THE "FIREPROOFING" OF WOOD

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The recent revival of interest in the "fireproofing" of wood has come from many and widely divergent sources. Forest and lumber industries are directly concerned because of the general trend in the building industry away from wood toward so-called "fireproof" construction. Wood-preserving and chemical industries see in fireproofing a possible field of enlarged activities. Architects, contractors, and builders, in the hope of finding cheaper and more adaptable fireproof building construction; the fire underwriters, city building commissions, and other governmental agencies, because of their concern over fire hazards and the reduction of loss of life and property; and the consuming public, with a vision of greater safety and reduced losses, are all interested in the possibility of fireproofing wood. The Forest Products Laboratory, in common with other governmental agencies, is concerned both with reducing the large, yearly losses of life and property from fire and with the bearing fireproofing has on the economical utilization of forests and forest products.

"Fireproof" Misleading

The terms "fireproof" and "fire-resistant" have come into rather general use to designate materials and constructions that vary considerably in their susceptibility to damage by fire. No material commonly employed in buildings and other structural fields is strictly "fireproof." Likewise, the term "fireproofed wood" can not be taken in a literal sense, for no treatment of wood, so far as is known, protects wood from destruction under high temperatures. "Fire-resistant" or "fire-retardant" expresses more accurately the properties of wood treated with fireproofing chemicals, and the author has used the terms "fireproof," "fireproofing," and "fireproofed" in this article in the more general sense because of established usage.

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Competition Stimulates Fireproofing Processes

The use of wood in buildings is without question a factor in the yearly loss of property and life from fire, but on the other hand there is danger of over-emphasis of the hazard of wood in certain details of construction. Statistics show that something like one-third to one-half of the annual fire loss to property occur in frame buildings and their contents. Whether this loss is out of proportion to property values and the extent to which it could be reduced by the use of more fire-resistant materials are not known. Undoubtedly, the use of more fire-resistant materials would reduce these losses somewhat, but fire losses would still be large even if wood were entirely eliminated. There are obviously many other lines of attack, such as better safeguards, less carelessness, and improved details of construction, that would make wood in buildings far less hazardous. Nevertheless, a decided trend away from wood to other materials of construction, such as steel, concrete, brick, and tile, has developed. In the more congested areas of cities and in certain types of buildings, wood has already been largely replaced, and there is a growing tendency to extend the use of substitutes for wood to suburban areas and to rural structures. This general movement away from wood has quite naturally been aided by the manufacturers of the substitute materials.

The loss of markets for wood has stimulated a search for ways and means of reducing the hazard incident to its use. Much can be accomplished through improved structural details and safeguards, but beyond that, there is also the possibility of making wood less inflammable or, expressed differently, more resistant to fire. Two general methods of increasing the fire resistance of wood are the use of surface coatings and treatments, and impregnation processes. The two methods vary distinctly as to ease of application, equipment required, and effectiveness obtained. This discussion is primarily concerned with the impregnation method.

Early Developments in Fireproofing

Attempts to increase the fire resistance of wood are by no means new. Coatings and dipping or steeping methods originated hundreds of years ago, and there are many patents covering materials for this purpose. Most coatings do not increase the fire resistance of wood materially and their effectiveness has generally failed to impress the engineer and others. Yet their values, although limited, should be recognized for what they are worth. Coatings are relatively cheap, are quickly and easily applied, and their more extensive use, as a means of reducing fire hazard, warrants careful consideration.

Impregnation methods of fireproofing wood are of more recent origin, though records of early efforts in foreign countries go back nearly a century. In the United States, the commercial treatment of wood with fire retardants by pressure methods was undertaken about 35
years ago, when the first real demand for fireproofed wood came from
the United States Navy for use in battleship construction. A few
years later, in 1899, the City of New York gave further impetus to the
fireproofing industry by adopting a revised building code, which re-
quired that wood, used in the construction of buildings over 150 feet
in height, must be treated to make it fireproof. Testing methods were
adopted by the Bureau of Buildings of the Borough of Manhattan to
judge the effectiveness of treatments.

The early experience of the United States Navy with fire-
proofed wood was unsatisfactory, and its use was discontinued in 1902,
after a 7-year trial. The discontinuance is reported to have been
based, not on a lack of original fire resistance, but on the corrosive
action of the chemicals on metal fastenings, on their hygroscopic
properties, their effect on paint and varnish coatings, and their lack
of permanence on decks and other parts exposed to the weather or to
frequent washing. In contrast to the experience of the United States
Navy, it is interesting to note that the British and Japanese govern-
ments are at present reported to be using fireproofed wood in the con-
struction of naval ships. The early experience of the British Admiralty
is reported to have been similar to that of our own Navy, but later
developments brought about improvements so that fireproofed wood was
later adopted and has been used in British ships for some 15 or 20 years.

In New York City, where fireproofed wood is used principally
for interior trim, flooring, and window sash of buildings, there has
apparently been no widespread or serious criticism of the treated wood
for the reasons that made it unacceptable to the United States Navy.
However, the conditions in the two classes of uses are very different
and might account, at least in part, for this difference in results.

Slow Growth of the Industry

On account of the demand created by the Navy and the City
of New York, several companies were formed to treat wood with fire retar-
dants. Some of these met early failure, while a few continued to operate
for several years. The entire industry had a severe setback during the
World War, but at its conclusion and also since then several new plants
have come into existence. During recent years, chiefly because of ex-
tensive building in the New York area, there has been a slow growth in
the industry, and it appears to be on a sounder basis than before.

There are several apparent causes for the comparatively slow
growth of the industry and the failure of various companies, chief of
which are the following:

1. No general recognition of the value of fireproofed
wood by engineers, building commissioners and
othersexists, chiefly because of a lack of knowledge of its properties, and the absence of adequate standards.

2. The use of objectionable chemicals, which affect adversely the properties of the treated wood.

3. Inadequate treatments, because of carelessness or a lack of fundamental knowledge of treating processes.


There is at the present time a more wholesome desire to learn the properties of fireproofed wood and to put out a satisfactory product. It is becoming more generally recognized that accurate and reliable testing methods must be found and clearly defined, that performance standards must be set up, that the chemicals used must not be objectionable, that the treatments must be thorough and properly made, and that the cost of the treated wood must be reduced. In other words, the industry is apparently putting itself in a position to make better progress and to meet the demands of the consumer. Much work must be done, however, before the properties of fireproofed wood will be fully known and generally recognized.

Work at the Forest Products Laboratory

Fireproofing studies were undertaken at the Forest Products Laboratory about 1913, but the work was discontinued during the World War. Some of the results of this work were reported in 1915. The work was again taken up in 1927 and is still under way. Recent studies at the Laboratory have been confined chiefly to two lines of endeavor, a study of testing methods, and the relative effectiveness of various chemicals as fire retardants in wood.

A brief statement of some of the fundamental characteristics of wood that are important from a fire-resistance standpoint is desirable here. Wood, in common with other organic materials, decomposes when subjected to high temperatures and gives off inflammable gases. Research in the fields of wood distillation and combustion indicates that the decomposition of wood subjected to increasing temperatures consists of the following steps: Vaporization of the moisture in the wood

(up to 212° F.); volatilization of extraneous materials (200° to 300° F. or higher); scorching and the slow evolution of inflammable gases (300° to 400° F.); charring with more rapid evolution of inflammable gases, accompanied by glowing and eventual flaring (400° to 700° F.); and quick ignition of inflammable gases and glowing of charcoal (700° to 950° F.). It is important to note that the decomposition of wood substance may occur at temperatures substantially below those prevailing in going fires.

Heat from an external source is necessary to ignite wood, but, once ignited, the exothermic heat, if not dissipated, is sufficient to carry on the process of combustion. The ignition temperature and other fundamental decomposition characteristics of wood do not vary greatly with different species. Treating wood with fire-retardant chemicals increases the ignition temperature somewhat but the order of magnitude of this increase has been shown by various investigators to be only something like 200° F., with even the most effective chemicals. On the other hand, moisture or suitable chemicals injected into the wood interfere materially with the process of combustion and if present in sufficient quantities may prevent it entirely unless sufficient heat is applied continuously from an external source. Present known fireproofing methods, however, do not prevent the decomposition or charring of wood at high temperatures and in this sense cannot be regarded as making wood fireproof.

Wood has good insulating properties so that it does not transmit heat readily and it thus retains its mechanical properties under high temperatures better than many materials. It is due to this fact that wood, even untreated, is less likely to buckle, twist, and fail under load at high temperatures than uninsulated steel and other structural metals. Its insulation properties are also responsible for slow flame penetration. Wood thus has certain natural advantages which, if combined with fire resistance, make it a desirable material for many purposes under conditions where high temperatures may prevail for some time. Fire-retardant treatments add to the advantages of wood by opposing the spread of flame and reducing the tendency of wood to support combustion or to build up high temperatures. They may also increase the insulation properties of wood and reduce the rate of flame penetration.

Fire-Resistance Tests

Tests on the inflammability or fire-resistance of wood may be grouped into two classes, tests on small pieces or representative samples, and tests on built-up assemblies under standard time-temperature conditions. Tests on built-up assemblies are expensive and are not adapted to systematic checking of commercial treatments nor to extensive routine laboratory or development work. Such tests are intended to measure the performance of materials under approximate fire
conditions, while tests on small samples are useful as measures of one or more of the properties of fireproofed wood and as measures of the effectiveness of treatments in plant operations.

Fire resistance in the broad sense embraces several properties or characteristics of a material, such as heat insulation, the extent to which the material gives off inflammable gases when heated, resistance to the spread of flame, and to the building up of temperatures, resistance to flame penetration, and the effect of high temperature on strength. Many attempts have been made to measure the fire resistance of wood through one or more of these properties. Some investigators have measured the volume and the character of gases evolved upon heating wood or the temperature and the time of ignition of the gases. Several tests, such as the shavings, crib, timber, splinter, muffle, cinder, and hat-plate, are based on the probability of ignition from a given heat source within a specified period or upon the persistence of flaming and/or glowing of the wood after ignition and removal from the source of heat. Measuring the time required for a flame to penetrate a piece of wood is a common test. The depth of flame penetration in a board, the unburned cross-sectional area of a timber, and the time required for a loaded timber to fail when subjected to a flame are different measures of the same essential property. Heat insulation, which is closely associated with flame penetration, has been included in some flame-penetration tests. In other tests the height of flame from the burning wood is taken as a measure of inflammability.

Most of the various tests show differences in fire resistance between untreated and fireproofed wood, but the results are often of limited value, because of many uncontrolled conditions and factors in the test and because of the lack of definite and significant units of measurement. For example, the density of the wood is perhaps as important a factor in flame penetration tests as is the presence or absence of fireproofing chemicals. Ignition temperature, of course, is related to fire hazard, but it fails to measure the behavior of wood under fire conditions. Likewise, the time required for ignition and the time of flaming and glowing after ignition are affected by so many conditions that they are of doubtful value as accurate measures of fire resistance. None of these tests appear to measure in definite units the tendency of fireproofed wood to resist the spread of flame and the building up of temperature under fire conditions.

The Fire-Tube Apparatus

In an attempt to develop a more accurate and significant test that would overcome some of the limitations of past test methods a

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fire-tube apparatus was designed at the Forest Products Laboratory. The apparatus (Fig. 1) consists essentially of an open, galvanized-iron tube in which a specimen of wood is burned while suspended from a balance arm. A gas flame is applied to approximately the lower quarter of the specimen for 4 minutes. To the balance arm is attached a pointer that indicates on a scale the percentage loss in weight as the burning proceeds. The temperature at the top of the tube is measured by means of a thermocouple type of pyrometer. As the wood is decomposed by the flame the coals that drop are caught in the bottom of the tube and their tendency to continue to glow is noted.

The ignition flame is controlled so as to give a temperature of $1832^\circ \pm 45^\circ$ F. ($1000^\circ \pm 25^\circ$ C.) measured with a No. 14 Awg. thermocouple, at the hottest part of the flame, and $356^\circ \pm 2^\circ$ F. ($180^\circ \pm 5^\circ$ C.) at a point 1 inch above the center of the top of the tube without a specimen in place. These conditions are obtained with a Bunsen burner, adjusted to give a blue flame approximately 11 inches in height with a tall, indistinct, inner cone; the fire-tube used is about 50 inches long over-all, and the specimens are about 40 inches. The specimen is suspended in a vertical position with its lower end 1 inch above the top of the burner. Calibration of the tube indicates that a little more than one-fourth of the lower end of the specimen is subjected to temperatures of the order of $1700^\circ$ to $1850^\circ$ F., and the upper half to temperatures of about $375^\circ$ to $500^\circ$ F. A sharp reduction in temperature occurs between the lower quarter and the upper half of the specimen. The specimen is thus exposed in test to temperatures ranging from those existing under severe fire conditions down to approximately the ignition temperatures of wood. Under these conditions untreated wood ignites quickly, flame spreads along the entire length of the specimen, which loses weight rapidly, and temperatures of $1350^\circ$ to $1500^\circ$ F. are built up at the top of the tube within 3 or 4 minutes. On the other hand, an effectively treated specimen ignite with difficulty, if at all, its lower end chars slowly during destruction, it does not spread flame or burn much beyond the igniting flame, and it causes little or no increase in temperature at the top of the tube.

In Figure 2 are shown some typical loss-in-weight and temperature records of tests in the fire-tube on wood of different degrees of fire resistance, plotted against time in test. These curves illustrate the type of data obtained on individual specimens ranging from untreated wood to wood impregnated with comparatively large amounts of an effective fire-retardant chemical.

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Tests of Various Chemicals

With the fire-tube apparatus developed to the point where it was considered reasonably accurate and reliable and a useful measure of fire resistance, tests were undertaken to determine the effectiveness of various chemicals as fire-retardants in wood. The object of these tests was to find chemicals that would add distinct fireproofing properties to wood and that either are cheap or will be effective in small quantities. The work was divided into two parts, as follows:

An extensive survey of chemicals to learn their possibilities as fire retardants in wood, and a more intensive study of the more promising chemicals to determine the quantity required to obtain a good degree of fire resistance. In both studies the wood specimens were impregnated by pressure methods in such a way as to obtain complete penetration of the chemicals.

In the extensive survey, test pieces, 3/8 by 3/4 by 40 inches in size, were treated with two concentrations of each chemical so as to give absorptions of approximately 1 pound and 5 pounds of dry chemical per cubic foot of wood. These quantities of effective fire-retardant chemicals provided a range sufficient to indicate the possibilities of the chemical as a fireproofing agent. The pieces were dried after treatment under controlled humidity and temperature conditions that bring untreated wood to approximately 7 percent moisture content. The pieces, without resurfacing, were then tested in the fire-tube. Figure 3 shows the results obtained with 33 chemicals. It is apparent that there is a wide difference in the fire resistance of wood specimens treated with various chemicals and that a number of chemicals stand out above the others.

In the intensive survey, an attempt is being made to learn more definitely the quantity of chemical needed to stop the spread of flame and the building up of temperature. The only chemicals included in this survey are those that showed distinct promise in the extensive survey and that from their properties would not be expected to have undesirable effects on the wood, to interfere with its use in service, or to be hazardous to health. In this series of tests, boards, approximately 7/8 by 8 inches by 6 feet in size, were impregnated under pressure with concentrations of solutions intended to give a range of absorptions from about 1 to 7 or 8 pounds of dry chemical per cubic foot of wood. The boards were dried after treatment and were then resurfaced to 3/4 inch in thickness. Standard test specimens, 3/8 by 3/4 by 40 inches, were then cut from the boards and tested. Figure 4 illustrates the relation found between the quantity of an effective chemical, diammmonium phosphate, and the total loss in weight of the specimen, expressed as a percentage of the original weight, and also the relation to the maximum temperature at the top of the fire-tube during test. The character of the data indicates a consistent relationship in two different kinds of woods.

Figures 5 and 6 show the results of tests on six chemicals in which the rate of combustion in terms of loss of weight of the specimen
and temperature increase per minute are plotted against absorption of dry chemical per 100 pounds of air-dry wood. In both figures a general curve is indicated for all six salts, although there is obviously considerable difference in the effect of the various chemicals on the rate of combustion, particularly in absorptions up to 10 percent of the weight of the wood.

Significance of the Fire-Tube Test

The results so far obtained with the fire-tube apparatus indicate that it is a reasonably accurate method of measuring the tendency of the wood to support combustion and that the test data can be expressed in definite numerical terms. The test apparently shows the tendency of wood to cause the spread of flame and the building up of temperature -- characteristics that are essentially important from the standpoint of fire hazard. Furthermore, the tests indicate that wood, through proper methods of impregnation with fire-retardant chemicals, can be made sufficiently fire resistant to warrant its more extensive use in fireproof construction. No claim is made that the fire-tube measures all the essential characteristics or properties of wood from the standpoint of fire safety. The conductivity of heat and the resistance to penetration of flame are other properties of wood, important in fireproof construction, that the fire-tube test does not evaluate. Still other properties of fireproofed wood, such as tendency to corrode metals, finishing and gluing properties, hygroscopicity, permanence of treatment, and effect of strength, must obviously be determined for different chemicals in order to have a complete picture of the value and practicability of such chemicals. Also there is need for determining the relation of the results obtained in the fire-tube to behavior under fire conditions by performance tests on built-up assemblies or similar large-scale testing.

The Possibilities of Fireproofed Wood

Although there is still much that must be done before the properties of fireproofed wood will be fully known and appreciated, it is evident that such wood offers distinct possibilities in reducing the large yearly losses from fire. A careful analysis of building construction and fire losses would undoubtedly reveal numerous structural details where material of even moderate fire resistance would have a most important effect in reducing the damage from fire. Fire-resistant coatings, though admittedly less effective than thorough impregnation methods, certainly have a place in the reduction of fire damage. The use of effectively impregnated, fireproofed wood in the more vulnerable points of construction would undoubtedly have a most important effect. Residential and small commercial construction, where most of the loss of life is sustained, offers unusual opportunities in this direction.

A broad attack of the problem is necessary. Requiring expensive fireproof construction in buildings that can not under any
circumstances be exposed to severe fires or where the safeguarding of certain details will largely eliminate fire loss obviously is wasteful and is likely to retard improvement rather than to assist it. Proper regard must be given to cost as related to hazard in various constructional parts and to the type of building and character of occupancy. The place of fireproofed wood and of fireproofing methods in building construction, even in the so-called fireproof type, is still largely to be worked out. The picture is still incomplete and more facts are needed before we can feel any degree of satisfaction with our knowledge of the subject.

(The published Proceedings of the annual meeting of the National Fire Protection Association contain Mr. Truax's paper, together with the discussion that followed its presentation. Reprints of the paper and the discussion may be obtained from the Association Secretary at 60 Batterymarch St., Boston, Mass., for 20¢ each.)
Fig. 1.—The fire-tube apparatus.

Fig. 2.—Typical loss-in-weight and temperature curves from the fire-tube test. Each curve represents a single specimen of southern yellow pine.
Fig. 3.—Results of tests in the fire-tube on wood treated with various chemicals in the extensive survey. Each chemical was used in light and in heavy absorptions. The curves are for diammonium phosphate.

Fig. 4.—Average results obtained with different absorptions of diammonium phosphate and two species of wood. Each plotted point represents the average results for 10 to 20 specimens cut from boards that were surfaced after treatment.
Fig. 5.—Effect of different amounts of six chemicals on the average rate of loss in weight in the fire-tube. Each plotted point represents the average results for 16 specimens cut from boards that were surfaced after treatment.

Fig. 6.—Effect of different amounts of six chemicals on the rate of temperature increase in the fire-tube. The tests were made on the same specimens reported in Fig. 5.