

FIRE RESEARCH AND RESULTS AT THE FOREST PRODUCTS LABORATORY

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FOREST PRODUCTS LABORATORY¹

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The performance of wood under fire conditions has been the subject of research and investigations for quite some time. Some of the early work in this field was done by the National Bureau of Standards, Underwriters, and Associated Factory Mutual Laboratories, and their affiliated fire insurance organizations, and certain municipalities, particularly New York City. It was aimed at establishing fire test procedures and defining performance standards for building construction. The results of these early tests influenced the use of wood in construction and the setting of insurance rates,

Many important commercial products, including, of course, wood products, will burn and eventually be destroyed by fire. This fact, however does not prevent them from being used and enjoyed in abundance every day. Nor does it mean that combustible products per se are less resistant to attack and damage by fire than many so-called incombustible materials. Steel beams, for example, will not burn, but they will soften and collapse when exposed to high temperatures. The problem, then, is to learn to take advantage of the natural advantages of wood as, for example, its self-insulating properties, to improve structural details, and to develop greater resistance of wood to fire for applications where circumstances warrant. To accomplish these objectives research becomes important. It is my aim to survey briefly some of the research that has been done at the Forest Products Laboratory, to summarize the more important results, and to refer to some of the important work of others.

A survey of past work indicates that research workers have sought to describe the performance of wood under fire conditions by defining three general characteristics, namely, (a) ignition, (b) fire spread, and

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

(c) resistance to penetration by fire, These characteristics are to some extent interrelated. Ease of ignition, for example, is a factor in the spread of fire but the terms are by no means synonymous. In large-size timbers ignition is relatively slow and fire spreads over them with considerable difficulty; in this case the two characteristics appear to be closely related. However, in finely divided wood materials, such as dry sawdust, ignition may be easy but fire spread slow. Again, decayed wood that has dried out ignites to glowing combustion relatively easily but spreads fire slowly. In these last two cases there is no close correlation between ease of ignition and fire spread. "Likewise, the property of wood to resist penetration and destruction by fire does not appear to be directly related to ease of ignition or rate of fire spread. These three characteristics, therefore, have served as the approach to most fire research on wood and wood products, with either no attempt or frequent unsuccessful efforts at correlation.

Fire research began at the Forest Products Laboratory about 1912, only a couple of years after the Laboratory was established. World War I interrupted the work, but it was revived in 1927 with some assistance and cooperation from the National Lumber Manufacturers Association. During the ensuing years investigations have continued on a relatively small scale, supplemented to some extent by financial support and cooperation from millwork, fiberboard, plywood, and other producers of forest products and from the Housing and Home Finance Agency.

Ignition Studies

The earliest fire studies at the Forest Products Laboratory involved ignition tests. In one series of tests Prince placed wood blocks 1-1/4 x 1-1/4 x 4 inches in a heated air stream of approximately constant temperature in the presence of a pilot flame. The specimens were allowed to remain in the heated air stream until the gases ignited or for 40 minutes if ignition did not occur. The times for ignition were determined for several temperatures. By this technique tests were made on 9 species of wood untreated and 1 species treated with 9 different fire-retardant chemicals. The wood was tested both oven-dry and air-dry. For air-dried blocks the temperatures at which the specimens could be heated for 40 minutes without ignition varied from about 313° to 385° F. for untreated wood, and from about 290° to 500° F. for the one species of wood treated with fire retardants. In another series using the same test procedure on 34 untreated softwood and hardwood species, but igniting the specimens within 4 to 6-1/2 minutes, the temperatures varied from 608° to 660° F. for the softwoods and from 595° to 740° F. for the hardwoods. The results of these tests, when plotted, show a fairly close relation between specific gravity and ignition temperature. In general low density species ignite at lower temperatures than high density species. This relationship was more consistent for hardwoods than for softwoods.

Later Van Kleeck studied the temperature at which exothermic heating develops in wood and from which heating logically progresses to the ignition point. Southern yellow pine untreated and impregnated with several retentions of fire retardants was used. A sample of small chips was exposed in an air stream of constant flow rate and uniform temperature increase, without a pilot flame. By progressively recording the time and the temperature in the air stream and within the sample, the point at which exothermic heating began was determined. For the untreated wood this was between about 445° and 465° F. For zinc chloride treated wood exothermic heating began at a slightly lower temperature than for untreated wood; for ammonium phosphate treated wood it was somewhat, higher, although not determined accurately.

A number of other research workers have used similar or modified methods in an attempt to determine the ignition temperature of wood. For example, Brown of the Bureau of Standards, using a method similar to that employed by Van Kleeck, reported ignition temperatures of 378° to 428° F. for 3 conifers and 2 hardwoods. Graf of the Oregon State College in more recent studies, using again a similar method, tested 20 species of wood. He reported ignition temperatures of 457° to 570° F. for 15 conifers and 423° to 500° F. for 5 hardwoods. In both cases, the samples were small and of finely divided material, varying from shavings to match size.

It is thus obvious that available data on the ignition temperatures of wood vary greatly. This is to be expected because of the large number of variables entering into such determinations. The species of wood, its size, form, and moisture content, the period of heating, air supply, the presence or absence of a pilot flame, and other factors affect the temperature at which wood will support flame or glowing combustion. Ignition temperature data, while informative, are not accurate criteria for judging the performance of wood as it is commonly used under fire conditions.

Ignition temperature determinations have also been used by research workers in the hope of finding treatments that would substantially raise the ignition temperature of wood and thereby provide a method of increasing its fire resistance. So far this approach has not accomplished significant results. Nor has it been possible to explain the properties of fire-retardant treated wood on the basis of ignition data.

Fire Spread

Up to about 1930 comparatively little attention had been given to determining fire spread on wood and wood structures by research workers. In the middle 1920's Dunlap conceived and developed preliminary plans for a fire tube as a means of comparing the rate of burning or fire spread over different species of wood, both untreated and treated with fire-retardant materials. After considerable further development and standardization,

the fire tube was used extensively at the Forest Products Laboratory. It was used for comparing the effectiveness of different chemical treatments for wood and the effect of various coatings on fire spread. The fire tube was later adopted as a fire-test method by the ASTM under designation E 69-70.

The crib test, developed previously by the City of New York as one of three small-scale tests for determining the effectiveness of fire-retardant treatments, is a type of fire-spread test. It, too, was adopted by the ASTM as standard E 160-50. Several other small-scale tests have since been devised and used in measuring flame spread over wood and wood products. Of these, Federal Specification SS-A-118a test, developed by the Bureau of Standards, has been used for some time in evaluating fire-spread characteristics of acoustical materials. The Schlyter test, developed in Sweden, was modified somewhat and has been used considerably at the Forest Products Laboratory. The inclined panel test, adapted by the Forest Products Laboratory from British Standard No. 476-1932, is used by the Insulation Board Institute and specified in Commercial Standard CS 42-49.

In a study conducted at the Forest Products Laboratory in cooperation with the Insulation Board Institute, several of the above small-scale tests were used to evaluate the flame-spread resistance of fiber insulating boards. The material tested included 20 fiberboards both with and without fire-retardant coatings. Results of this study are reported in the Forest Products Laboratory Report No. 1756.

The tunnel test developed by the Underwriters Laboratories followed the issuance of various reports giving the results from smaller scale fire-spread tests. It is a well known method and has been adopted as tentative standard E 84-50T by the ASTM. The Underwriters Laboratories, Inc., describe the tunnel test in Research Bulletin No. 32 entitled "Fire Hazard Classification of Building Materials." They have made extensive tests on lumber, plywood, wallboard, and other materials. However, (because of the size and complexity of the Underwriters Laboratories' equipment) attempts are underway³ at the Forest Products Laboratory in cooperation with ASTM Committee E-5 to develop a smaller scale piece of equipment that will simulate the performance of the larger tunnel test and be more readily adaptable to commercial and other testing laboratories.

Fire-spread tests have also been made at the Forest Products Laboratory on structural assemblies containing combustible materials and contents. One of the earlier investigations on assemblies consisted of a series of tests to determine the probable ignition from incendiary bombs in the

³The Forest Products Laboratory 8-foot tunnel-furnace apparatus has now been successfully developed (1959). Tests of materials in this furnace indicate good correlation and reproducibility for the method. The method and results are reported in Forest Products Laboratory Reports Nos. 207 (1957) and 2140 (1959) and in ASTM Bulletin No. 230 (1958). The method is being considered for adoption as an ASTM Standard

attics of buildings. A structural assembly representing the corner of an attic was used. Incendiary bombs of different types and sizes were placed on the attic floor and ignited, and various fire-retardant coatings were used in an attempt to reduce or prevent fire in the adjacent wood members. This method of test and results obtained were described by McNaughton in an article in the Quarterly of the National Fire Protection Association of January 1943.

A second form of fire-spread tests used to a considerable extent at the Forest Products Laboratory is the semi-burn-out. For this purpose a specially constructed fire-test house is employed. The walls and adjacent ceiling are covered with the material under test. A pilot fire is placed on the floor at the base of the wall as an ignition source and allowed to burn out. The extent and velocity of fire spread over the wall and ceiling is recorded. This form of test has been made both on the side walls and in the corners of the room. With the same size of ignition source, the corner test is the more severe of the two. A number of wall coverings, including wallboards, lumber, and plywood have been tested. In one series of tests the results from a semi.-burn-out were compared with various small-scale fire tests. These various flame-spread test methods are described in Forest Products Laboratory Report No. 1443.

Complete burn-out tests have also been made in the special fire-test room. Report No. 1941 entitled "Experimental Dwelling-Room Fires" gives the results of six such burn-out tests. Wall and ceiling coverings of insulation board, gypsum wallboard, plaster, and interior Douglas-fir plywood were tested. The fire was started in simulated furniture in the center of the room and allowed to burn until the entire interior of the room was involved. The report describes the nature and location of fuel, effect of wall coverings, temperature buildup, and composition of the flue gases. A number of interesting results were obtained. Among the more significant was the buildup of temperatures, unbearable to a human being, from the burning of the contents of the room before the walls were ignited and before carbon monoxide had been produced in toxic concentrations.

A number of other fire-testing agencies have investigated the fire-spread characteristics of various materials including wood and wood products. Of these the Factory Mutual Laboratories have used a semi-burn-out procedure similar to that described above but on a larger scale. Their method of test and procedure is described in their laboratory report No. 11760.

The British have studied fire spread experimentally in two full-scale two-story houses,⁴ The fires were started at the wall and somewhat different conclusions were drawn on the effect of the combustibility of the wall boards than in our experiments in which the fires were started in the furniture.

⁴Combustible Linings in Dwelling Houses. Fire Protection Association No. 16, London, March 1953.

Research on the resistance of wood to penetration by fire has likewise been the subject of considerable research. The Germans and English are reported to have done testing on the fire resistance of structural members before active work was undertaken in this country. However, early work here dating back some 50 years was done by Columbia University, the Underwriters Laboratories, and the Bureau of Standards, which served as a basis for establishing the conditions under which building structures and materials are tested for fire resistance. The present time-temperature curve, which is part of ASTM Standard E 119-50 for fire tests of building construction and materials, was prepared in 1918. It has since come into use by practically all fire-testing agencies.

Fire-test facilities at the Forest Products Laboratory for determining the fire resistance of wood and wood-base materials were provided shortly after the new building was erected in 1932. These facilities have since been used for testing resistance of many materials and constructions, such as walls, doors, and floors. Most of such tests have been made without loads since the facilities are generally inadequate for applying loads to structural members under test.

Walls

An investigation was made of the fire resistance of "stressed covered" wall units used in prefabricated house design. It determined the degree to which fire resistance was affected by construction details, such as kinds of plywood, width of studs, and type of insulation. The program involved tests on 2- x 2- and 4- x 8-foot sections at the Forest Products Laboratory (fig. 1) and 8- x 16-foot sections at the National Bureau of Standards. Report No. 1257 covers the results of tests made at the Forest Products Laboratory. A second series of fire-resistance tests of walls involved 23 sections, made in cooperation with the Insulation Board Institute. All structures were 4 x 8 feet made of 2- x 4-inch framing members with the interior wall covering of plaster and the exterior covering of redcedar siding. The sheathing and lath varied as to materials and thickness. Both interior and exterior wall coverings were exposed to the furnace fire. Other fire resistance tests on walls have involved paper core panels of sandwich type construction,

Doors

Tests of door assemblies have been made on the large furnace and of door sections on a small furnace. Most of this work has been done in cooperation with the National Woodwork Manufacturers Association and individual manufacturers.

Report R1239 entitled "Fire Tests on Wood Doors" covers the results of full-scale door tests with two designs of solid core doors and on hollow core doors with and without insulation. Untreated and fire-retardant treated wood was used. A second series of tests was made on door sections 19 x 19 inches to determine the comparative fire resistance of 8 types of flush door construction. All doors had solid core of wood or incombustible material. Treated and untreated wood was included in the test. Still other tests have been made on doors and sections of doors to determine the best types of fastenings so as to avoid early failures that normally occur in connection with hinges and locks.

Ceilings

A study was made of the temperature buildup between ceiling and joists under standard time-temperature conditions. The sections involved plaster and metal lath attached to standard wood joists with and without floors above the ceiling and with and without insulation between the studs. The primary object of the study was to determine if ASTM E119 standard requirement limiting temperature rise to 250° F. between ceiling and wood joists is realistic. Observations were made on the time when glowing or flaming of the wood joists occurred and these observations were correlated with the temperature rise at the contact surfaces between joists and ceiling. All thermocouples placed between the ceiling and joists showed 250° F. temperature rise in from 8.5 to 10.6 minutes but in all cases the times when glowing and flaming were first observed were much longer. In some cases flaming or glowing was not observed until after an hour of exposure with a temperature rise between ceiling and joists of well over 1000° F.

Heavy Timbers

Fire tests on heavy timber construction have generally been of the resistance type. The National Bureau of Standards has made tests on columns and wood-framed structural elements and assigned fire-resistance ratings to them in report "BMS92 - Building Materials and Structures." The Underwriters' Laboratories reported on "Fire Exposure Tests on Loaded Timber Columns" in Research Bulletin No. 13. The Underwriters' Laboratories reported that timber columns, when given adequate end protection sustained the fire and load tests for 78 to 112 minutes before failure. The Factory Mutual Laboratories have also made extensive investigations of the fire resistance of heavy timber construction.

Work at the Forest Products Laboratory on the fire resistance of heavy timbers has been limited. However, in connection with the construction of the laminated arch building at the Forest Products Laboratory, some fire-resistance tests were made on glue-laminated wood members. A section from one of the arches, consisting of 25 laminae of nominal 1-inch southern yellow pine glued with casein glue, was placed against a furnace with

one side exposed to a gas flame under standard temperature conditions. The edges of the glue lines were exposed to the fire. After 30 minutes' exposure the section was examined for depth and character of char. It was observed that the glue lines were separated to the depth of the char and that the depth of char at the glue lines was slightly deeper than in the wood laminations. Shear tests were also made on the glue lines of the uncharred part of the member. There were indications that the shear strength immediately adjacent to the charred area was reduced slightly, of the order of 7 to 10 percent, in comparison with the part of the member not exposed to the fire.

A second series of tests was made on matched solid and laminated specimens, also glued with casein glue. In these tests where the laminated beam was exposed so that the face of the laminated member was adjacent to the fire, the outer lamination became loose when the char reached the glue line. However, other tests have shown that glue bonds, made with phenolic, resorcinol, and melamine adhesives, hold the charred wood in place and the performance is similar to that of solid wood.

To determine the rate at which wood chars when exposed to fire, another test was made that yielded some interesting information (figs. 2, 3, and 4). The test was on a 4- x 8-foot Douglas-fir panel 7.56 inches thick, exposed on one side to approximately the standard time-temperature conditions. The panel was constructed by nailing together nominal 2 x 8 inch planks 4 feet long. Eighteen thermocouples were distributed within the panel at depths of 1/1.6, 1, 2, 3, 4-1/2, and 6-1/2 inches from the face of the panel exposed to the fire. The wood was at an average moisture content of 11.4 percent before test.

The temperature in the furnace was measured by 6 thermocouples placed 6 inches from the face of the panel. The fire was allowed to burn for 2 hours and 20 minutes. The result of measurements on the panel after burning indicated that 0.48 inch of the original thickness had been lost by destruction of wood substance and shrinkage; 3.11 inches were charcoal and 3.91 inches were uncharred wood. The average rate of penetration of the zone of char into the wood was 1.54 inches per hour.

In summary, the following general conclusions, based on past research and results obtained, are indicated:

1. Investigations of the ignition temperature of wood, while informative, have not yielded results that can be used for predicting the actual performance of wood under fire conditions, nor in evaluating the significance of fire-retardant treatments and coatings.
2. Fire spread is the characteristic of wood that is most affected by fire-retardant treatments and coatings. Size, form, density, moisture content, and arrangement of members are other factors that have an important affect on the fire-spread characteristic of wood.

3. Resistance of wood to destruction by fire, such as rate of penetration of fire and maintenance of structural properties under standard time-temperature conditions, is affected by its physical properties and structural details. Resistance to charring is not greatly increased by fire-retardant treatments, perhaps at most by some 10 to 20 percent.

4. Good performance of wood construction under fire conditions is obtained by taking advantage of the self-insulating qualities of wood, by employing good structural details, and by using fire-retardant treatments and coatings where circumstances warrant.

5. There is much yet to be learned about wood and wood products in relation to fire. In view of the importance of fire in the construction field the research effort put forth by the Forest Products Laboratory and the wood utilization industries in the past has been relatively small and inadequate and a sustained and enlarged effort seems fully justified in the future.

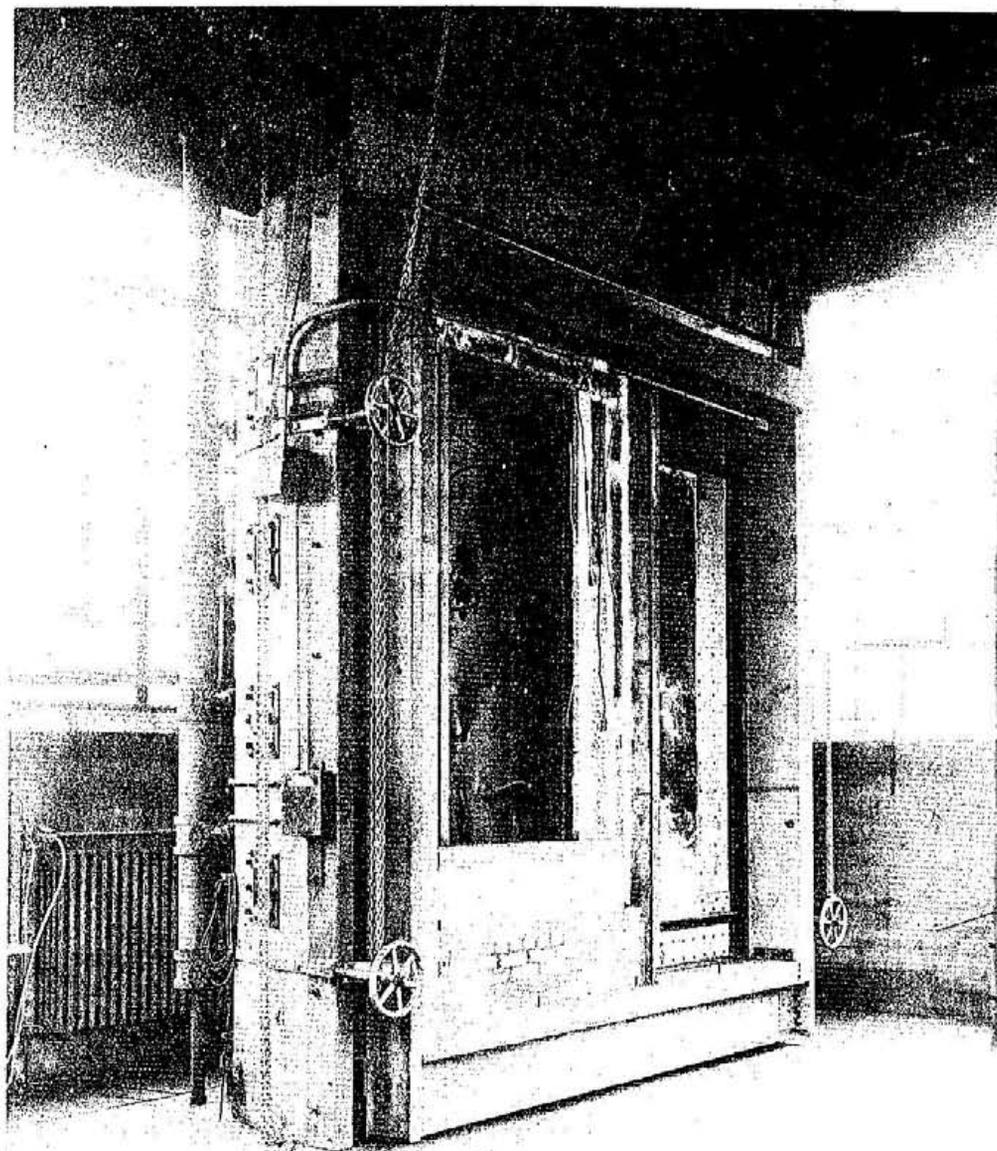


Figure 1.--Furnace used for testing the fire resistance of wall, door, and other wood assemblies. Frame on front of furnace is partitioned off for full-scale door test. Thermocouples for measuring furnace temperature are enclosed in protection tubes.

ZM 46920 F

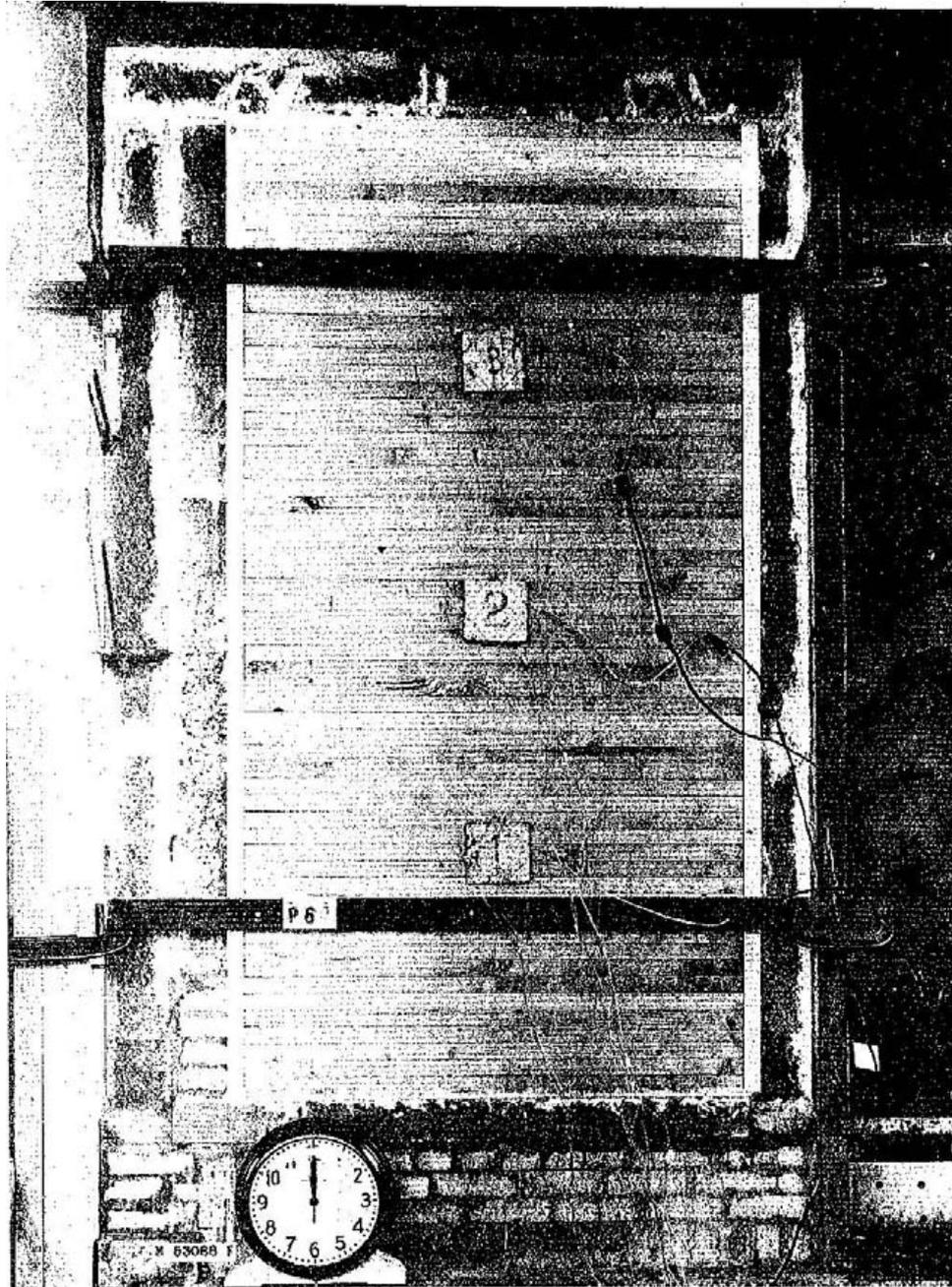


Figure 2.--Built-up Douglas-fir member set in furnace for the start of test. Laminations 1-5/8 x 7-1/2 inches x 4 feet nailed together to produce panel 8 x 4 feet x 7-1/2 inches. Thermocouples are in place to measure temperatures on un-exposed face and at depths of 1/16, 1, 2, 3, 4-1/2, and 6-1/2 inches from the face of panel exposed to fire.

ZM 53088 F

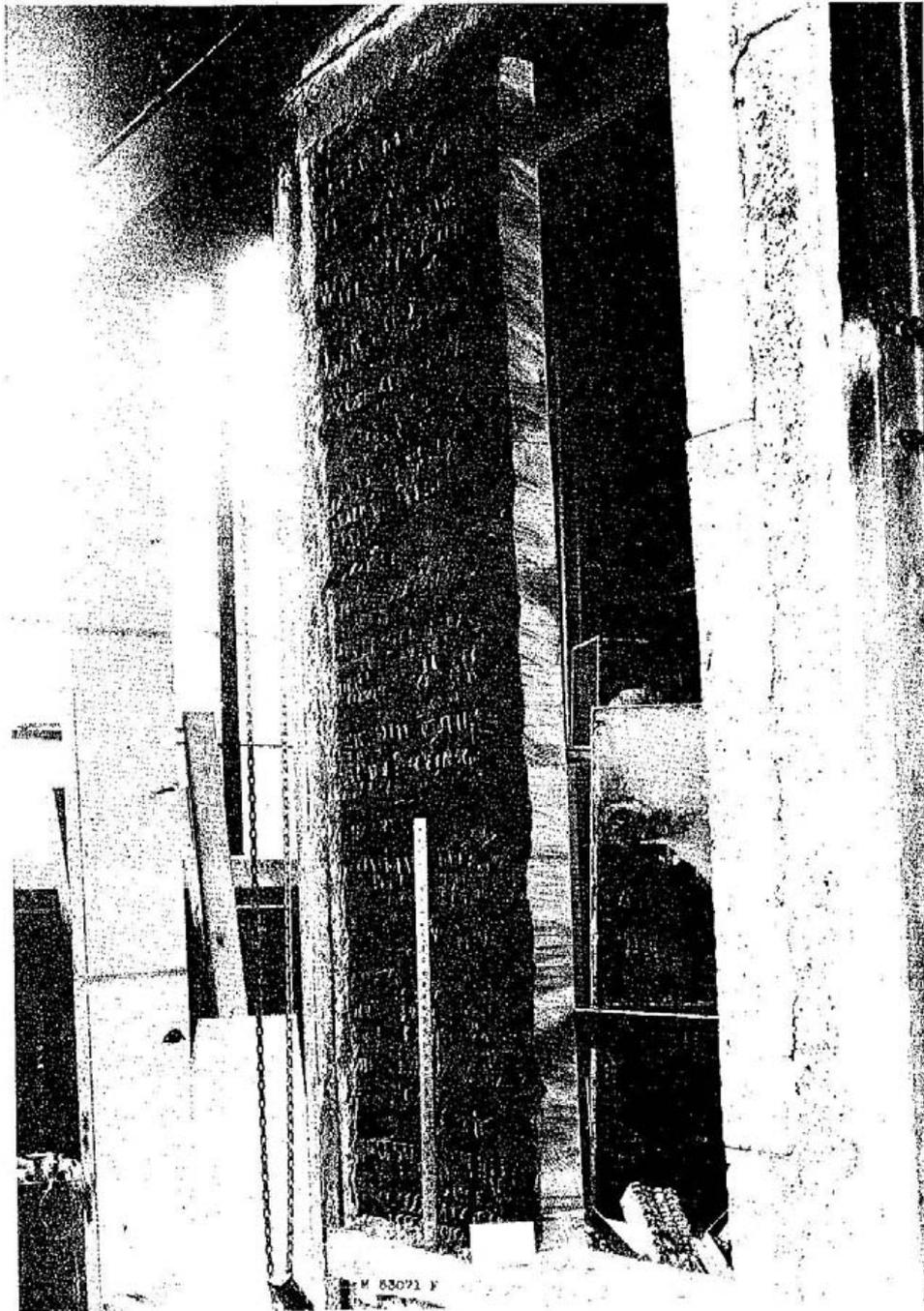


Figure 3.--After 2 hours and 20 minutes fire exposure under approximate standard time-temperature conditions, the panel shown in Figure 1 was removed from furnace and cut through from top to bottom at its center, showing depth of charring and of uncharred wood.

ZM 53071 F

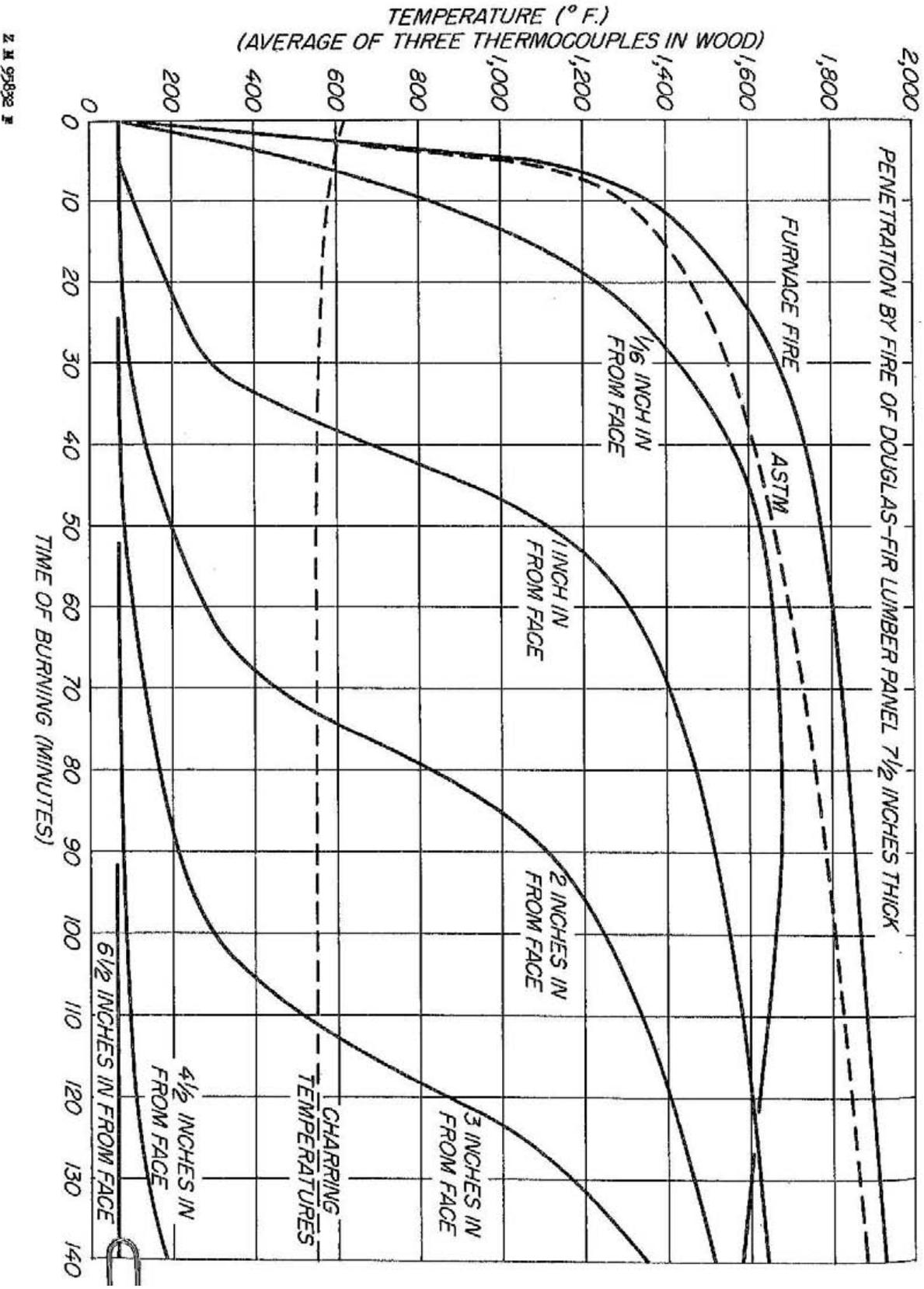


Figure 4.--Temperatures developed during the test shown in Figure 3 within the furnace and at various depths of from 1/16 to 6-1/2 inches from the exposed face are plotted against time. The actual furnace temperatures exceeded the standard temperature curve during most of the test. The approximate time of charring is shown by the nearly horizontal dotted line. Average rate of char was determined as 1.54 inches per hour.