A NEW TEST FOR MEASURING
THE FIRE RESISTANCE OF WOOD

By T. R. TRUAX
Senior Wood Technologist
and
C. A. Harrison
Assistant Engineer

Published in Proceedings of the
AMERICAN SOCIETY FOR TESTING MATERIALS,
Philadelphia, Pa., Vol. 29, Part II,
1929
A NEW TEST FOR MEASURING
THE FIRE RESISTANCE OF WOOD

(Published in Proceedings of the American Society for Testing Materials, Philadelphia, Pa., Vol. 29, Part II, 1929)

By
T. R. Truax
Senior Wood Technologist

and
C. A. Harrison
Assistant Engineer

Synopsis

The object of this paper is to describe the Forest Products Laboratory fire-tube apparatus and to present a tentative procedure for testing the inflammability of wood and the effectiveness of various fire-retardant treatments. The fire resistance is expressed in percentages of loss in weight and increase in temperature resulting from the combustion of a specimen of uniform dimensions. The method gives definite numerical values which can be duplicated. Results are presented to show the development of the apparatus and procedure, typical variations in fire resistance between treated and untreated wood, and
comparisons with other methods of test. As a measure of the property of wood to support combustion, that is, to cause the spread of flame and contribute to an increase in temperature under fire conditions, the Forest Products Laboratory fire-tube test is reliable, consistent, and quickly and easily made.

The Forest Products Laboratory has recognized the necessity of developing and standardizing test methods for fire resistance of wood for a number of years. In 1927, Dunlap of the Forest Products Laboratory and Cartwright of the National Lumber Manufacturers' Association discussed briefly the existing test methods and the forms of tests which they considered essential in evaluating the fire resistance of combustible building materials. Since that time, with the cooperation of the National Lumber Manufacturers' Association, the Forest Products Laboratory has been able to continue studies in the development of apparatus for the purpose.

Considered as to fire resistance, the important properties of wood, and for that matter other building materials, are (1) the extent to which it resists combustion, (2) its capacity to retain strength properties under fire conditions, and (3) its resistance to the passage of heat through it. The relative importance of these properties varies for different uses. The first property is of primary importance from the general standpoint of reduction of damage by fire; the second is significant in timber for structural purposes; and the third is of importance for doors and partitions in buildings.

Obviously, small scale laboratory tests on samples of treated wood are not a sufficient measure of the fire resistance of completed structural assemblies, such as doors, window frames, sash and floors. Performance ratings for such assemblies must be arrived at by full-scale tests under the customary or the standard methods in use for the purpose. Laboratory tests do, however, afford a practical means of evaluating the fire resistance of wood entering into built-up assemblies.

---

assemblies. Such tests must not only give information on one or more of the important properties of fire-resistant wood, but they should be of such character that they can be quickly and easily made, will give results that can be expressed numerically, and are capable of duplication.

The Forest Products Laboratory fire-tube apparatus, described in this paper, was developed in an attempt to find a satisfactory numerical measure of the resistance of wood to combustion and particularly of its resistance to the spread of flame and to a rise in temperature. It was desired that this method of test should give results that could be duplicated with a reasonable degree of certainty and that it should measure relatively small differences in degree of fire resistance. The fire-tube test is not proposed as a measure of all the properties of fire resistance. Other tests will be necessary to evaluate properties, such as the retention of strength under fire conditions, flame penetration, and heat insulating value. The effect of fire retardants on the finishing, hygroscopicity and gluing of wood, and on corrosion of metals is also important to the user of fire-resistant wood that require special testing methods.

Fire-Tube Apparatus

The apparatus (see fig. 1) consists essentially of an open galvanized iron tube, T, in which the specimen, Sp, suspended from a balance arm, A, is burned. To the balance arm is attached a pointer, P, which indicates on a chart, Ch, the percentage of loss in weight as the burning proceeds. The apparatus is also equipped with a thermocouple, Th, and pyrometer, Pr, for measuring the temperature at the top of the tube. The specimen shown at the side of the tube is hung in the center of the tube during test. A gas flame, F, is applied to the lower one-fourth of the specimen. A wire screen cage, Ca, attached to the bell-shaped bottom of the tube, serves to catch burning embers that fall during the test. A double row of slots on opposite sides of the tube allows the entrance of air and permits the operator to watch the progress of the burning.

A test in the fire-tube apparatus is conducted substantially as follows: The empty tube is balanced by means of counterweights, W and W1, so that the pointer is in a vertical position and reads 100 on the percentage chart. The specimen, which is first weighed on a separate balance, is then suspended in the tube. This brings the pointer to

2Original design by M. E. Dunlap of the Forest Products Laboratory.
Figure 1.—The Forest Products Laboratory fire tube apparatus
the left, and the scale is raised or lowered as may be re-
quired to bring the end of the pointer on the zero line.
The flame is then applied to the specimen with the top of
the burner 1 inch below the bottom of the specimen and
records are taken, at 1/2-minute intervals, of the percent-
age of loss in weight of the specimen and of the temperature
at the top of the tube, as shown on the chart and pyrometer,
respectively. The flame is removed at the end of 4 minutes,
but records are taken to the end of 6 minutes or until
flaming ceases. Observations are also made of the tendency
of any fallen embers to glow.

Typical Results of Test

Typical results obtained in the fire-tube test are
shown in Figure 2, where the percentage of loss in weight of
the specimen and maximum temperatures developed at the top
of the tube during the test are plotted against time of test.
An example of the application of the results of the tests to
specific problems is shown in Figure 3, where the absorption
of diammonium phosphate in pounds per cubic foot of wood is
plotted against the percentage of loss in weight and against
maximum temperatures recorded at the top of the tube. If
desired, the amount of dry salt may be expressed in percent-
ages of the weight of wood instead of in pounds per cubic
foot, but in so doing the amount of moisture in the wood
must be taken into consideration in order to afford a true
basis for comparison. It is also a simple matter to calcu-
late the actual losses in weight of the specimen in grams
or other units from the weight of the specimen, taken just
before test, and the percentage losses during test. However,
the percentage loss in weight appears to be more significant
as a measure of the property of wood to spread flame than
the actual loss in weight. Actual loss in weight varies
with the density of the wood in contact with the ignition
flame, whereas percentage loss shows more clearly the extent
of burning beyond the ignition flame.

With the loss in weight and the temperatures at
the top of the tube recorded, as the burning proceeds, the
rate of burning and increase of temperature can be readily
determined (see fig. 3). The rate of burning may be an even
more significant and accurate measure of fire resistance
than total loss in weight or maximum temperatures. For
example, of two specimens nearly equal in fire resistance,
one may burn slowly but eventually be almost completely
destroyed, showing a large total loss in weight, and the
other may cease to burn after a short time, showing a small
Fig. 2.—Typical loss in weight and temperature-time curves of tests made in the Forest Products Laboratory fire-tube apparatus.

Legend:
- Loss in weight during flaming and maximum temperatures.
- Loss in weight after flaming ceased.
Numbers on curves indicate absorption of dry di-ammonium phosphate in lbs. per cu. ft. of wood.
Fig. 3.—Relation of absorption of di-ammonium phosphate to percentage of loss in weight and maximum temperatures developed in the Forest Products Laboratory fire-tube test.
loss in weight. If, however, the total loss in weight expressed as a percentage and the maximum temperature are divided by time of occurrence the results are similar. Any one of the three factors; namely, time of ignition and burning, loss in weight, and increase in temperature, may be misleading when taken alone. With the fire-tube apparatus, these three factors can be expressed in definite numerical values and correlated as desired.

Development and Standardization of Test

In the development and standardization of the test, a number of variations of the apparatus and method of procedure have been investigated. The following are the more important factors studied:

Type and size of tube; Heat source; and Size and number of specimens burned at one time.

Some data were also assembled on the following factors:

Kind, density, and moisture content of wood; and Method of sampling material.

Type and Size of Tube

Several different types of tubes were tried out and a series of tests was made with each. The principal variations in the construction of the tubes investigated were: size; open and closed; insulated and noninsulated; cage and screen bottom; horizontal and vertical slots; and size and number of slots.

Size of tube. -- Tubes of 3, 4, and 5-inch diameters, constructed otherwise alike, were used and the results were compared with results obtained by burning specimens in the open without a tube. Burning in any of the three sizes of tubes was more severe than burning in the open. With the three tubes, the severity of the test varied inversely with the diameter of the tube, the 3-inch tube showing the largest loss in weight and the highest temperatures, and the 5-inch tube the lowest values. It was also found that burning a single specimen in the 3-inch tube gave almost the same results and represented about the same degree of severity as burning five specimens together in the open.
Open and closed tubes.—A series of comparative tests was made in tubes with bottom and slots open, bottom and slots closed, and bottom closed and slots open. Closing the tube had the effect of raising the temperature surrounding the specimen. This was shown by temperature measurements with the ignition flame in place but without a specimen. With wood treated with medium to heavy absorptions of fire retardants, the higher temperature caused the flame to spread farther up the specimen and increased combustion. On the other hand, closing the tube reduced the amount of oxygen available for combustion and the temperatures at the top of the closed tube were lower than with the open type of tube. With untreated wood the loss in weight was almost the same for the three types of tubes, which indicated that the temperatures were sufficiently high to drive the gases from the wood, even though complete combustion of the gases did not occur in the tube.

Insulated and uninsulated tubes.—A comparison was made in the 3-inch tube with the end and slots open having one tube insulated with about a 1-inch layer of asbestos and the other without insulation. The results of the tests indicated that the conditions in the insulated tube were somewhat more severe than in the uninsulated tube. The insulated tube had the disadvantage, however, in that it changed weight as it was heated, necessitating a frequent rebalancing of the apparatus.

Cage-bottom and screen-bottom tubes.—Originally a tube was used with a 3-1/2-mesh screen in the lower end of the tube and the burner placed below the screen. It was found, however, that falling embers and charcoal often collected on the screen and interfered more or less with the flame from the burner during test. A modification was made, using a wire cage with solid bottom, as shown in Figure 1, fastened to the bottom of the tube and the burner inserted through a slot in the side of the cage. It was found that this method eliminated the interference of the embers with the flame and that otherwise there was no pronounced difference in the results from the two tubes.

Position, size, and number of slots.—Slots, 0.10 by 1-1/2 inches in size, were placed horizontally in one tube and vertically in another at intervals of 4.1 inches center to center, on one side of the tube. The test results indicated that the conditions were a little more severe in the horizontal-slot tube than in the vertical-slot tube. In other tubes the size of the slots was progressively increased from the bottom to the top and two rows of slots were used.
on opposite sides of the tube. The tube with two vertical rows of horizontal slots of uniform size (see fig. 1) was finally selected as admitting sufficient air and giving most uniform burning.

Heat Source

Heat may be applied to the specimen in different ways, such as by direct contact with flame, indirectly from an electrical heating element, or by passing heated air into the tube. The flame and electrical heating element have both been tried. The latter was not well suited in the fire-tube apparatus for determining the loss in weight of the specimen at intervals during test and had certain other disadvantages. Furthermore, the flame was considered more nearly comparable to exposure under actual fire conditions.

Flames developed from burning a given quantity of inflammable material, such as alcohol, were tried but the height and temperature of such flames were more difficult to control and measure accurately and they were more affected by air currents than flames obtained from gas under pressure. A Bunsen flame using manufactured gas as a fuel was found to be a more reliable heat source.

Control of heat source.—It is necessary to control the flame in three respects: (1) temperature, (2) height, and (3) amount of heat evolved. The approximate temperature and height of the flame can be readily measured. Tests were made on untreated wood and wood treated with varying amounts of fire-retardant salts, using yellow and blue flames ranging in height from 6 to 14 inches and in temperatures from 780° to 1085° C. In all cases the top of the burner was placed 1 inch below the bottom of the specimen. The results

---


4Amédée Lullin, "Recherches sur les Températures d'Inflammation du bois et sur les Enduits Ignifuges," thesis submitted to the Federal Polytechnic Institute, Zurich, Switzerland.
indicated that the effect of the variation in temperature of the flame within the range used was negligible with untreated or lightly treated wood and small with heavily treated wood. The maximum variation was about 1 per cent loss of weight for 25° C. difference in the temperature of the flame, which occurred with intermediate absorptions of fire retardants. The height of the flame within the range of 6 to 14 inches had no appreciable effect on the results for untreated or lightly treated wood, but for heavily treated wood 1-inch variation in height of flame resulted in maximum variation of 2 to 2.5 per cent in the loss in weight of the specimen, about the same proportion as 1 inch is to the total length of the specimen. In other words, the higher flames caused greater loss in weight because they were in direct contact with a greater proportion of the length of the specimen.

No attempt has been made to measure accurately the amount of heat evolved by the flame. The amount of heat applied is important only in so far as it affects the conditions surrounding the specimen during test. The temperature at the top of the tube with the flame in place but without a specimen has been considered a satisfactory check of this condition. The temperature and volume of flame can be controlled sufficiently by the use of an ordinary burner with the gas orifice and air intake properly adjusted and in this way a relatively uniform temperature at the top of the tube can be obtained.

Temperature calibration curves for the fire tube are shown in Figure 4. The measurements were made in the center and near the inner side of the tube at various points along the tube with a Bunsen blue flame 11 inches high with continuous inner cone, in place but without a specimen. Under an actual test the lower end of the specimen is subjected to a temperature of approximately 1000° C. (1832° F.) immediately upon applying the flame. Above the flame, the temperature surrounding the specimen gradually decreases to about 180° C. at the top. As the testing proceeds, the temperature at the top of the tube increases more or less depending upon the inflammability of the material, with maximum temperatures of about 800° C.

Size and Number of Specimens Burned

In order to measure the property of wood to carry flame and to support combustion, it seemed advisable to use a comparatively long specimen with the flame applied only to the lower end. Specimens of different lengths and cross sections have been used. Of three lengths tried, namely 20, 27-1/2, and 40 inches, the longest gave the greatest
Fig. 4—Temperature calibration curves for Forest Products Laboratory fire-tube apparatus.

Tube: 3-inch diameter, uninsulated, cage bottom type with two rows of horizontal slots, each slot 1/10 by 1-1/2 inches, arranged 4 inches apart on opposite sides of the tube.

Heat source: A Bunsen blue flame 11 inches in height and 1000° C. at the hottest point. Without specimen in place.

Legend:
- Maximum temperatures at center of tube.
- Minimum temperatures near circumference of tube.

Temperature --- °C.

Distance above top of burner --- Inches.
difference in results between treated and untreated wood and
the most accurate measure of differences in effectiveness.
The cross-sectional area and form of the specimen were also
varied 1/8 to 1/2 inch in thickness and 1/2 to 1-1/4 inches
in width. Considered as to the ease of preparation, accuracy,
and time required for testing, a specimen 3/8 by 3/4 by 40
inches was found to be the most desirable.

Some tests were also made by burning specimens
singly, in threes, and in fives. The results showed that
burning three or five specimens at a time resulted in a
larger loss in weight for the moderate to heavily treated
wood than burning a single specimen. When burning five
specimens together in the 3-inch tube, it was also noted
that a considerable amount of the gas escaped from the tube
before it ignited. Several pieces burned together apparently
added to each others destruction. This resulted in a con-
tinuation of burning beyond the point where a single speci-
men supplying its own heat ceased to burn. As previously
mentioned, however, a single specimen in the tube gave
about the same results as burning five together in the open.
Furthermore, considering the fact that the specimen is ex-
posed to flame on all sides, it seems that several such
specimens, tested together in a tube, would result in a
more severe condition than actually prevails in the initia-
tion of fires under most conditions and that burning a
single specimen more nearly approximates the severity under
actual incipient fire conditions.

Effect of Other Conditions on the Results of Test

Moisture content of wood.—A number of factors,
such as moisture content, density, species of wood, and the
method of cutting specimens, have an important effect upon
the results of the test. Comparative tests made in the fire
tube have shown that the moisture content of the wood at the
time of the test markedly affects the results. Since the
moisture-humidity equilibrium of wood may be influenced by
the presence of chemicals, it seemed desirable to condition
the wood previous to test to a constant weight under a given
atmospheric condition rather than to a fixed moisture content.
It is recommended that wood, intended for use in heated
buildings, be conditioned at about 80° F. and in a relative
humidity of about 30 per cent before test. This brings un-
treated wood to a moisture content of about 7 per cent, which
is close to its average in service in heated buildings.
Heartwood and sapwood.—Preliminary work has indicated that heartwood and sapwood of some species are sufficiently different in fire resistance to show a different result in the fire-tube test. The presence of heartwood and sapwood also affects the impregnation process and the amount of absorption and distribution of chemicals, the sapwood being the easier to impregnate.

Density.—Density is another factor that is closely related to fire resistance. The rate at which a flame burns a given volume of wood, the percentage of loss in weight within a given time, and the amount of fire retardant required per unit volume of wood, all depend more or less upon the specific gravity of the wood. The heavy, dense woods burn more slowly than woods of low density, other things being equal.

Method of cutting specimens.—Sufficient work has not been done to permit of a detailed statement on the method of sampling fire-resistant material. However, in the laboratory experiments with the fire-tube test, a total of 16 specimens, four cut from each of four boards, has been regarded as sufficient for evaluating a given species and treatment. Where heartwood and sapwood are present, the material should be selected and cut so as to obtain a proper proportion and distribution of heartwood and sapwood in the specimens. Fire-resistant lumber that is to be remanufactured should be surfaced lightly on the edges and sides before cutting test specimens, because of the possibility of uneven absorption and of a greater concentration of fire retardant at or near the surface of the material caused by drying. Surfacing is done in many remanufacturing processes, so that the test specimens should represent as nearly as possible the wood as it will ultimately be used. Tests in the fire tube have shown a distinct difference in effectiveness between specimens cut from the outside and inside of thoroughly impregnated material. The specimens should be cut not less than 1 foot from the ends of the piece because of the greater concentration of chemical at the ends.

Proposed Standard Method

A choice of the details of the apparatus and method of procedure, such as the size and type of tube, the extent to which it is insulated, the amount of air admitted, the amount and distribution of heat applied to the specimen, and the size and number of specimens tested at one time, depends
upon the severity of the test desired. It is desirable, of course, that the conditions of the test be similar to those existing under actual incipient fire conditions, but at the same time they must be such as to differentiate between different fire-resistant treatments. In the absence of data correlating the results of the test more closely with those obtained under actual fire conditions, the following method is proposed:

**Tube:** Three-inch diameter, galvanized iron, uninsulated, cage-bottom type with two rows of horizontal slots on opposite sides of the tube, each slot 0.10 by 1-1/2 inches, arranged 4 inches apart center to center.

**Heat source:** A Bunsen blue flame, from a horizontal, low-form burner, 11 + 1/2 inch in height with a tall indistinct inner cone, 1000° C. ± 25° C. at the hottest point and giving a temperature of 180° ± 5° C. at top of tube, top of burner to be placed 1 inch from the bottom of the specimen.

**Specimen:** Single, 3/8 by 3/4 by 40 inches. Specimen to be conditioned to constant weight under uniform humidity and temperature conditions to bring it to about 7 per cent moisture content and accurately weighed immediately before test.

**Duration of test and measurement of result:** The ignition flame to remain under specimen 4 minutes; percentages of loss of weight and temperature to be taken at 1/2-minute intervals from beginning of test until 2 minutes after flaming ceases; loss in weight to be noted at time flaming stops; temperatures to be taken by placing a thermocouple not more than 1 inch above the center of the top of the tube at the beginning of the test.

**Comparison of the Fire Tube with Other Forms of Test**

Comparative tests have been made between the fire-tube and other forms of test. An apparatus used by Prince\(^5\)...

was tried. The method consists in exposing a specimen of wood in the center of an insulated quartz tube, which is electrically heated, and the time required for the flame to develop and the time of flaming after the specimen is removed from the heated tube is noted. The results did not show a definite relation between the time required for the flame to develop and the fire resistance of the material as measured by the fire-tube test. Neither did the time of burning after removal from the ignition chamber appear to offer a consistent measure of the relative effectiveness of fire-retardant treatments, although the duration of blazing became less, in general, as the amount of chemical increased.

It seemed desirable to make a comparison between the fire-tube test and the shavings, crib, and timber tests which are in use as acceptance tests by the Borough of Manhattan, New York City. A series of tests was made using southern yellow pine untreated and treated with amounts of zinc chloride ranging from about 1 to 5-1/4 pounds of salt per cubic foot of wood. The southern yellow pine, which was all sapwood, was thoroughly impregnated by a pressure treating process. Specimens for each of the four tests were then cut from the same boards. Four boards were tested for each treatment. The shavings, crib, and timber tests were made in accordance with the procedure adopted by the Board of Standards and Appeals of New York City. The results obtained are shown in Figures 5 and 6. In Figure 5, the units employed as a measure of effectiveness in the various tests are plotted against absorption of dry salt in pounds per cubic foot of wood. In Figure 6, the amount of dry salt is expressed as percentages of the weight of the wood.

Crib Test

In the crib test, the results are measured in terms of time of flame and glow persistency of the specimen after the ignition flame is removed. These measures showed no consistent difference in fire resistance of wood untreated and treated with light absorptions of salt, a marked difference between 2 and 3 pounds of salt per cubic foot (about 6 to 9 per cent of the weight of the wood) and small differences for all absorptions above 3 pounds per cubic foot.

Fig. 5.—Results obtained with the New York tests and with the fire-tube tests. Tests made on southern yellow pine sapwood treated with zinc chloride. Absorptions expressed as pounds of dry salt per cubic foot of wood.
Fig. 6.—Results obtained with the New York tests and with the fire tube tests. Tests made on southern yellow pine sapwood treated with zinc chloride. Absorptions of dry salt expressed as percentage of the original weight of the wood.
Timber Test

The results of this test are judged by the cross-sectional area of wood unburned at the most burned section of the specimen and by the persistence of flame and glow after the ignition flame is removed. None of the material tested passed the requirement as to the amount of unburned area. The percentage of unburned area was quite inconsistent in reference to treatment and was apparently affected as much or more by the density of the wood and other factors as by the amount of fire retardant in the wood. The average persistence of flame and glow showed a rather definite relation to the amount of fire retardant in the wood, but again there was a large variation among individual boards in the untreated or lightly treated material.

Shavings Test

In the shavings test, the results are judged by the maximum height of flame and by the time that combustion continues in the shavings. Considerable care was used to obtain shavings of uniform thickness and form, which is very difficult to do by hand, and to conduct the test in a standard way. In spite of this, the time of burning showed no apparent relation to the amount of fire retardant present. The height of the flame could not be measured accurately and had to be estimated. The estimated values, although dependent upon the judgment of the operator, did show a fairly definite relation to the amount of fire retardant present. However, in another series of tests in which the thickness and form of shavings was purposely varied, there was a marked difference in results obtained from boards receiving the same treatment. There are so many uncontrolled factors in this test, such as the fineness and form of shavings, quantity of shavings, distribution of shavings in the container, and degree of packing and measurement of height of flame, as to make the test of doubtful value for differentiating between fire-resistant treatments.

Fire-Tube Test

The results obtained in this series of tests in the fire tube are fairly typical. Individual boards treated with about the same amount of fire retardant showed about the same percentage loss in weight and the same maximum temperatures, except in the region of the 2-pound absorption of dry salt per cubic foot of wood (about 6 per cent of wood by
weight). (See figs. 5 and 6.) The fire resistance of the southern yellow pine containing 2 pounds of zinc chloride was just sufficient that the specimen might or might not support combustion, depending upon the density of the wood and perhaps other factors. Consequently there was greater variation among individual boards at this absorption. When the amount of fire retardant was expressed as a percentage of the weight of the untreated air-dry wood (see fig. 6), the test results were more consistent. The wood that gave the test results shown in Figures 5 and 6, had been conditioned to a fairly uniform moisture content before treatment. If there had been wide variations in the moisture content of individual boards before treatment, as may be the case in commercial lots of lumber, the absorptions by percentage of weight of air-dry wood would have been less significant and less consistent.

The fire-tube test, in comparison with the crib, timber, and shavings tests, gave more consistent results both as regards boards of the same treatments and boards treated with different amounts of the fire retardant. Moreover, the results can be more accurately determined and the test can be made much more quickly. The persistence of flame and glow, shown by the crib and timber tests, are apparently measures of the same essential property of flammability as is measured more accurately in the fire-tube test. It is possible that the timber test, or a similar test, might give some information about the properties of fire-retardant wood not revealed by the fire-tube test, but it is apparent that density of wood and possibly other factors must be carefully controlled to obtain comparative results. As a measure of the property of wood to support combustion, that is, to cause the spread of flame and to contribute to an increase in temperature under fire conditions, the Forest Products Laboratory fire-tube test is reliable, consistent, and quickly and easily made.