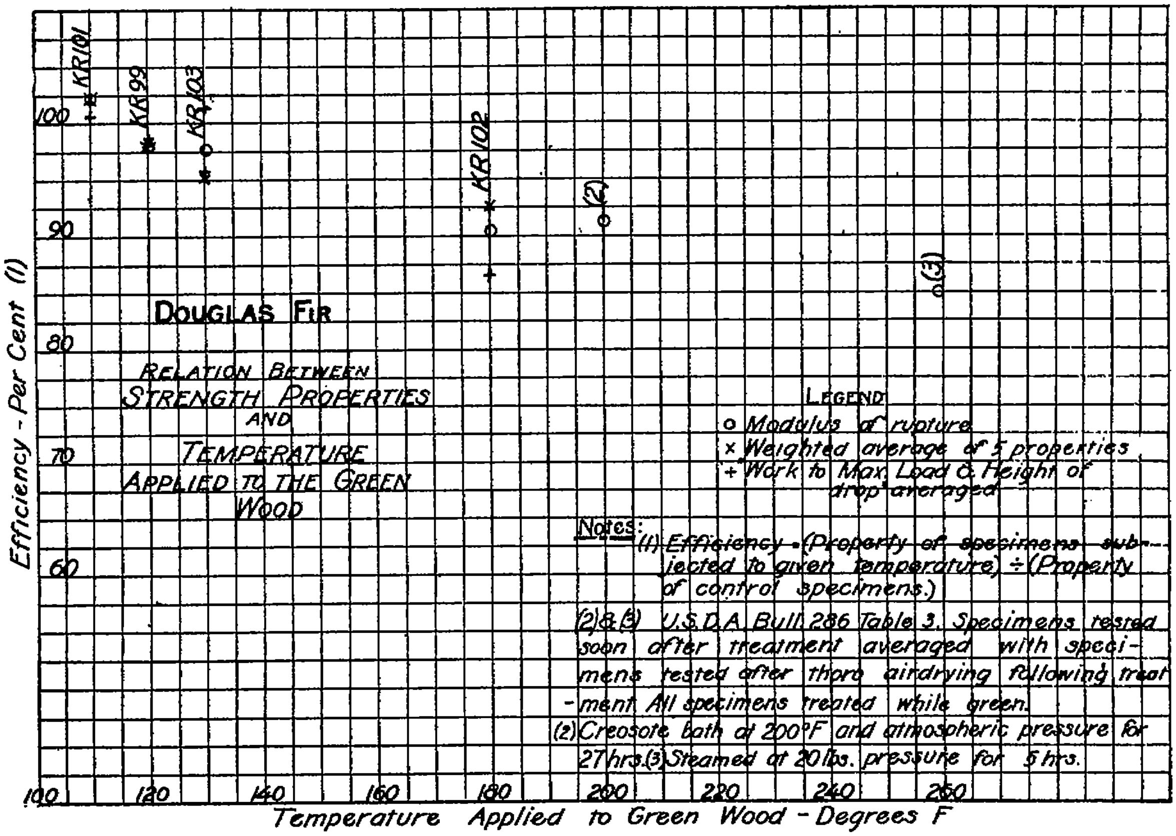

FIG. 15.—Relation between strength properties of Douglas fir and temperature applied to the green wood.

20500–A does not exceed 5 per cent. In all probability the susceptibility to damage by heat decreases as the moisture content decreases, so that even this damage is not really to be expected. (5) When maximum safety is desired, as for aircraft material, it seems doubtful if the temperature of 120° F. should be exceeded before the material is reasonably dry. (6) It is to be expected that Table 2 of Specification 20500–A will produce material fully equal to that air dried.

RECOMMENDATIONS.

It is recommended that the temperature of Table 2 of Specification 20500–A should not be exceeded in drying Douglas fir for maximum strength value. Humidities used should be such as to keep checking and casehardening to a minimum. Steaming as permitted by Specification 20500–A would be expected to have no harmful effect.

WESTERN WHITE PINE.

SOURCE OF MATERIAL.

Four experimental kiln runs have been made on material from two shipments of logs. Shipment 488, which furnished stock for kiln runs 95 and 110, consisted of logs from 24 trees cut in Idaho. These logs were 10 to 20 inches in diameter and too knotty to be considered of airplane grade. Test specimens were, however, so selected as to be unaffected by the defects and were representative of the clear wood.

Shipment 570 furnished stock for kiln runs 149 and 150. This shipment consisted of seventeen 16-foot butt logs sent to the Laboratory from Keeler, Idaho. These were of better quality than the previous shipment and were 18 to 36 inches in diameter.

Data on these two shipments are compared with data from green and air-dried material from one log of shipment 224. This shipment came from Missoula County, Mont., and was tested prior to the beginning of the present series of tests.

CUTTING OF STOCK.

The logs of shipment 488 were cut into 8-foot bolts, which were subdivided similarly to the logs of commercial white ash. (See fig. 10.) The resulting planks were cut into 2 by 3 inch, 2 by 4 inch, 2 by 5 inch, and 3 by 4 inch stock.

Table 16 shows how the material was divided for drying in two kiln runs.

The 16-foot logs of shipment 570 were sawed in a manner similar to that shown for Douglas fir in figure 1 (B). Material for test green and after air drying was derived from a 2½-inch flitch extending through the center of each log. Half of the remaining material from each log was dried in the form of 2½-inch planks, of various widths and 16 feet long.

DESCRIPTION OF KILN DRYING CONDITIONS.

Figure 16 shows graphically the kiln conditions and the moisture contents of samples of stock for the four runs 95, 110, 149, and 150.

Run 95.—The charge consisted of 2 by 3 inch, 2 by 4 inch, 2 by 5 inch, and 3 by 4 inch pieces derived from shipment 488. (See Table 16.) The arrangement of the kiln was much as for run 147 of Sitka spruce (see fig. 7), except that the material was flat piled. The piling was open (2-inch stickers and 2½ to 3 inches between the pieces in the layers), with the 2-inch stock on top of the 3-inch.

TABLE 16.—*Western white pine—Shipment 488—List of trees and bolts to show which bolts were represented in each kiln run.*

Tree and bolt.	Kiln run 95.	Kiln run 110.	Tree and bolt.	Kiln run 95.	Kiln run 110.
1 a-b		*	13 a-b		*
2 a-b	*		14 a-b	*	
2 c-d		*	14 c-d		*
3 a-b		*	15 a-b		*
4 a-b	*		16 a-b	*	
4 c-d		*	16 c-d		*
5 a-b		*	17 a-b		*
6 a-b	*		18 a-b	*	
6 c-d		*	18 c-d		*
7 a-b		*	19 a-b		*
8 a-b	*		20 a-b	*	
8 c-d		*	20 c-d		*
9 a-b		*	21 a-b		*
10 a-b	*		22 a-b	*	
10 c-d		*	22 c-d		*
11 a-b		*	23 a-b		*
12 a-b	*		24 a-b	*	
12 c-d		*	24 c-d		*

* Indicates that material from the bolt listed at the left was represented in the kiln run whose number appears at the top of the column. Material was taken from each bolt for tests in green and air-dried condition.

The run was begun with 4½ hours' preliminary steaming at 90° to 135° F. Temperatures and humidities were as shown in figure 16. The irregularities in these factors during the first few days were due to derangement of controlling apparatus. As shown by the curves of figure 16, the samples of 2-inch stock reached a satisfactory dryness and it was removed from the kiln three days ahead of the 3-inch stock.

Considerable trouble was experienced from lack of uniformity in drying. This was largely due to wide variations in the initial moisture content of different pieces and to apparently nonuniform distribution of moisture lenthwise of individual pieces.

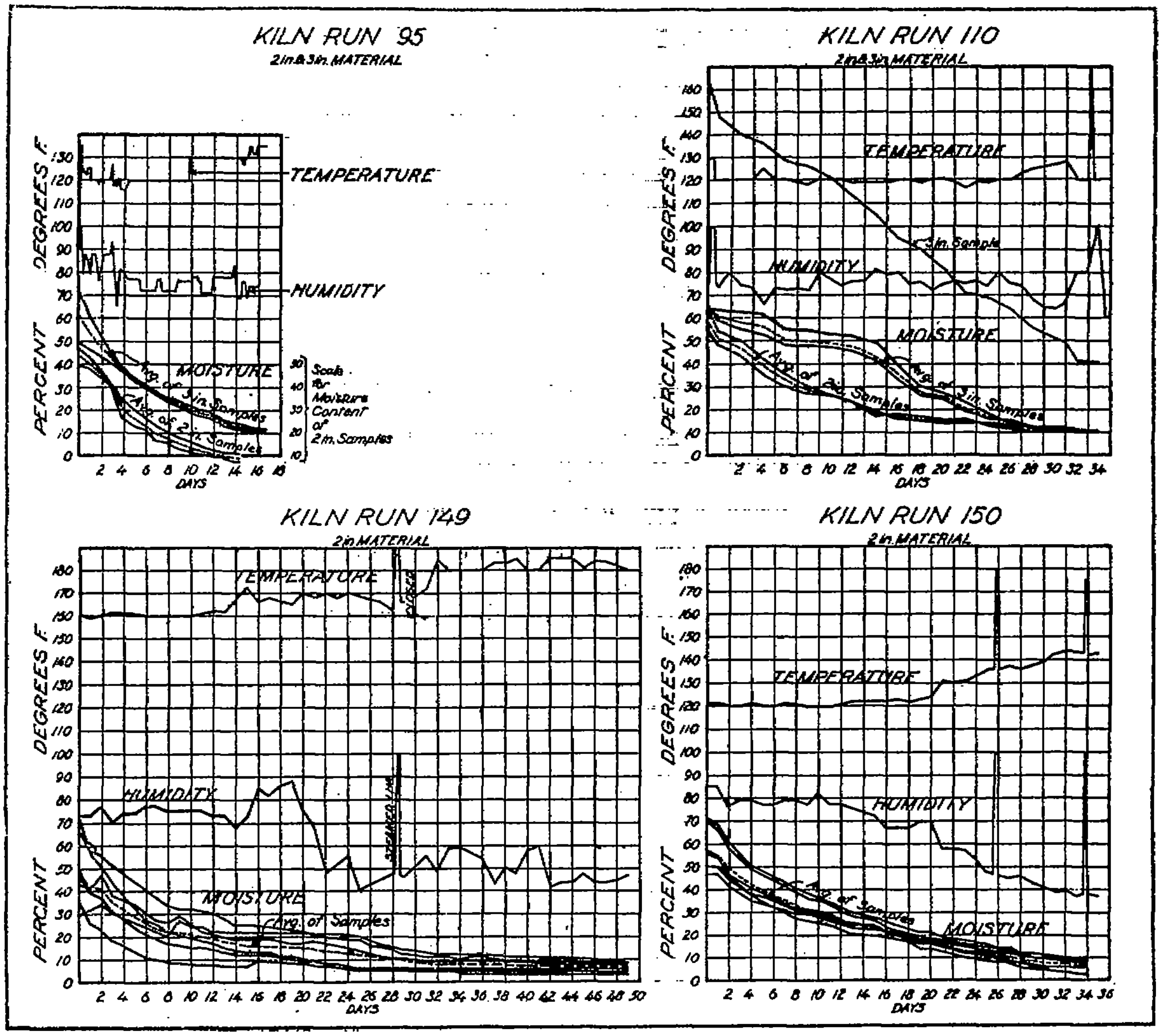

FIG. 16.—Kiln conditions for western white pine, kiln runs 95 and 110 (shipment 488) and 149 and 150 (shipment 570).

Some slight evidence of casehardening was found near the end of the run. It was not sufficient, however, to necessitate steaming.

Run 110.—The charge for this run, as for 95, was of 2 by 3 inch, 2 by 4 inch, 2 by 5 inch, and 3 by 4 inch pieces derived from shipment 488 (see Table 16). Arrangement of the kiln and piling of stock was quite similar to run 95. Spaces between pieces in the layers were, however, only one-half to three-fourths of an inch.

After preliminary steaming at 135° F. for 18 hours, drying conditions were established and continued as shown by figure 16. As in run 95, considerable trouble was experienced because of nonuniformity of moisture distribution in the charge. This condition obtained both at the beginning and at the end of the run. The closer piling was perhaps in part responsible for the longer drying period than in run 95. Furthermore, because of the very high moisture content of one sample, raising of temperature and lowering of humidity were delayed longer than in run 95.

Run 149.—The charge consisted of 3 by 3 inch, 3 by 5 inch, and 3 by 8 inch pieces, 16 feet in length, derived from shipment 570. Material was flat piled on 1½-inch stickers with 2-inch spaces.

The very long time required for this run is due largely to the fact that it was made in an experimental kiln in which a fan circulatory system had been devised and which had not yet been rendered controllable. Circulation was very poor and resulted in nonuniformity of temperature between different parts of the kiln. Slight casehardening was relieved by steaming for one hour at 185° F. on the thirtieth day. No casehardening was evident at the close of the run.

Run 150.—The charge consisted of 3 by 3 inch, 3 by 4 inch, and 3 by 5 inch pieces, 16 feet in length and of various widths, derived from shipment 570. The material was close-piled on a slant, with 1½-inch stickers. Material was steamed for one hour on two occasions at 180° and 174° F., respectively, to relieve casehardening. Slight casehardening was present when the material was removed from the kiln.

AIR DRYING.

Material was stored for air drying under conditions similar to those for Sitka spruce and Douglas fir, as previously described.

STRENGTH DATA.

Table 17 gives the complete data available after the testing of the air-dried material Improvement ratios derived from this table are shown in Table 18 and graphed in figure 17.

TABLE 17.—*Average mechanical test values of western white pine—(Tabulations as tested—No adjustment for moisture content).*

Property.	Shipment 224.		Shipment 488.						Shipment 570.			
	Green.	Air dry.	Green, to match kiln run 95.	Air dry, to match kiln run 95.	Kiln run 95.	Green, to match kiln run 110.	Air dry, to match kiln run 110.	Kiln run 110.	Green, to match kiln run 149.	Kiln run 149.	Green, to match kiln run 150.	Kiln run 150.
STATIC BENDING.												
Moisture (per cent)[1]	47.9	8.0	65.9	11.6	11.0	57.3	12.0	8.0	46.4	7.9	45.7	8.5
Specific gravity[2]	.405	8.414	.360	.397	.388	.372	.400	.403	.347	.390	.345	.386
Fiber stress at elastic limit (lbs. per sq. in.)	3,961	12,938	3,400	6,360	6,610	3,600	6,270	8,500	3,280	7,560	3,240	7,310
Modulus of rupture (lbs. per sq. in.)	6,147	1,356	5,130	9,420	10,000	5,410	9,200	11,330	5,160	11,480	5,100	10,600
Modulus of elasticity (1,000 lbs. per sq. in.)	1,210	,468	1,132	1,486	1,512	1,112	1,471	1,719	1,169	1,623	1,149	1,528
Work to elastic limit (inch-lbs. per cu. in.)	.73	2.9	6.2	1.5	1.6	6.7	1.5	2.4	.6	2.2	5.3	2.0
Work to maximum load (inch-lbs. per cu. in.)	5.5	10.7	4.6	7.9	7.5	5.2	7.6	7.7	5.4	9.3	5.3	9.2
IMPACT BENDING, 50-POUND HAMMER.												
Moisture (per cent)[1]	46.1	8.3	64.5	11.1	11.8	59.4	11.8	9.9	45.5	7.7	45.6	10.5
Specific gravity[2]	.362	15.402	.362	.385	.379	.366	.396	.399	.361	.383	.358	.388
Fiber stress at elastic limit (lbs. per sq. in.)	7,218	1,070	7,650	11,900	12,160	7,150	11,250	12,730	7,980	11,640	7,930	11,120
Modulus of elasticity (1,000 lbs. per sq. in.)	1,221	,967	1,364	1,756	1,860	1,324	1,678	2,099	1,403	1,765	1,402	1,701
Work to elastic limit (inch-lbs. per cu. in.)	....	....	2.5	4.6	4.5	2.2	4.2	4.3	2.6	4.3	2.6	4.0
Drop causing complete failure (inches)	17.0	25.0	17.4	19.6	20.3	16.4	21.3	24.0	17.6	25.6	17.6	23.9
COMPRESSION PARALLEL TO GRAIN.												
Moisture (per cent)[1]	58.2	7.9	55.0	11.7	12.0	62.1	12.1	6.6	47.1	7.8	47.1	8.2
Specific gravity[2]	.393	7.432	.360	.389	.379	.362	.389	.394	.350	.385	.350	.382
Maximum crushing strength (lbs. per sq. in.)	3,070	,840	2,540	5,120	5,630	2,470	5,190	7,090	2,390	5,750	2,390	6,000

[1] Per cent moisture based on oven-dry weight.

[2] Specific gravity based on oven-dry weight and volume as tested.

TABLE 18.—*Average improvement ratios of western white pine.—(With and without adjustment to 9 per cent moisture).*

Shipment.	Seasoning.	Static bending.							Impact bending, 50-pound hammer.			Compression parallel to grain.		
		Moisture.	Modulus of rupture.		Modulus of elasticity.		Work to maximum load.		Moisture.	Height of maximum drop.		Moisture.	Maximum crushing strength.	
			I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.
		Per ct.							Per ct.			Per ct.		
224	Air-dry	8.0	2.01	1.87	1.21	1.19	1.95	1.81	8.3	1.47	1.42	7.9	2.55	2.30
488	Air-dry	11.6	1.84	2.01	1.31	1.37	1.72	1.87	11.1	1.13	1.14	11.7	2.02	2.26
488	Kiln run 95	11.0	1.95	2.08	1.34	1.38	1.63	1.71	11.8	1.17	1.20	12.0	2.22	2.58
488	Air-dry	12.0	1.70	1.88	1.32	1.40	1.46	1.57	11.8	1.30	1.36	12.1	2.10	2.44
488	Kiln run 110	8.0	2.09	1.94	1.55	1.48	1.48	1.42	9.9	1.46	1.47	6.6	3.11	2.54
570	Kiln run 149	7.9	2.23	2.03	1.39	1.34	1.72	1.62	7.7	1.46	1.39	7.8	2.41	2.17
570	Kiln run 150	8.5	2.08	1.97	1.33	1.30	1.74	1.67	10.5	1.36	1.38	8.2	2.51	2.40

Fiber-saturation point assumed to be at 24 per cent moisture content. I. R.=Improvement ratio.

In Table 19 and in figure 18 are given the ratios which were available for the first analysis. These ratios differ slightly from those in Table 18 and figure 17 because when Table 18 was

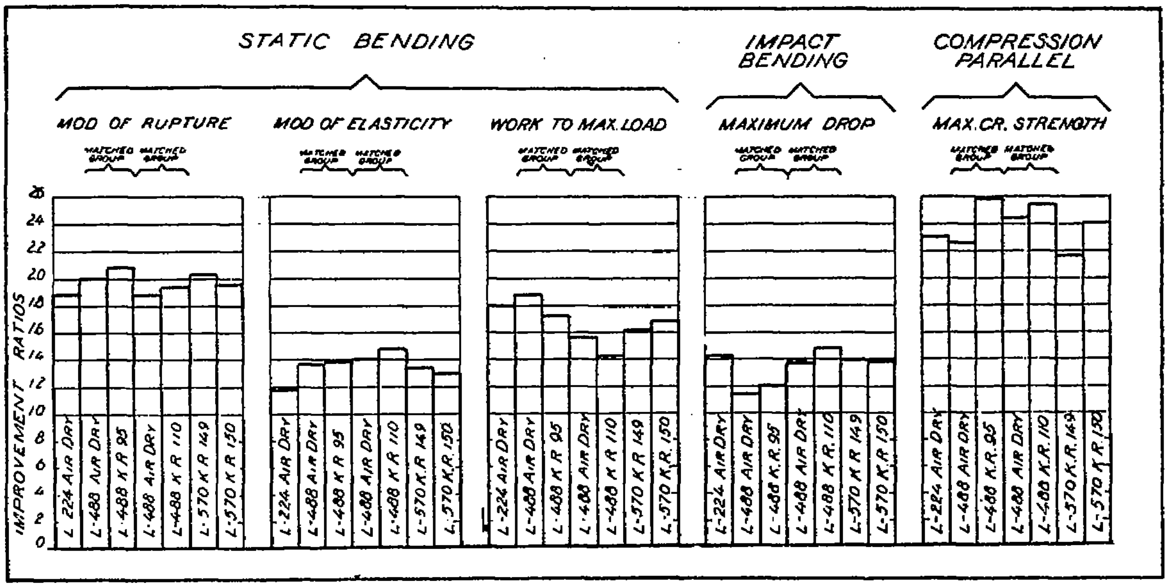

FIG. 17.—Improvement ratios for comparison of groups of kiln and air dried stock, western white pine.

made up it became necessary, in order to secure the best matching, to reject some specimens, results from which had been used in making up Table 19.

TABLE 19.—*Average improvement ratios of western white pine.—(With and without adjustment to 9 per cent moisture.)*

[Shipments 224 and 448.]

Seasoning.	Static bending.							Impact bending, 50-pound hammer.			Compression parallel to grain.		
	Moisture.	Modulus of rupture.		Modulus of elasticity.		Work to maximum load.		Moisture.	Height of maximum drop.		Moisture.	Maximum crushing strength.	
		I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.
	Per ct.							Per ct.			Per ct.		
Air-dry[1]	8.0	2.01	1.93	1.21	1.19	1.95	1.87	8.3	1.47	1.45	7.9	2.55	2.39
Kiln run 95	10.9	1.96	2.16	1.35	1.41	1.64	1.76	11.6	1.32	1.40	12.0	2.24	2.74
Kiln run 110	8.0	2.09	2.00	1.55	1.51	1.53	1.49	8.0	1.42	1.39	6.6	3.12	2.66

[1] Air-dried material from shipment 224. I. R.=Improvement ratio.

DISCUSSION AND CONCLUSIONS.

As mentioned on page 20, western white pine is to be used as an example of the two methods of analysis:

1. First or preliminary analysis based on comparison of kiln-dried and previously air-dried material by means of the increase in strength properties produced by kiln drying as compared to the previously observed increase from air drying.
2. Second analysis based on comparisons of matched kiln and air-dried material.

FIRST ANALYSIS.

As the example of this first analysis, the discussion, conclusions, and recommendations substantially as given in a report made when the data of Table 19 and figure 18 only were available will be repeated here.

Discussion.—Figure 18 shows that the improvement in strength properties produced by kiln drying, with the exception of work to maximum load, is practically as great as is secured by air drying as determined by previous tests from a single tree.

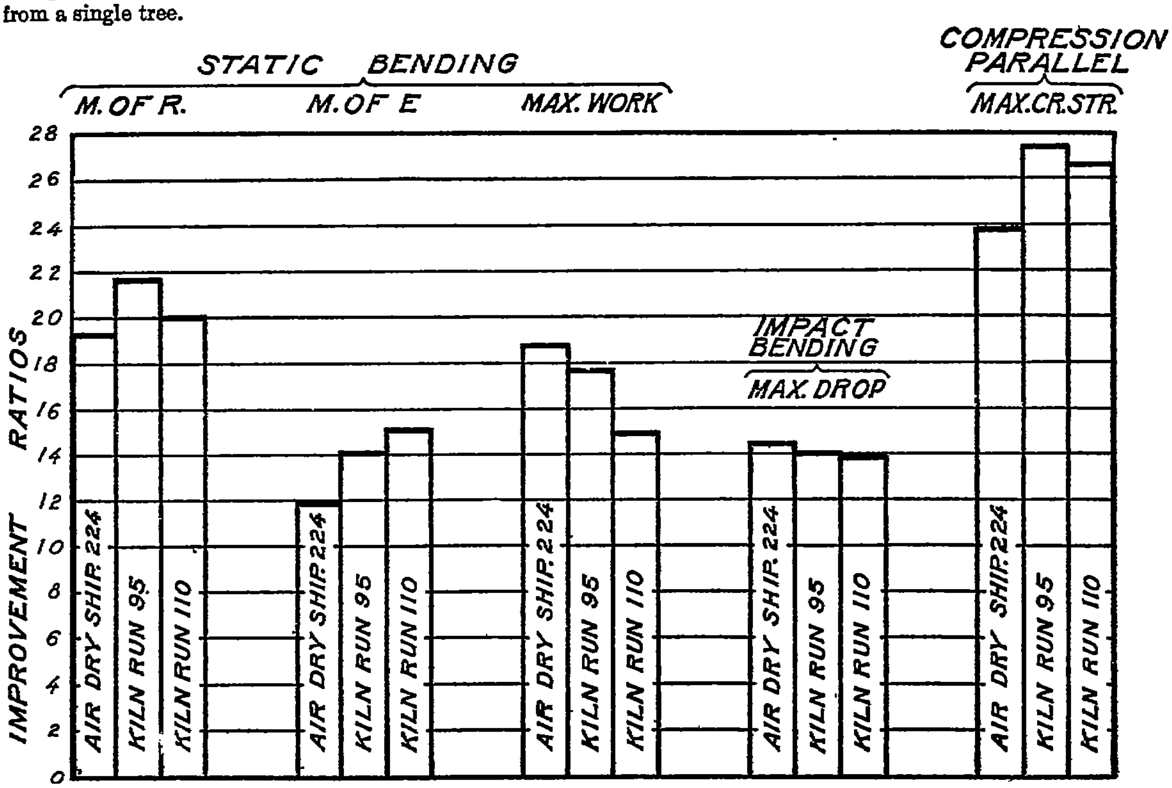

FIG. 18.—Improvement ratios for comparison of kiln runs 95 and 100 with air-dried stock of a previous shipment (shipment 224), western white pine.

Apparently air drying produced in the material of this one tree exceptional improvement in work to maximum load. This belief is supported by the fact that in most if not all cases other coniferous woods have shown less increase in this property. Also the actual values for work to maximum load for the air-dried material of this one tree is higher than for any other coniferous species except the very heavy and dense ones, such as longleaf pine. Furthermore, it is the general, but not invariable, rule that deflection to maximum load should decrease in air drying. Data on deflections to maximum load are given in Table 20.

TABLE 20.—*Average deflections to maximum load with and without adjustments.*

	Air-dry shipment 224.	Kiln run 95.	Kiln run 110.
Deflection of green sticks to match ....inches..	0.73	0.73	0.70
Deflection of seasoned sticks ....inches..	.75	.73	.68
Size of seasoned sticks ....inches..	2 by 2	1.75 by 1.75	1.75 by 1.75
Deflection of seasoned material—adjusted for size of sticks ....inches..	.75	.64	.60
Improvement ratio of deflection [1]	1.03	.85	.85

[1] Adjusted for size of stick and moisture content. All green sticks were 2 by 2 inches.

From the foregoing it is concluded that the increase in work to maximum load obtained from the one tree previously air dried is abnormal and that the improvement of the kiln-dried material in this respect has probably been as great as would have resulted had the same material been air dried.

Conclusions.—It is concluded, then, that in all probability runs 95 and 110 have produced as good results as would have resulted from air drying the same material. The conditions in these runs were less severe than permitted by Specification 20500–A in that the specification admits of lower humidities than were used near the end of the run. However, the high humidities maintained until the end of the runs (in 110 because of the very high moisture content of a single sample) are not believed essential to the preservation of strength properties. A lower humidity would perhaps have shortened the time of drying somewhat. Data on material dried in accordance with Specification 20500–A are not yet available.

The difficulty experienced in these runs through large variations in moisture content of the stock, and through drying two thicknesses together, emphasizes the desirability of classifying material on the basis of moisture content and size, and of drying each class separately. A rough moisture classification such as could be obtained by "hefting" each piece as loaded into the kiln would probably expedite the drying.

Recommendations.—It is recommended:

1. That, until additional data on the effect of various temperatures and humidities on the strength of western white pine can be obtained, Table 1 of Specification 20500–A be used for drying this species.

2. That consideration be given to grouping material into two or more classes on the basis of moisture content, and to drying material of but one moisture content class in the same kiln charge or placing the material containing the most water in the fastest-drying portion of the kiln.

SECOND ANALYSIS.

Discussion of runs 95 and 110.—Referring now to figure 17, it is seen that material from kiln runs 95 and 110 excels matched air-dried material in all properties except work to maximum load. This is the property in which the kiln-dried material seemed to fall short when the first analysis was made. However, this shortage is believed to be entirely offset by the superiority in drop values and in other properties.

In fact, almost any reasonable weighting of properties and summing up of the effect of drying on the properties as a whole shows that the two kiln runs have been practically equal in their effect, and have produced results fully as good as air drying.

The differences between runs 95 and 110 and the corresponding groups of air-dried material are in all probability not a result of the different methods of seasoning, but are actual inherent differences in material, impossible to avoid.

Discussion of runs 149 and 150.—In the absence of air-dried material corresponding to runs 149 and 150 it is not possible, of course, to make positive statements in regard to their effects. By comparison with the improvement in the air-dried material of shipment 224 and 488, the results of these two runs seem quite satisfactory. Moreover, the lack of any consistent or apparently appreciable superiority of one run over the other, material for the two runs having been secured from the same trees and being very much alike (compare "green to match kiln run 149" with "green to match kiln run 150," Table 17), indicates practical equality.

This equality, taken together with the fact that run 149 was at a considerably higher temperature than 150, might also be taken as an indication that, up to the limits of run 149, no damage from high temperatures was to be expected. Caution must be observed here, however. It is indicated by the long period required for drying in run 149, and also shown by records of this run, that circulation was not good. The natural accompaniment of poor circulation is nonuniformity of temperatures in different parts of the kiln. Hence it is entirely possible that some of the material tested may not have been subjected to as severe temperature conditions as are indicated in figure 16.

It must be said that, in general, the kiln drying of western white pine in these runs has not been eminently satisfactory. This is attributed largely to the character of the material with respect to moisture content. As has been mentioned, moisture content has been found to be very nonuniform.

Conclusions.—It is believed that the data presented herein justify the following conclusions:

1. Western white pine can be kiln dried without damage to strength properties.

2. Table 1 of Specification 20500–A can be depended on to dry western white pine without damage to strength properties.

Recommendations.—It is recommended that, pending the results of further tests, the temperatures of Specification 20500–A be not exceeded in drying western white pine, and that the humidity and steaming be regulated to keep casehardening to a minimum.

COMMERCIAL WHITE ASH.[1]

Eight kiln runs (81, 82, 83, 90, 96, 97, 92, and 100) have been made on white ash to show the effect of drying under various combinations of temperatures and humidities.

SOURCE OF MATERIAL.

Shipment 499 consisted of partially air-dried rough planks furnished by one of the airplane companies. This furnished material for runs 81, 82, and 83, which included both ash and Sitka spruce and are previously mentioned as "preliminary runs."

Shipment 505 consisted of one log from each of 33 trees from southeastern Arkansas. Three logs were 12 feet long and the remainder 16 feet. Top diameters ranged from 13 to 23 inches and the average total taper from top to butt of log was 6½ inches.

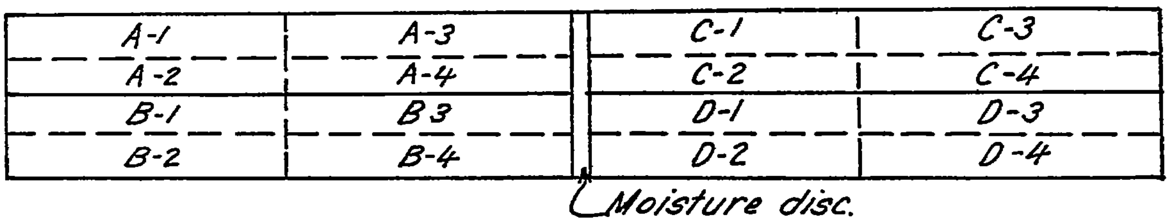

FIG. 19.—Cutting of white ash planks, shipment 499.

Material from logs 1 to 12, inclusive, was dried in run 90. Logs 13 to 33, inclusive, were represented in each of the runs 96 and 97. Mechanical test specimens for runs 96 and 97 were derived from material from the even-numbered logs.

Shipment 507 consisted of fifty 12-foot logs from near Goshen, Ind. Top diameters ranged from 11 to 19 inches and the average total taper was 2½ inches. Material for runs 92 and 100 was derived from this shipment.

MARKING AND MATCHING.

The material from shipments 505 and 507 was cut from the logs as illustrated in figure 10, and was marked and matched in the usual manner, as previously described.

Material for runs 81 and 82 was derived from 10 planks of shipment 499, cut and numbered as shown in figure 19. Pieces marked "D" were dried in run 81 and those numbered "A"

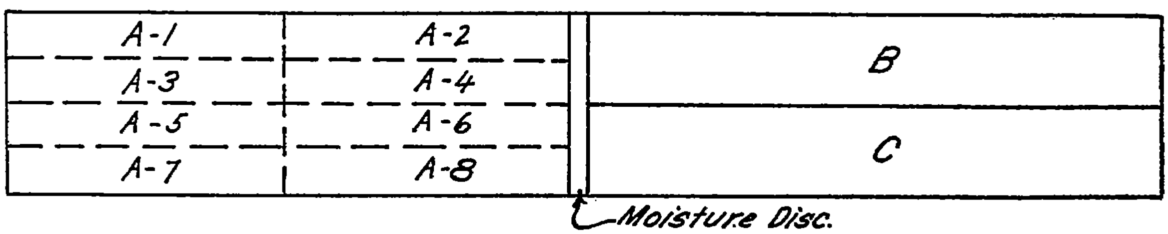

FIG. 20.—Cutting of white ash planks, shipment 499.

in run 82. Sticks A–1, A–4, D–1, and D–4 were tested as dried; A–2, A–3, and D–2, and D–3 were steamed and bent after kiln drying;[2] B–1, B–4, C–1, and C–4 were tested partially air-dried, or as received at the laboratory; and B–2, B–3, C–2, and C–3 were stored for complete air drying.[3]

In grouping data for the analysis of the effect of kiln drying on strength, A sticks were considered as matched to C, and D to B.

The material for run 83 was taken from 20 planks of shipment 499, cut as shown in figure 20. Piece A was kiln dried and tested, and pieces B and C were tested after air drying for about 11 months.

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[1] The white ash tested was not identified as to exact species. It was, however, of some of the species included in the term "commercial white ash," the most important of which are: White ash (*Fraxinus americana*), green ash (*Fraxinus lanceolata*), blue ash (*Fraxinus quadrangulata*), biltmore ash (*Fraxinus biltmoreana*).

[2] The results of the steaming and bending tests are not to be discussed here.

[3] These sticks have not been tested.

DESCRIPTION OF KILN DRYING CONDITIONS.

Quantity and sizes of stock, method of piling, and condition before and after drying are given for each kiln run in Table 21. Figure 21 shows the drying conditions for each run. Steaming to relieve casehardening was done in runs 82 and 90 and is indicated on the diagrams (fig. 21) by a sudden high humidity held for a short time near the end of the run. Initial steaming was used in runs 90, 92, and 96.

TABLE 21.—*Description of commercial white ash dried in kiln runs 81, 82, 83, 90, 96, 97, 92, and 100.*

Run.	Amount of stock.	Size of pieces.	Piling.	Condition on entering the kiln.	Condition when taken from kiln.
81	10 planks	1½-inch planks, various widths.	Open—flat	Partially air dry; good condition except very badly weather stained.	No visible harm.
82	do	do	do	do	Do.
83	20 planks	do	do	Partially air dry; slight checks.	O. K.
90	71 planks	2-inch planks, various widths, 16 feet long.	Close—flat, 1¼-inch stickers every 2 feet.	Good condition	Less than ¼ per cent degrade, all being in 7 planks, 6 of which were checked and 1 cupped; no signs of casehardening.
96	183 pieces	2 by 2 inches by 16 feet	Open—flat, 1¼-inch stickers every 2¼ feet.	Badly sprung and in some cases checked.	No visible degrade.
97	202 pieces	do	Open—flat, 2-inch stickers every 2¼ feet.	Very badly sprung and checked.	No visible degrade; most of warping was eliminated.
92	282 pieces	2 by 2 inches, 10, 12, and 16 feet long.	Open—flat, 1¼-inch stickers every 2 feet.	Badly warped, twisted, and checked.	No visible degrade; twisted and bent condition considerably relieved.
100	253 pieces	2 by 2 inches by 14 feet	Open—flat, 1¼-inch stickers, 2-inch chimneys.	Good condition	No degrade.

AIR DRYING.

Material was air dried under conditions similar to those previously described for Sitka spruce and Douglas fir.

STRENGTH DATA.

Average strength values for the various groups of material are given in Table 22.

Table 23 gives the improvement ratios for the more important properties of the air-dried material and for that dried in the various kiln runs, both without adjustment and after adjustment to 10 per cent moisture. Each ratio given in this table is based on the average of all the material of any kiln or air dried group, as compared to the average from the corresponding green material.

Figure 22 presents in graph form the adjusted improvement ratios of Table 23.

DISCUSSION.

The absence of complete data, i. e., green and air-dried matching that kiln dried, on runs 81, 82, and 83 makes it necessary that they be judged by comparing the improvement they have produced with that produced in air drying the *other groups*. Proceeding on this basis, it is seen that 83 is normal or above normal in all respects, while 81 and 82 are quite low in work to maximum load, and 82 is very low in drop. (See Table 22 and fig. 22.) It is concluded that 83 has in all probability produced as good results as would be secured from air drying, but that 81 and 82 have failed to give good results in work and drop values which are measures of shock-absorbing ability and of great importance in airplane material.

Careful scrutiny of Tables 22 and 23 and figure 22 shows that runs 90, 96, 97, 92, and 100 are all fully equal to the corresponding air-dried material in the important properties "work to maximum load" and "drop"; that all except 90 are equal or superior to air-dried in modulus of elasticity; and that 96 only is fully equal to the air-dried in modulus of rupture and maximum crushing strength. Furthermore, run 90 falls very considerably below air dried in these latter properties. A résumé of the above amounts to this:

1. That the apparent "efficiency" of the kiln drying as shown in figure 22 and Table 24 is greatest for those properties which are least affected by changes of moisture content—work to maximum load, drop, and modulus of elasticity—and least for those properties which are most influenced by changes of moisture content—modulus of rupture and maximum crushing strength.

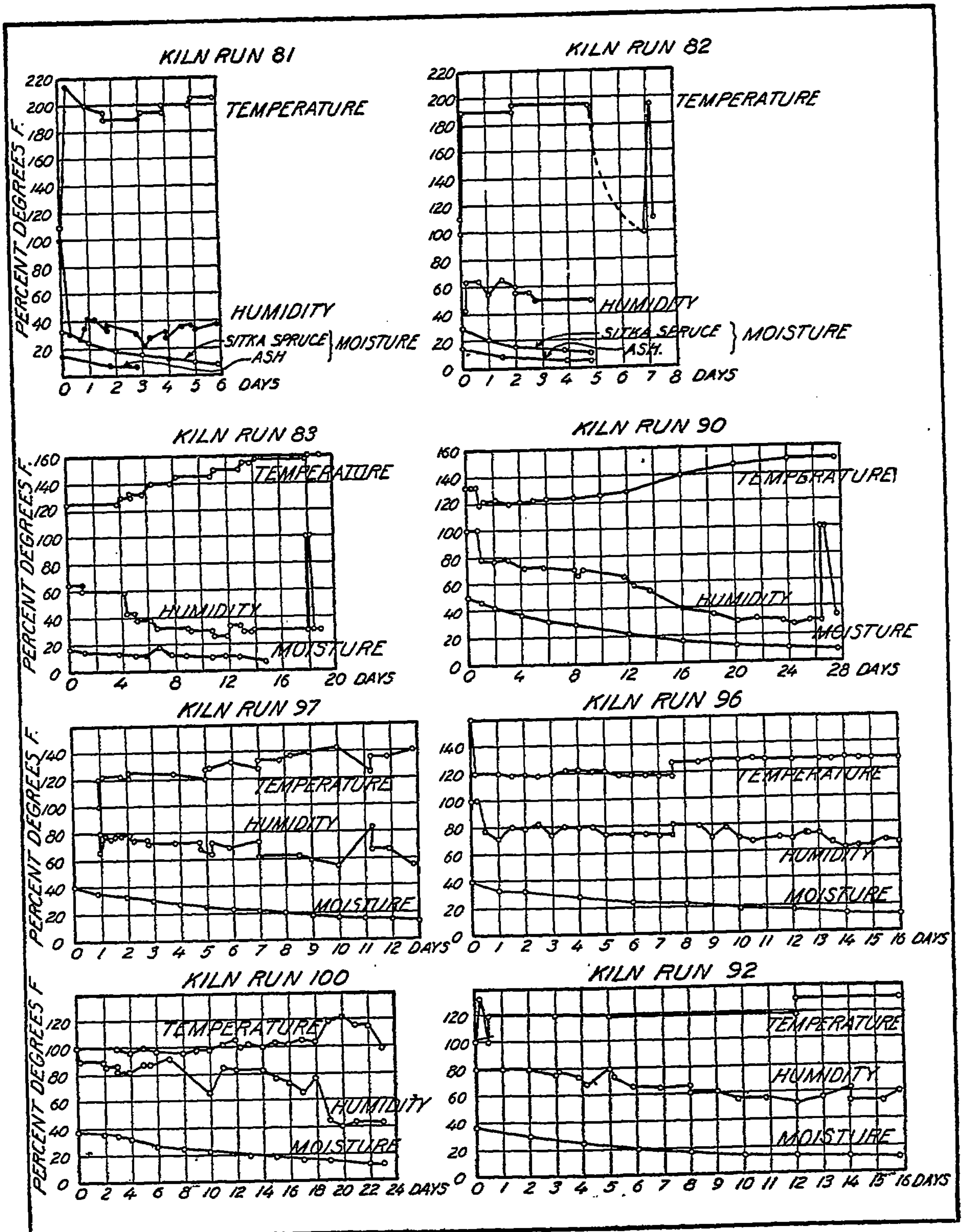

FIG. 21.—Kiln conditions for white ash kiln runs 81, 82, and 83 (shipment 499), runs 90, 96, and 97 (shipment 505), and runs 92 and 100 (shipment 507).

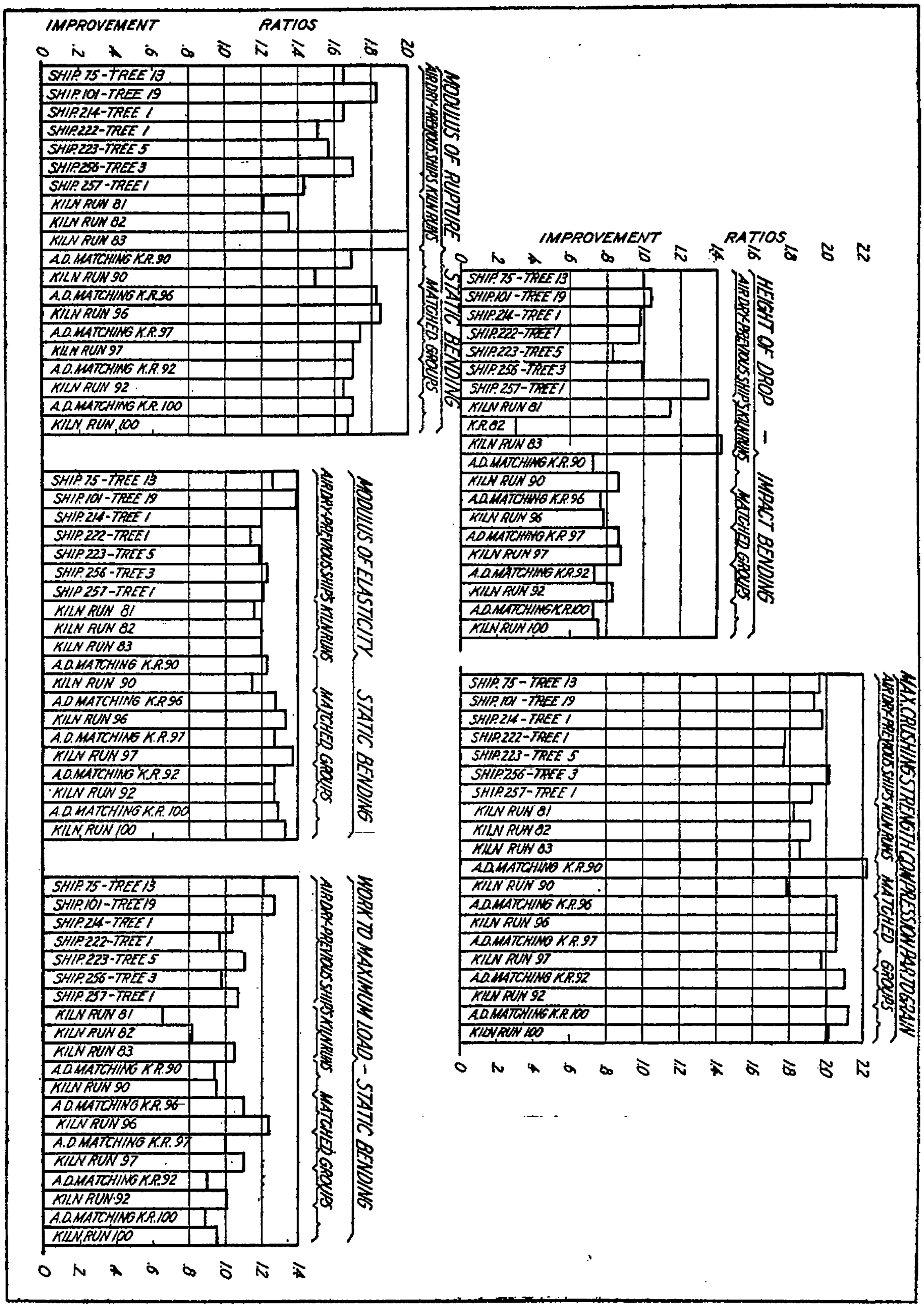

FIG. 22.—Improvement ratios adjusted to 10 per cent moisture for comparing ten kiln runs on commercial white ash.

2. That the run (90) showing the lowest apparent efficiency in modulus of rupture and maximum crushing strength is the run in which moisture content of the kiln-dried material is farthest below the corresponding air-dried material; consequently, for which adjustment of moisture had to be made across the widest interval.

Now it is recognized that the methods of moisture adjustment, while the best that it has been possible to devise, are not perfect, and it can be demonstrated that any errors in the applicability of the fundamental assumptions underlying the methods of adjustment used will have the largest *percentage* effect on the computed "efficiencies" as presented in Table 24, when:

1. Applied to those properties which are most largely affected by change of moisture content.

2. The interval across which moisture adjustment must be made is largest.

TABLE 22.—*Mechanical properties of commercial white ash (summaries of original test values).*

	Various shipments.		Shipment 499.					Shipment 505.			
	Tree. 13 19 1 1 5 3 1	Ship. 75 101 214 222 223 236 257	Partially air-dry matching kiln runs 81–82.	Kiln run 81.	Kiln run 82.	Air-dry matching kiln run 83.	Kiln run 83.	Green matching kiln run 90.	Air-dry matching kiln run 90.	Kiln run 90.	Green matching kiln run 96.
	Green.	Air-dry.									
STATIC BENDING.											
Moisture (per cent)[1]	41.0	8.9	15.9	4.4	7.2	12.6	6.2	45.1	12.9	8.9	42.4
Specific gravity[2]	.54	.597	.558	.573	.602	.568	.588	.534	.574	.536	.519
Fiber stress at elastic limit (lbs. per sq. in.)	5,750	11,060	6,280	8,560	9,300	7,280	10,340	5,460	8,320	8,110	4,910
Modulus of rupture (lbs. per sq. in.)	10,050	16,940	10,940	13,460	14,250	12,440	16,530	8,010	12,970	13,970	8,520
Modulus of elasticity (1,000 lbs. per sq. in.)	1,509	1,900	1,437	1,639	1,676	1,569	1,748	1,349	1,563	1,613	1,266
Work to elastic limit (inch-lbs. per cu. in.)	1.26	3.64	1.55	2.52	2.97	1.95	3.46	1.30	2.49	2.32	1.10
Work to maximum load (inch-lbs. per cu. in.)	14.29	15.4	13.40	8.34	11.2	13.3	18.5	13.0	12.51	12.2	12.20
Work, total (inch-lbs. per cu. in.)	40.29	30.5	21.0	1.9	18.3	......	23.2	......	......	......	......
IMPACT BENDING, 50-POUND HAMMER.											
Moisture (per cent)[1]	41.6	8.7	17.0	4.8	7.2	13.5	6.0	44.4	12.8	8.8	41.0
Specific gravity[2]	.534	.592	.560	.581	.586	.556	.590	.542	.587	.596	.527
Fiber stress at elastic limit (lbs. per sq. in.)	12,280	19,500	15,290	17,750	15,510	19,120	21,750	13,030	13,880	13,200	10,020
Modulus of elasticity (1,000 lbs. per sq. in.)	1,605	2,189	2,151	2,708	2,616	3,006	2,697	1,848	2,254	2,026	1,605
Work to elastic limit (inch-lbs. per cu. in.)	5.25	9.77	6.1	6.5	5.4	6.8	9.9	5.1	4.7	4.8	3.5
Drop causing complete failure (inches)	38.7	39.0	32.4	37.8	10.1	38.0	48.1	43.1	34.1	36.0	43.6
COMPRESSION PARALLEL TO GRAIN.											
Moisture (per cent)[1]	42.2	9.0	16.5	4.7	7.4	11.7	6.9	45.8	12.5	9.0	43.5
Specific gravity[2]	.541	.597	.558	.586	.591	.585	.592	.531	.578	.590	.518
Maximum crushing strength (lbs. per sq. in.)	4,310	8,760	4,650	9,390	8,380	6,530	8,850	3,730	6,800	6,990	3,780
COMPRESSION PERPENDICULAR TO GRAIN.											
Crushing strength at elastic limit (lbs. per sq. in.)	855	1,772	......	......	......	......	......	865	1,546	1,567	828
HARDNESS, BALL TEST.											
End (pounds)	1,033	1,964	1,171	1,410	2,118	......	1,919	954	1,628	1,691	1,006
Radial (pounds)	952	1,422	1,026	1,305	1,377	......	1,441	860	1,278	1,292	909
Tangential (pounds)	984	1,398	1,030	1,248	1,440	......	1,453	889	1,250	1,358	940
SHEARING STRENGTH.											
Radial (lbs. per sq. in.)	1,299	2,106	......	......	......	......	......	1,364	1,920	2,036	1,256
Tangential (lbs. per sq. in.)	1,284	2,028	......	......	......	......	......	1,316	1,774	1,966	1,262
TENSION PERPENDICULAR TO GRAIN.											
Radial (lbs. per sq. in.)	551	810	......	......	......	......	......	......	934	......	608
Tangential (lbs. per sq. in.)	679	789	......	......	......	......	......	......	677	......	561
CLEAVAGE.											
Radial (lbs. per inch of width)	330	457	......	......	......	......	......	......	433	......	329
Tangential (lbs. per inch of width)	376	248	......	......	......	......	......	......	415	......	309

TABLE 22.—*Mechanical properties of commercial white ash*—Continued.

	Shipment 505—Continued.					Shipment 507.					
	Air-dry matching kiln run 96.	Kiln run 96.	Green matching kiln run 97.	Air-dry matching kiln run 97.	Kiln run 97.	Green matching kiln run 92.	Air-dry matching kiln run 92.	Kiln run 92.	Green matching kiln run 100.	Air-dry matching kiln run 100.	Kiln run 100.
STATIC BENDING.											
Moisture (per cent) [1]	13.0	12.2	42.1	13.0	12.9	35.8	12.7	11.0	36.0	12.6	11.3
Specific gravity [2]	.577	.566	.525	.579	.596	.565	.599	.619	.561	.598	.612
Fiber stress at elastic limit (lbs. per sq. in.)	7,720	7,640	5,110	7,870	7,210	5,770	9,390	8,800	5,680	9,340	9,240
Modulus of rupture (lbs. per sq. in.)	12,940	13,780	8,820	12,930	12,850	9,750	14,340	15,230	9,660	14,280	15,020
Modulus of elasticity (1,000 lbs. per sq. in.)	1,502	1,588	1,294	1,528	1,613	1,452	1,729	1,796	1,429	1,736	1,833
Work to elastic limit (inch-lbs. per cu. in.)	2.17	2.10	1.17	2.24	1.86	1.30	2.94	2.44	1.28	2.96	2.63
Work to maximum load (inch-lbs. per cu. in.)	13.0	14.45	12.75	12.77	13.6	16.32	15.12	16.50	16.47	15.03	15.9
Work, total (inch-lbs. per cu. in.)	....	41.6	....	....	....	....	....	....	....	....	....
IMPACT BENDING, 50-POUND HAMMER.											
Moisture (per cent) [1]	13.4	11.9	40.2	13.2	11.9	36.7	12.6	11.1	36.7	12.7	11.2
Specific gravity [2]	.567	.582	.529	.572	.570	.579	.604	.617	.567	.604	.608
Fiber stress at elastic limit (lbs. per sq. in.)	12,280	12,110	10,170	12,540	12,100	12,830	16,340	13,480	12,700	16,350	13,310
Modulus of elasticity (1,000 lbs. per sq. in.)	2,015	2,176	1,590	2,082	1,995	1,910	2,145	2,334	1,876	2,165	2,281
Work to elastic limit (inch-lbs. per cu. in.)	4.2	3.8	3.7	4.2	3.9	4.8	7.0	4.5	4.8	7.0	4.4
Drop causing complete failure (inches)	36.4	35.8	40.6	36.7	36.1	52.6	41.7	44.5	53.3	42.2	41.3
COMPRESSION PARALLEL TO GRAIN.											
Moisture (per cent) [1]	12.9	12.0	43.5	12.9	12.6	37.0	12.8	11.0	36.9	12.8	11.0
Specific gravity [2]	.570	.572	.518	.570	.569	.565	.611	.626	.553	.610	.605
Maximum crushing strength (lbs. per sq. in.)	6,260	6,660	3,780	6,260	6,240	3,950	6,770	7,330	3,920	6,750	7,310
COMPRESSION PERPENDICULAR TO GRAIN.											
Crushing strength at elastic limit (lbs. per sq. in.)	1,465	1,490	828	1,465	1,196	904	1,641	1,642	904	1,641	1,630
HARDNESS, BALL TEST.											
End (pounds)	1,430	1,469	1,006	1,430	1,464	978	1,651	1,753	975	1,648	1,914
Radial (pounds)	1,191	1,232	909	1,191	1,164	950	1,288	1,299	944	1,293	1,425
Tangential (pounds)	1,398	1,245	940	1,398	1,226	981	1,382	1,364	981	1,375	1,505
SHEARING STRENGTH.											
Radial (lbs. per sq. in.)	2,110	2,079	1,286	2,110	1,911	1,363	2,254	2,053	1,363	2,254	2,151
Tangential (lbs. per sq. in.)	1,876	1,882	1,262	1,876	1,820	1,363	2,083	2,021	1,363	2,083	2,085
TENSION PERPENDICULAR TO GRAIN.											
Radial (lbs. per sq. in.)	736	....	608	736	....	....	....	....	....	....	....
Tangential (lbs. per sq. in.)	838	....	561	838	....	....	....	....	....	....	....
CLEAVAGE.											
Radial (lbs. per inch in width)	446	....	329	446	....	....	....	....	....	....	....
Tangential (lbs. per inch of width)	341	....	309	341	....	....	....	....	....	....	....

[1] Per cent moisture based on oven-dry weight. [2] Specific gravity based on oven-dry weight and volume at test.

NOTES:
Shipment 75—Green ash (*Fraxinus lanceolata*) grown in Richland Parish, La.
Shipment 101—White ash (*Fraxinus americana*) grown in Stone County, Ark.
Shipment 214—White ash (*Fraxinus americana*) grown in Oswego County, N. Y.
Shipment 222—Blue ash (*Fraxinus quadrangulata*) grown in Bourbon County, Ky.
Shipment 223—Green ash (*Fraxinus lanceolata*) grown in New Madrid County, Mo.
Shipment 256—White ash (*Fraxinus americana*) grown in Pocahontas County, W. Va.
Shipment 257—Biltmore ash (*Fraxinus biltmoreana*) grown in Overton County, Tenn.
Test specimens of shipment 499 were 1.25 by 1.25 inches.
Values of drop, shipment 499 adjusted to 2 by 2 inch sticks.

TABLE 23.—*Commercial white ash.* (*Improvement ratios with and without adjustment to 10 per cent moisture of kiln-dried and air-dried material.*)

[Fiber-saturation point=20 per cent moisture.]

Shipment.	Seasoning.	Static bending.							Impact bending, 50-pound hammer.			Compression parallel to grain.		
		Moisture.	Modulus of rupture.		Modulus of elasticity.		Work to maximum load.		Moisture.	Height of maximum drop.		Moisture.	Maximum crushing strength.	
			I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.	I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.		I. R. as tested.	I. R. adjusted.
		Per ct.							*Per ct.*			*Per ct.*		
75	Air dry	11.4	1.54	1.65	1.22	1.26	1.18	1.21	11.3	1.00	1.00	11.2	1.81	1.96
101	....do	10.4	1.78	1.83	1.37	1.39	1.26	1.27	10.8	1.04	1.035	10.5	1.87	1.93
214	....do	9.0	1.73	1.65	1.22	1.20	1.04	1.035	9.0	.98	.93	9.5	2.04	1.97
222	....do	9.7	1.53	1.51	1.15	1.14	.97	.97	9.3	.97	.97	9.6	1.85	1.77
223	....do	9.5	1.61	1.57	1.20	1.19	1.12	1.11	9.3	.82	.83	9.6	1.80	1.76
256	....do	7.0	1.92	1.65	1.31	1.23	.98	.935	6.2	.98	.99	6.9	2.50	2.01
257	....do	5.6	1.68	1.43	1.32	1.21	1.01	1.08	5.3	1.55	1.35	5.4	2.60	1.92
499[1]	Kiln run 81	4.4	1.23	1.20	1.18	1.16	.62	.66	4.8	1.17	1.14	4.7	2.02	1.82
	Kiln run 82	7.2	1.30	1.35	1.17	1.20	.84	.82	7.2	.31	.30	7.4	1.80	1.91
	Kiln run 83	6.2	1.56	2.00	1.12	1.20	1.03	1.05	5.9	1.30	1.42	6.8	1.35	1.85
505	Kiln run 90	8.9	1.56	1.49	1.197	1.15	.94	.95	8.8	.84	.86	9.0	1.83	1.78
	Air dry	12.9	1.45	1.69	1.16	1.23	.96	.94	12.8	.79	.72	12.5	1.82	2.22
	Kiln run 96	12.2	1.62	1.85	1.25	1.33	1.18	1.24	11.9	.82	.78	12.0	1.77	2.05
	Air dry	13.0	1.52	1.83	1.19	1.28	1.07	1.10	13.4	.835	.76	12.9	1.66	2.05
	Kiln run 97	12.9	1.46	1.70	1.25	1.37	1.07	1.10	11.9	.89	.87	12.6	1.65	1.97
	Air dry	13.0	1.47	1.74	1.18	1.27	1.00	1.00	13.2	.90	.86	12.9	1.66	2.05
507	Kiln run 92	11.0	1.57	1.65	1.24	1.27	1.01	1.01	11.1	.85	.83	11.0	1.87	2.00
	Air dry	12.7	1.47	1.70	1.19	1.27	.93	.90	12.6	.79	.73	12.8	1.71	2.10
	Kiln run 100	11.3	1.56	1.67	1.28	1.33	.97	.96	11.2	.78	.75	11.0	1.87	2.01
	Air dry	12.6	1.48	1.70	1.21	1.29	.915	.89	12.7	.79	.72	12.8	1.72	2.12

[1] I. R. as tested $=\frac{\text{kiln-dried}}{\text{air-dried}}$ (no green to match).

TABLE 24.—*Efficiencies for kiln runs on white ash.*

Property.	F	Shipment 505.						Shipment 507.			
		Kiln run 90.		Kiln run 96.		Kiln run 97.		Kiln run 92.		Kiln run 100.	
		E	E×F	E	E×F	E	E×F	E	E×F	E	E×F
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Modulus of rupture	2	88.1	176.2	101.1	202.2	97.7	195.4	97.0	194.0	97.7	195.4
Modulus of elasticity	4	93.5	374.0	103.8	415.2	107.9	431.6	100.0	400.0	103.1	412.4
Work	3	101.1	303.3	112.8	338.4	110.0	330.0	112.1	336.3	107.9	323.7
Drop	3	119.2	357.6	102.7	308.1	101.1	303.3	113.6	340.8	104.1	312.3
Compression parallel	2	80.3	160.6	100.0	200.0	96.2	192.4	95.3	190.6	94.8	189.6
Σ(E×F)			1,371.7		1,463.9		1,452.7		1,461.7		1.433.4
Σ(E×F)+ΣF=weighted average E			98.0		104.6		103.8		104.4		102.4
ΣE		482.2		520.4		512.9		518.0		507.6	
ΣE+5=average E		96.4		104.1		102.6		103.6		101.5	

F=Weighting factor

E=Efficiency $=\frac{\text{Improvement ratio for property of kiln dry}}{\text{Improvement ratio for same property of corresponding air dry}}$

CONCLUSIONS.

From the above discussion the following conclusions are drawn:

1. Runs 81 and 82, made on partially air-dried material at high temperatures (180° to 210° F.) and with comparatively low humidities, resulted in rather severe damage to the important properties of work to maximum load and drop. (It is notable that neither of these runs produced any *visible* damage.)

2. Run 83 on partially air-dried material, and 90, 96, 97, 92, and 100 on green, at more moderate temperatures (initial 100° to 125° F. and maximum 120° to 160° F.) and somewhat higher humidities, have all produced material practically equal in mechanical properties to air-dried.

3. Results of this latter group of kiln runs furnish no basis for coordination between severity of kiln conditions and effect on mechanical value of the product.

4. From 2 follows the conclusion that Table 1 of Specification 20500–A is a safe schedule for the drying of white ash.

RECOMMENDATION.

It is recommended that in drying white ash for use where the retention of maximum strength is essential, the temperatures of Table 1 of Specification 20500–A should not be exceeded.

PORT ORFORD CEDAR.

Four kiln runs have been made on Port Orford cedar. The runs were numbered 124, 125, 126, and 157.

Kiln run 124 subjected the stock to slightly milder conditions than those specified in Table 1, Specification 20500–A.

Run 125 was made under rather severe high-temperature conditions. From an initial temperature of 165° F. and a relative humidity of 80 per cent, near the fiber-saturation point the temperature reached 175° F. and the relative humidity 40 per cent, ending with a temperature of 152° F. and a relative humidity of 35 per cent.

The temperatures and humidities called for by Table 2 of Specification 20500–A were used as a basis for the conditions of kiln run 126.

For kiln run 157, a practically constant temperature of 120° F. with a relative humidity of 80 per cent was used.

PHYSICAL RESULTS.

The average moisture content of green material in all four runs was 35 per cent, with samples from 124 containing 32 per cent, 125 containing 38.2, 126 containing 35.5, and 157 containing 33 per cent. The moisture contents were reduced to 8, 4, 8.2, and 8 per cent respectively. The time varied from eight days for run 125 to thirty-eight days for run 157, with run 124 taking nineteen days and run 126 twenty-eight days. Runs 124 and 125 showed practically no visible degrade, while runs 126 and 157 showed 3 and 8 per cent, respectively.

MECHANICAL RESULTS.

Comparison of kiln-dried material with previously tested air-dried material shows improvement ratios for the kiln-dried material lower in varying degrees than for air-dried material for all properties except maximum crushing strength in compression parellel to grain. The kiln material approximately equals air-dried in modulus of elasticity in static bending, lagging slightly behind air-dried material in modulus of rupture in static bending, and dropping well behind the air-dried for work to maximum load in static bending and drop in impact bending. There are no appreciable differences in the improvements of the first three kiln runs, all being exceptionally uniform. Run 157, however, is somewhat erratic. It is noticeably higher than the previous runs in improvement in work to maximum load, and noticeably lower in drop in impact bending.

CONCLUSIONS.

The previously tested air-dried material with which the kiln-dried is compared came from one tree only, and from evidence at hand it is concluded that it showed exceptional improvement in air drying. It is therefore probable that the kiln-dried material gave as great improvement as it would have done had it been subjected to a long period of air seasoning. A comparison of various kiln runs shows no significant difference in the improvement in strength values between the different runs, in spite of a considerable range of the temperatures used in drying.

RECOMMENDATIONS.

In view of the fact that positive conclusions can not be reached until tests have been made on air-dried material corresponding to that kiln-dried, and the further fact that any lack of control of kiln conditions is more likely to result in damage when attempting to run by a high-temperature schedule, it is recommended that higher temperatures and lower humidities than those of Table 1, Specification 20500–A, should not be used in drying Port Orford cedar, unless there is urgent need for rapid drying, and then only in case the kiln operation is in charge of an experienced man.

BALD CYPRESS.

One kiln run has been made on bald cypress. In this run 2 and 3 inch material was dried, using the temperatures and humidities of Table 1 of Specification 20500-A. During the last two weeks of the run it was not possible to reduce humidity below 40 per cent, thus causing a departure to that extent from Table 1. It was necessary to steam nine different times at temperatures ranging from 150° to 176° F. for periods of one to five hours, to relieve casehardening. (Total time of steaming 24½ hours.)

PHYSICAL RESULTS.

The average moisture content was reduced from 91.8 to 7.3 per cent in 80 days, with an average visible degrade of 8 per cent due to springing and warping.

The material from butt logs was found to dry much more slowly than that from upper logs.

MECHANICAL RESULTS.

The kiln-dried material gave practically as great an improvement in static bending as previously air-dried material, the former being noticeably greater in "work". The kiln-dried material from lower bolts gave a greater improvement than that from the upper bolts in every case except drop in impact bending. In this property, and also in maximum crushing strength in compression parallel to grain, the air-dried material gave a greater improvement than the kiln-dried material.

CONCLUSIONS.

It is not possible from results in one kiln run to form final conclusions on the proper method of kiln drying this species. From data collected it is concluded that:

1. Upper-log material can be dried much more rapidly than that from butt logs, and the two classes should be dried separately.
2. Cypress requires more than ordinary care in drying in order to prevent checking, honeycombing, warping, and casehardening.
3. Cypress can be kiln dried so as to produce material equal in its mechanical properties to air-dried material, but final judgment on this point can not be reached until matched material has been air dried and tested.

RECOMMENDATIONS.

1. That butt-log material and material from upper logs be kiln dried separately.
2. That, pending the results of further tests, the temperatures of Specification 20500–A should not be exceeded in drying bald cypress, and that humidity and steaming be regulated to keep casehardening at a minimum.

WESTERN HEMLOCK.

Two kiln runs have been made on 3-inch material of this species. In one run the material was dried by using temperatures and humidities approximately as called for by Table 1, Specification 20500–A (temperatures 120° F. initial, and 145° F. final; humidities 80 per cent initial, and 35 per cent final). This resulted in decreasing the moisture content from an average of 79 per cent to an average of 6.7 per cent in a period of 33 days, with a resultant visible degrade of 3 per cent due to opening up of checks.

The second, which was a high-temperature run (temperatures 160° F. initial to 180° F. final, with humidities 70 per cent initial to 50 per cent final), compares favorably with the first run both in time required for drying and in amount of degrade. The time was 19 days to reduce the moisture content from 98.4 per cent to 8.2 per cent, as compared with 25 days to reduce to 4.8 per cent for the first run. The average visible degrade was less than 1 per cent. The first run had only slight indications of casehardening on resawing, while severe casehardening was indicated in the second run.

MECHANICAL RESULTS.

The two runs are practically equal to each other and to previously-tested air-dried material in improvement of modulus of rupture and work to maximum load in static bending. However, in modulus of elasticity, while the high temperature run equals the air-dried, the Table 1 run falls considerably lower. Both runs fail to show improvement equal to that shown by previously tested air-dried material in impact drop and compression parallel to grain. Were it not for the known facts concerning the variability of timber—and of improvement ratios as previously brought out in this report—cases of inferiority in improvement to previously air-dried material might be assumed to indicate actual damage resulting from kiln drying. However, the fact that the more severe kiln conditions have produced material practically equal in all and considerably superior in some properties to that resulting from kiln drying under milder conditions is accepted as the better basis of judgment. Groups of material tested after drying in the two kiln runs are closely matched to each other; hence, comparisons between the runs are much more accurate and positive than comparisons with the air-dried material.

CONCLUSIONS.

The conclusion that neither kiln process damaged the material must be regarded as tentative, pending testing of matched air-dried material, but it is believed that conditions scheduled in Table 1 of Specification 20500–A are safe for drying western hemlock. Probably considerably higher temperatures could be used without damage.

RECOMMENDATIONS.

In view of the fact that positive conclusions can not be reached until tests have been made on air-dried material corresponding to that kiln dried, and the further fact that any lack of control of kiln conditions is much more likely to result in damage when attempting to run by a higher temperature schedule, it is recommended that Table 1 of Specification 20500–A be used in drying western hemlock.

WHITE AND NORWAY PINE.

Material of both white and Norway pine was dried in each of two kiln runs. One run was made with temperature varying from 180° to 200° F. and relative humidity varying from 76 to 60 per cent. The second kiln run followed quite closely the schedule of temperatures and relative humidities of Table 1 of Specification 20500–A.

PHYSICAL RESULTS.

The result of the first run was that the white pine was dried from an average moisture content of 99 per cent to an average of 5.3 per cent and the Norway pine from 22.5 to 6 per cent in a period of 16 days. Both species had a visible degrade of about 6 per cent, due mostly to checking. The high temperature caused the pitch and resin to flow to the surface and harden.

In the second run the white pine was dried from an average moisture content of 99 per cent to an average of 10 per cent and the Norway pine from 35.5 per cent to 8.6 per cent in a period of 67 days. Both species had a visible degrade of 6 per cent, due to checking, twisting, and warping.

MECHANICAL RESULTS.

The results from the mechanical tests on small clear specimens indicate that the two runs produced approximately as good improvement in nearly all values as resulted from previous air drying and that, in spite of the great difference in temperature, the two runs produced about equally good results. The high-temperature run gave considerably better improvement in modulus of rupture and maximum crushing strength of Norway pine, and slightly better in modulus of elasticity of both species, while in other values the low temperature run gave slightly, but not significantly, better improvement.

CONCLUSIONS.

It is concluded that there is no damaging effect to be expected from temperatures as high as were used in this instance. This conclusion, however, must be regarded as tentative until confirmed or disproved by tests on matched material which is now air drying.

RECOMMENDATIONS.

Table 1 of Specification 20500–A is recommended for use in drying these species until additional data can be obtained on the effect of various temperatures and relative humidities on the strength.

WHITE FIR.

Two kiln runs have been made on white fir, in stock of 3-inch thickness and various widths. The temperature in one run ranged from 160° F. initial to 180° F. final. The other run followed quite closely the schedule of Table 1 of Specification 20500–A, as shown in Table 25.

TABLE 25.—*Kiln conditions used in runs 157 and 158, compared with Table 1 of Specification 20500–A.*

Stage of drying.[1]	Average drying conditions.					
	Temperatures.			Humidities.		
	Kiln run 157.	Kiln run 158.	Table 1.	Kiln run 157.	Kiln run 158.	Table 1.
	Degrees F.	*Degrees F.*	*Degrees F.*	*Per cent.*	*Per cent.*	*Per cent.*
At the beginning	120	163	120	80	70–80	80
After fiber-saturation point is passed (25 per cent moisture)	120	165	125	80	75	70
At 20 per cent moisture	120	170	128	80	75	60
At 15 per cent moisture	125	177	138	70	71	44
At 12 per cent moisture	125	179	142	60	71	38
At 8 per cent moisture	140	181	145	37	68	33
Final	145	180	145	33	50	33

[1] As determined from moisture contents of samples.

Kiln run 157.—This run was made in a kiln which had been equipped with fans to produce circulation.

The material was steamed 18 hours at 136° F. before the kiln conditions given in Table 25 were established. Casehardening stresses which developed during the run made four additional steamings necessary, at temperatures of 135° to 160° F., for periods of one to two hours. (Total time, six hours.)

Drying from an average moisture content of 100 to 8.2 per cent was accomplished in 57 days, with an average visible degrade of about 8 per cent. This degrade was the result of twisting, warping, and surface checking.

Kiln run 158.—This run was started without preliminary steaming, but it was necessary to steam six times (total time 19 hours) during the run to relieve casehardening. The steaming periods ranged from one and one-half to six hours, at temperatures ranging from 170° to 182° F.

The material was dried from an average moisture content of 149 to 7.7 per cent in 12 days; but in order to relieve casehardening it was necessary to continue the run for 9 days, during which the moisture content of the samples was reduced to 5.1 per cent. The moisture content of the green material ranged from 69 to 208 per cent.

The material was in good condition on entering the kiln, although several pieces showed end and heart checks, shakes, and springing. After being dried the material came out with an average degrade from warping, springing, twisting, and surface checking of approximately 6 per cent.

DISCUSSION AND CONCLUSIONS.

The material was compared with various air-dried firs (silver, grand, and noble) as well as white fir. In every case, except maximum drop in impact bending, kiln run 157 is superior to the average of the air-dried firs. Kiln run 158 is somewhat lower than this average in maximum drop in impact bending and in maximum crushing strength in compression parallel to grain.

Both runs produced material which was better in improvement of strength properties than material from the one available tree of air-dried *white* fir, except in compression parallel to the grain. In this property the high-temperature run (158) was inferior to the air-dried material.

It appears that no significant damage occurred to the strength properties from either kiln treatment, and it is probable that the Table 1 run (157) produced at least as good results as would have resulted from air drying.

RECOMMENDATIONS.

1. Pending the completion of tests on air-dried material matching that kiln dried, it is recommended that Table 1 of Specification 20500–A be used in drying white fir for use where maximum strength is essential.

2. If faster drying than can be produced by following the above recommendation is necessary, the temperatures as used in run 158 appear to be fairly safe, providing the humidity is regulated to prevent severe casehardening.

3. Because of the large variation in moisture content of different boards of this species, it is recommended that this material be divided into two or more groups according to the weight of the pieces, which is an indication of the moisture content, and that either the groups be kiln dried separately or the heavier material be placed in the most rapid drying part of the kiln.

AFRICAN AND CENTRAL AMERICAN MAHOGANIES.

Mechanical tests have been made on small, clear specimens of material from several experimental kiln runs on African and Central American mahoganies. Runs 106, 107, 108, and 109 included both species. Central American mahogany was dried in runs 161 and 162, and African mahogany in runs 164 and 165.

The ranges in temperatures and humidities for all eight runs are given in Table 26, which also lists, for the purpose of comparison, the temperatures and humidities of Tables 1 and 2 of Specification 20500–A.

TABLE 26.—*Kiln conditions used in runs 106, 107, 108, 109, 161, 162, 164, and 165, compared with Tables 1 and 2 of Specification 20500–A.*

Stage of drying.	Average drying conditions—temperatures.									
	Kiln run 106.	Kiln run 107.	Kiln run 108.	Kiln run 109.	Kiln run 161.	Kiln run 162.	Kiln run 164.	Kiln run 165.	Table 1.[1]	Table 2.[1]
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*
The beginning	105	180	90	120	105	120	105	115	120	105
After fiber saturation point is passed (25 per cent moisture)	108	180	95	120	106	128	108	104	125	110
At 20 per cent moisture	110	180	106	120	106	130	110	107	128	117
At 15 per cent moisture	115	180	118	130	116	128	118	118	138	129
At 12 per cent moisture	116	180	118	120	128	150	131	120	142	135
At 8 per cent moisture					135	154	130	120	145	135
Final	118	160	120	138	135	147	90	129	145	135

Stage of drying.	Average drying conditions—humidities.									
	Kiln run 106.	Kiln run 107.	Kiln run 108.	Kiln run 109.	Kiln run 161.	Kiln run 162.	Kiln run 164.	Kiln run 165.	Table 1.[1]	Table 2.[1]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
The beginning	85	85	86	80	94–85	80–88	97	82	80	85
After fiber saturation point is passed (25 per cent moisture)	75	85	75	70	80	78	74	80	70	73
At 20 per cent moisture	72	90	65	72	76	76	74	74	60	62
At 15 per cent moisture	68	85	50		57	72	65	60	44	46
At 12 per cent moisture	65	85	42		60	61	42	50	38	42
At 8 per cent moisture					46	64	43	50	33	40
Final	60	80	42	54	46	64	60	55	33	40

[1] These are maximum allowable temperatures and minimum allowable humidities.

The length of time required for drying, the amount of degrade, and the original and final average moisture content for each run are all given in Table 27.

TABLE 27.—*Physical results of various kiln runs of African and Central American mahoganies.*

Species	African mahogany.						Central American mahogany.					
Kiln run	106	107	108	109	161	162	106	107	108	109	104	165
Days in kiln	42	14	21	20	21	24	42	14	21	20	13	25
Average per cent moisture content, initial	66.5	56.6	70.0	69.6	60.0	60.3	66.5	56.5	70.0	69.6	41.0	48.7
Average per cent moisture content, final	9.9	10.0	12.0	8.4	8.9	8.6	9.9	10.0	12.0	8.4	7.7	8.4
Per cent visible degrade	None.	2.0	1.0	1.0	2.4	3.0	None.	2.0	1.0	1.0	2½	4½

The material for all runs was approximately 1 inch in thickness.

The material for all runs except 108 was steamed before drying was commenced, and all runs except 106 were again steamed from one to four times to relieve casehardening. The steaming for run 162, however, was to relieve only very slight casehardening.

MECHANICAL RESULTS.

African mahogany.—A decided gain in improvement was made by all kiln runs over the previously tested air-dried material in modulus of rupture and maximum drop. Work to maximum load, modulus of elasticity, and maximum crushing strength may all be considered equal to the average of the air-dried in improvement.

No apparent damage is shown in any kiln run, and the material is considered to have made at least as good improvement as would have resulted from air drying.

Central American mahogany.—Material from all the kiln runs shows very good improvement in strength properties over the corresponding green material. Improvement ratios are in nearly every case as high as resulted from the air drying of material previously tested.

There appears to be but very little difference in the improvement for the various strength properties produced by the different processes of drying.

DISCUSSION AND CONCLUSIONS.

The satisfactory results from these kiln runs indicate that the temperatures of both Tables 1 and 2, Specification 20500–A, are safe, as four of the runs were made with temperatures approximately those called for by Table 1 or 2, and one run subjected the stock to severer temperatures.

The consistent though slight inferiority of the high-temperature run (107) to run 106, which was made on material from the same trees, indicates a possible relation between strength and temperature used in drying.

Run 162, the material in which was Central American mahogany, was made with temperatures closely approximating those of Table 1, but the relative humidities were not permitted to drop below 60 per cent. This run produced material which was in excellent condition for propeller stock and which was slightly better in improvement of strength properties than material from the same shipment dried in run 161. While no run was made on African mahogany using conditions similar to run 162, it is believed, since the two woods are seemingly closely related in physical properties, that such a run would produce practically the same results. Special tests taken on this run showed even cross-sectional drying and very slight casehardening. These results indicate that the condition under which the material in run 162 was dried is very satisfactory for drying propeller stock.

RECOMMENDATIONS.

It is recommended that in drying Central American and African mahoganies, the temperatures of Table 1 of Specification 20500–A be used, but that the relative humidity be not allowed to drop below 60 per cent at any time during the run.

BLACK WALNUT.

In order to develop a process of kiln drying black walnut satisfactorily, two kiln runs were made, one in accordance with Table 1 and the other in accordance with Table 2 of Specification 20500–A.

The Table 1 run consisted of 1-inch and the Table 2 of both 1 and 2 inch stock.

The Table 2 run was controlled by both 1 and 2 inch samples, which delayed the drying process slightly as the 2-inch material dried very slowly. The 2-inch samples were discarded from calculations during the last stages of the run and conditions better adapted to 1-inch stock were secured. The material was steamed at 120° F. for six hours at the beginning and for one hour at 150° F. at the end of the run, the latter to relieve casehardening.

The 1-inch material dried from an average of 72 to an average of 8 per cent in a period of 38 days, but 2-inch material in the same period reduced only to 18 per cent from 54 per cent. The material entered the kiln with end and heart checks, heart rot, and springing, and came out with an average degrade of about 7 per cent caused by springing, checking, and warping.

The condition of the second run during the final stages was slightly milder than required by Table 1 of Specification 20500-A. The material was frozen when loaded into the kiln and it was necessary to thaw it out, by steaming, before drying could begin. Toward the end of the run it was necessary to steam the material one hour at 150° F. to relieve casehardening.

At the beginning of the run the stock contained an average moisture content of 78.6 per cent, which was reduced to 7.7 per cent in 31 days. It left the kiln in good condition, showing a visible degrade of about 2½ per cent caused by end checking.

CONCLUSIONS.

The improvement ratios show that, with exception of drop in impact bending, both kiln runs produced greater improvement in strength properties than resulted in the case of the previously air-dried material, and in all probability as good results as would have been obtained by air drying the same material. As both runs follow closely Tables 1 and 2 of the specification, it follows that either of these tables can be expected to give satisfactory results when used for drying 1-inch black walnut. The strength data give no basis for a choice between the two kiln runs.

RECOMMENDATIONS.

The work so far done gives, of course, no basis for judging the effect of conditions more severe than Table 1. Until the effect of more severe conditions can be ascertained, it is recommended that Table 1 of Specification 20500-A be used for drying black walnut.

SUGAR MAPLE.

Seven experimental kiln runs in the drying of sugar maple have been made, but only the first three, 132, 133, and 134, have reached a stage where discussion and analysis are possible and figures are available.

The first run (132) was on 1-inch material only; the last two runs (133 and 134) were on both 1-inch and 2-inch material. Run 132 was made to determine the effect of a practically constant temperature of 170° F. and the same relative humidities as called for by Table 2 of Specification 20500-A; run 133 was in accordance with Table 1, and run 134 was in accordance with Table 2 of this specification. Runs 133 and 134 were both steamed near the end of the run to relieve casehardening. No steaming was necessary on run 132.

The high-temperature run (132) was made in the least time, requiring 12 days, but had the smallest difference between initial and final moisture contents, the initial moisture content being 48 and the final 8 per cent. This run had the largest average degrade—about 15 per cent. The degrade was due chiefly to warping, with some springing and twisting. Slight casehardening was evident on resawing.

The Table 1 run (133) required 23 days, practically twice the time of the previous run, but reduced the average moisture content from 56 to 5.8 per cent, with an average degrade of 11 per cent due to cupping, warping, and springing, the greater portion being due to cupping. Very little casehardening developed on resawing.

Kiln run 134 required 29 days to reduce the average moisture content from 56 to 7.5 per cent, but had the smallest degrade of any run—about 8 per cent, due to cupping and warping. The material showed very slight reverse casehardening on being resawed.

RESULTS.

There is no marked or consistent difference in the mechanical results of the three runs. The kiln-dried material showed improvement over matched green material equal or superior to that previously obtained by air drying.

CONCLUSIONS.

Absolutely definite conclusions can not be reached until tests on corresponding air-dried material have been made; but the data warrant the conclusions:

1. That kiln drying can be carried on without injury of material, and probably with better results than can be obtained by air drying.

2. That there are no consistent differences in the effects of the three runs. This indicates that a considerable range of temperature can be employed with little, if any, difference in the effect on the mechanical properties.

RECOMMENDATIONS.

Until the above conclusion (No. 2) has been checked by tests on corresponding air-dried material, and because of the greater danger of damage through accidental departure from schedules when operating at higher temperatures, it is recommended that maple be dried by schedule of Table 1 of Specification 20500–A.

YELLOW BIRCH.

Five kiln runs have been made on yellow birch, as follows:

Run 84 was on 2½-inch plank, with temperatures 130° F. initial to 180° F. final, initial and final humidities of about 77 and 13 per cent, respectively. The average moisture content was reduced from 60 to 4 per cent in about 31 days. There was evidence of casehardening in some parts of the pile at the end of the run.

Run 168 was on 1-inch stock. Temperatures were approximately those of Table 1. Initial and final humidities were about 80 and 35 per cent, respectively. The material was steamed six times, at temperatures varying from 150° to 165° F. and periods of one-fourth to one hour, for the relief of casehardening, which persistently developed. There was slight casehardening at the end of the run. Uneven sawing, which prevented proper piling and weighting of the stock, was chiefly responsible for the degrade of about 10 per cent. Moisture content was reduced from 64 to 7.6 per cent in 16 days.

Run 169 was on 1-inch stock. Kiln conditions were approximately those of Table 1, Specification 20500–A. Steaming three times, at 160°, 170°, and 160° F. for three hours, two hours, and two hours, respectively, near the end of the run, left part of the stock severely casehardened and part in a condition of severely reversed casehardening. Degrade was about the same as in run 168 and due to the same causes. Moisture content was reduced from 58 to 8 per cent in 17 days.

Run 170 was on 1-inch stock, with kiln conditions approximately as prescribed by Table 2 of Specification 20500–A. Five steamings were made at about 20° F. above the scheduled drying temperatures. The stock was practically free from casehardening at the close of the run. Degrade of about 7.5 per cent resulted from the same causes as in run 168. Moisture content was reduced from about 65 to 8.2 per cent in 31 days.

Run 203 was made on 1-inch partially air-dried stock. Kiln conditions were approximately those of Table 1. Steaming for one hour at 160° F. on the eighth day and for two hours at 170° F. on the tenth day successfully relieved the casehardening which had developed. The moisture content was reduced from 18.5 to about 7 per cent in 10 days. There was about 5 per cent degrade.

MECHANICAL RESULTS.

Comparisons by means of improvement ratios indicate that runs 168, 169, and 170 produced practically equal improvement, and that this improvement is equal to the average of two trees previously air dried, being less than one and greater than the other. Improvement in run 84 is less than the minimum for the previously air-dried material. Comparisons of run 203 with the others are difficult to make because of the partially air-dried condition of the stock before it was placed in the kiln.

CONCLUSION.

The kiln conditions of Tables 1 and 2 produced results in the drying of yellow birch which are equal to those to be expected from air drying.

It seems probable that the one run at temperatures of 130° to 180° F. has failed to produce as good results as would have been obtained from air drying.

RECOMMENDATIONS.

Both Table 1 and Table 2 of Specification 20500-A are recommended as suitable for the drying of yellow birch.

OAK.

Seven kiln runs were made on oaks, including red and white oak species from the South and white oak (presumably true white (*Quercus alba*)) from northern Indiana. The testing work, inclusive of tests on air-dried material, has been entirely completed. The data, however, are very erratic and it is difficult to arrive at consistent conclusions.

One run (A), at temperatures varying from 150° to 165° F. and relative humidities from 85 to 60 per cent, produced very good results from the strength standpoint on southern red and white oak species, with the exception of Spanish oak. The charge was steamed for one hour and two hours at temperatures of 179° and 170° F., respectively, to relieve casehardening stresses. However, this run resulted in a degrade of 60 per cent as determined from inspection before and after kiln drying. The causes of degrade included severe casehardening, warping, cupping, honeycombing, and collapse.

Two runs (B and C) on northern white oak gave entirely satisfactory results from the strength standpoint. Run B was with temperatures approximately as prescribed in Table 2 of Specification 20500-A and relative humidities ranging between 90 and 70 per cent. This run was steamed at 135° F. for one hour to relieve casehardening stresses. Run C was at temperatures of 120° F. initial and 140° F. final, with relative humidities about 90 initial and 50 final. It was necessary to steam this material three times, at temperatures from 160° to 164° F., for a total of two and one-half hours, to relieve casehardening stresses at the end of the run. Both gave results fully equal to air dry, with the lower temperature run (B) slightly the better. Material in both cases came from the kiln in excellent condition, there being less than 1 per cent degrade in run B and less than 1½ per cent in run C.

In another run (D), with temperatures 90° F. initial to about 125° F. final and humidities ranging from saturation down to 40 per cent, northern white oak came from the kiln with about 1 per cent degrade, resulting from springing and warping. At the close of the run the charge was steamed seven hours at 155° F. to relieve the casehardening stresses. Strength tests indicated that this material was slightly deficient in strength properties as compared to matched air-dried material.

Still another run (E), with initial temperature of about 100° F. to final 130° F. and humidities ranging from saturation to about 45 per cent, resulted in about 7½ per cent degrade. The material was steamed twice at 185° and 170° F. to kill mold and mildew. A final steaming at 180° F. was to relieve casehardening stresses. This run, however, included southern red oak and both northern and southern white oaks, and while the different species were not separately graded, it was observed that the degrade was more serious in the red than in the white oak. The northern white oak from this run was also slightly deficient in strength properties as compared to matched air-dried stock.

Southern white oak was included in runs A and E, as above described. Run A produced quite satisfactory results from the strength standpoint, while run E resulted in a considerable loss of strength as compared to air-dried material.

Two additional runs, F and G, included southern white oak. Run F was made with temperatures of 105° F. initial and about 135° F. final and relative humidities 85 initial to about 40 per cent final—approximately the condition of Table 2. Run G was with temperatures of 120° F. initial to about 140° F. final and with humidities as in F. These runs included also southern red oak species. Run F was steamed three times for periods of one hour each, at 155° F., to relieve casehardening stresses. The degrade in run F was 12 per cent, from warping, springing, and cupping; while G resulted in 50 per cent degrade from springing, warping, cupping, checking, twisting, collapse, honeycombing, and casehardening. Run G was steamed on three occasions for periods of one-half hour, at temperatures of 150° to 170° F., to relieve casehardening stresses. Run F gave quite satisfactory results from the strength standpoint, while in G the results were unsatisfactory, there being a loss of 25 to 30 per cent in modulus of rupture, work to maximum load, and height of drop in impact. Exclusive of Spanish oak, the results from the strength standpoint were as follows:

Southern red oaks, including Spanish oak, were dried in runs A, E, F, and G. Run F produced approximately as good material as air dry, run G material considerably inferior to air dry, and run E, as indicated by maximum drop in impact and maximum crushing strength in compression parallel (there being no static bending tests), material very much inferior to matched air-dried stock.

None of these runs (A, E, F, and G) gave satisfactory results from the strength standpoint on Spanish oak. Runs F and G resulted in losses in all strength properties, with F possibly slightly superior to G. Run A gave results somewhat superior to either F or G, while the results in E were inferior to either F or G.

From the results as presented above it is concluded: (1) That under the same kiln conditions northern white oak can be expected to dry with smaller losses, both from the strength standpoint and the standpoint of degrade in appearance, than southern oaks, either red or white; (2) that of the southern oaks the red oak species require more care than the white oak species; (3) that Spanish oak is considerably more liable to damage of strength properities in kiln drying than the other red oak species from the southern region; (4) that, in general, the northern oaks are more easily kiln dried than the southern.

It is evident from experience in these runs, and the conclusion is borne out by experience in drying oak on a commercial scale, that the maintenance of suitable kiln conditions requires more care in the case of oaks than in other species or groups of species. Oak has been found in all experimentation with it, as well as in its utilization, to be more variable than other species. To attempt to specify beforehand exactly what kiln condition should be used seems unwise. The results of these kiln-drying and strength tests indicate that the temperatures of Table 1 of Specification 20500–A are probably the maximum which are safe for northern white oak, and likewise that the temperatures of Table 2 should not be exceeded in drying southern oak, either red or white. In drying any of the oaks very careful attention must be given to the condition of the stock in all parts of the kiln. Temperatures and humidities must be regulated not only by the moisture content of the stock but also by its condition with respect to checking, casehardening, the existence of a difference in moisture content between the outside and the inside of the piece, and the existence of stressed conditions.

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