Flame-Spread Measurements

BY THE RADIANT PANEL FLAME-SPREAD METHOD[1]

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Moisture content, mean density, and surface grain structure of untreated wood affect flame-spread index significantly. Flame-spread indices of fire-retardant-coated assemblies were significantly lower. This method can be used to evaluate fire-retardant coatings for wood-base materials.

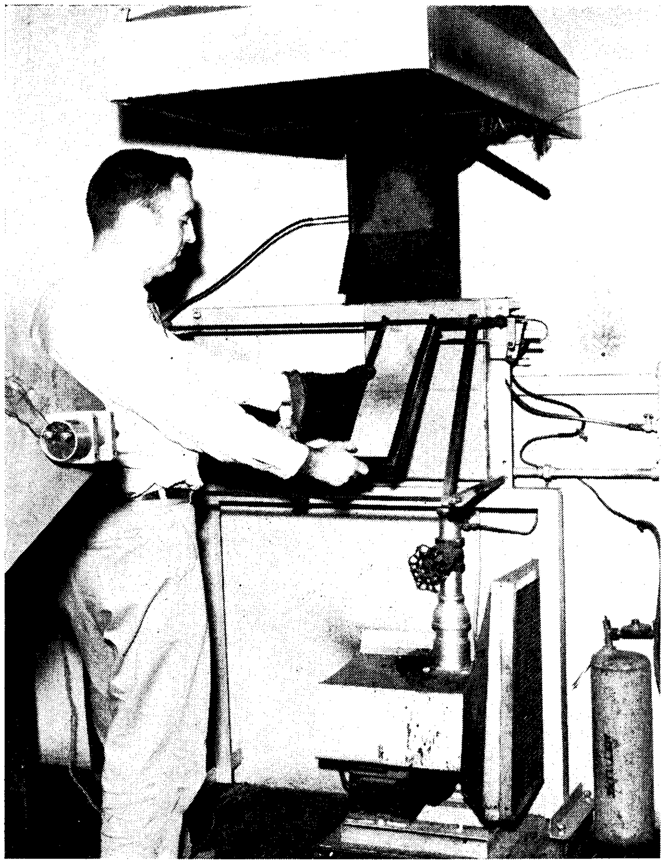


Fig. 1.—Radiant panel test apparatus.

THE USE OF WOOD and wood-base materials as construction and finish materials in almost every type of construction and for all types of occupancies is well known. Building and Code officials and others concerned with the regulation of surface flammability of interior finish materials have used wood as a measuring stick and, in some instances, as a basis for distinguishing certain limits of acceptability of surface spread of flame. Underwriters' Laboratories, Inc., for example, has been using select grade red oak flooring as an arbitrary "standard" with a designation of 100 in its 25-foot tunnel test method[2] for many years, and compares a material according to its performance relative to that of red oak.

Recently, the Forest Products Laboratory developed an eight-foot tunnel test method[2] and the National Bureau of Standards a surface flammability test method based on a radiant energy source.[4]

The latter test apparatus has been installed in 8 or 10 laboratories, and is being used for the development and rapid evaluation of materials and retardant coatings, as well as for general measurements of the flame-spread properties of materials. Information on the correlation between the results of surface-flammability test methods and the hazards associated with the lining of buildings with particular materials is currently being sought.

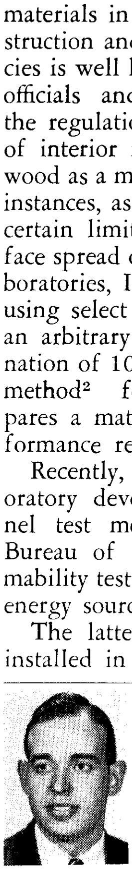
A test program to evaluate the flame-spread properties of some common building-finish materials by means of the radiant-panel test method has been completed[5] and has shown to what extent the thickness of the surface finish material and the substrate to which it is applied govern the flame-spread behavior of composite assemblies.

The purpose of this paper is twofold: Firstly, to indicate, with a few examples, the importance of such physical factors as density and moisture content and to thereby illustrate the importance of maintaining close control over material and test conditions, and secondly, to illustrate, again with several radiant panel test results, the extent to which flame-retardant coatings and treatments applied to wood-base materials are effective in retarding the development and spread of flame.

Test Procedure

The apparatus used for the tests is shown in Fig. 1, and has been described in detail by Robertson, Gross, and Loftus.[4] It consists of a radiant panel, a frame for support of the test specimen, and associated measuring equipment.

The radiant panel consists of a cast-iron frame enclosing a 12- by 18-inch porous refractory material. The panel is mounted in a vertical plane, and a premixed gas-air mixture supplied from the rear is burned in intimate contact with the refractory surface to provide a radiant heat source. The energy output of the panel, which is maintained by regulating the gas flow according to the indication of a radiation pyrometer, is that which would be obtained from a black body of the same dimensions operating at a temperature of 670°C. A stack placed under the hood above the test specimen receives the hot products of com-



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[1] Presented at Session VI, Wood Preservation, FPRS 13th National Meeting, June 28-July 3, 1959, in San Francisco. Information on the fire-protective coating systems is released by permission of the Bureau of Yards and Docks, Department of the Navy.

[2] Steiner, A. J. 1944. Fire hazard classification of building materials. Bul of Res. No. 32, Underwriters' Labs., Chicago.

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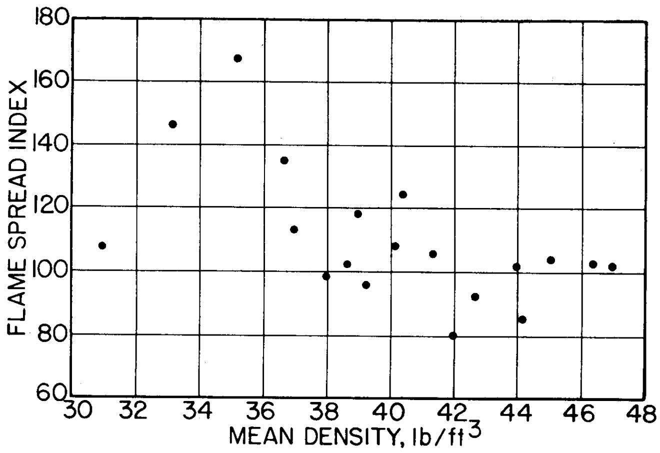

Fig. 2.—Effect of density upon the flame-spread index of red oak.

Table 1. Effect of Moisture Content on Flame Spread Index

	Specimen Condition		
	Dry*	Normal†	Moist‡
Cellulose fiberboard	353	230	150
Poplar wood	320	200	210
Sugar pine wood	420	140	70
Mahogany wood	210	90	60

Note: Each result based upon one or two tests only.

* Dry - cellulose fiberboard conditioned to equilibrium in atmosphere at 5 per cent R.H. Moisture content approximately 1 per cent. Wood materials dried at 105°C.

† Normal - All materials conditioned to equilibrium in atmosphere at 50 per cent R. H. Moisture content of cellulose fiberboard approximately 7 per cent.

‡ Moist - All materials conditioned to equilibrium in atmosphere above 80 per cent R. H. Moisture content of cellulose fiberboard approximately 12 per cent.

bustion and smoke. Specimens are placed in a room maintained at 75°F. and 50 percent relative humidity for not less than one week's conditioning before they are tested.

For test, the 6- by 18-inch specimen is placed in a metal holder and backed with a ½-inch sheet of asbestos millboard of 60 pound per cubic foot density. At time zero, the specimen is placed in position on the supporting frame facing the radiant panel and inclined 30 degrees to it. A pilot igniter fed by an air-acetylene mixture serves both to initiate flaming at the upper edge of the test specimen and to ignite combustible gases rising from the specimen. Observations are then made of the progress of the flame front, the occurrence of flashes, and so forth. An electrical timer calibrated in minutes and decimal fractions to hundredths is used for recording the time of occurrence of events during the tests. The test duration is 15 minutes, or until sustained flaming traverses the entire 18-inch length of the specimen, whichever time is less.

The flame-spread index, I_s, is computed as the product of the flame-spread factor, F_s, and the heat evolution, Q, thus

$$I_s = F_s Q$$

where:

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}$$

($t_3 \ldots t_{15}$ correspond to the times in minutes from specimen exposure until arrival of the flame front at a position 3. . . 15 inches, respectively, along the length of the specimen) and $Q = 0.1\Delta\Theta/\beta$, where 0.1 is an arbitrary constant, $\Delta\Theta$ is the observed maximum stack thermocouple temperature rise at any stage of combustion of the specimen minus the maximum temperature rise observed with an asbestos-siderations suggest that only about one-half of the variations noted can be as-cement board substituted for the specimen, in degrees F. and β is the slope of the line obtained by plotting the maximum stack thermocouple temperature rise, in degrees F., as a function of the corresponding measured heat input rate, in Btu per minute as supplied by a diffusion-type gas burner placed near the top of an asbestos-cement board specimen during normal operation of the radiant panel.

Results

Effect of Density: Considerable density variations are common in any lot of finished lumber. A small batch of 2-¼ inch face select-grade tongue-and-groove red oak flooring was separated according to density. Identical size pieces were found to range in weight from 245 to 383 grams, which corresponds to a density range of 30.7 to 48.0 pounds per cubic foot. An attempt was made to relate the surface flammability as measured by the flame-spread index to the mean density of the specimen, which consisted of pieces of closely matched density. The results are shown in Fig. 2, in which there is the suggestion that the flame-spread index increased as the density of the specimen decreased. Statistical con-signed to variations in the mean density. Inasmuch as the surface grain orientation and distribution were not controlled in these experiments, the scatter in the results actually reflects differences due to the distribution of the annual growth rings. It was observed in almost every instance that the flame front proceeded at a greater rate along the less dense portions of these annual growth rings.

Effect of Moisture Content (Regain): The results of a limited number of tests have indicated that moisture content has a pronounced effect upon the flame-spread index of cellulosic materials. The qualitative results are shown in Table 1. Although the dry and moist conditions were considerably more extreme than those likely to be found in practice, the importance of careful conditioning prior to test is apparent.

Fire-Protective Coating Systems: Flame-spread tests were performed on eight types of fire-protective coating systems and one conventional paint coating applied to similar panels of

Table 2. Flame Spread Test Results on Fire Protective Coating Systems
Four tests on each material

Symbol	Material	Estimated Thickness of Coating in.	Mean Flame Spread Factor, F_s	Mean Heat Evolution Factor, Q	Mean Flame Spread Index	Coefficient of Variation per cent
A	Exterior grade Douglas Fir plywood (control)	-	9.2	18.8	172	4.2
B	Olive drab enamel (TT-E-485b)	.003	10.6	12.2	129	4.4
G	Exterior fire resistant mastic	.020	5.5	14.4	79	7.9
J	Inorganic fire resistant primer plus intumescent interior fire-retardant paint	.007	4.3	10.7	47	16.0
D	Exterior fire-retardant paint	.006	4.8	8.3	39	13.2
F	Commercial system	.006	2.8	10.2	28	10.5
H	Inorganic fire-resistant primer plus olive drab enamel (TT-E-485b)	.007	2.7	8.0	22	44.1
E	Exterior fire resistant mastic	.030	2.3	8.6	22	57.5
I	Inorganic fire resistant primer plus vinyl resin finish	.006	2.3	6.6	16	49.2
C	Intumescent interior fire retardant paint	.006	2.0	3.3	6.6	55.7

[3] Bruce, H. D. and Miniutti, V. P. 1958. Small tunnel-furnace test for measuring surface flammability. ASTM Bul. 230: 61-68.

[4] Robertson, A. F., Gross, D. and Loftus, J. 1956. A Method for measuring surface flammability of materials using a radiant energy source. Proc. ASTM ,56: 1437-1453.

[5] Gross, D., and Loftus, J. 1958. Flame spread properties of building finish materials. ASTM Bul. 230: 56-60.

Table 3. Flame Spread Test Results on Australian Finish Materials
Four Tests on each Material

Symbol	Base Material	Thickness of Base Material, nominal, in.	Coating	Estimated Thickness of Coating, in.	Flame Spread Factor, F_s avg	Heat Evolution Factor, Q avg	Mean Flame Spread Index	Coefficient of Variation per cent
3j	Softboard	1/2	Pigmented nitro-cellulose lacquer	.003	58.9	18.4	1090	17.6
6a	Plywood, coachwood veneer	3/16	Varnish	.003	20.6	36.0	538	36.4
1a	Softboard	1/2	None	-	17.2	12.9	220	9.4
1d	Hardboard	3/16	None	-	4.68	42.2	198	8.4
2h	Hardboard	3/16	Water paint, alkyd-resin, casein-bound	.004	3.66	35.4	130	11.6
2d	Hardboard	3/16	Oil paint, exterior gloss	.005	3.86	33.8	130	12.0
1o	Chipboard	3/8	None	-	5.35	23.2	130	16.8
1q	Hardboard 4	1/2	Paper	.004	5.07	18.9	96	17.3
3b	Softboard	1/2	Oil modified alkyd resin paint, interior flat	.004	8.59	9.2	78	15.1
2e	Hardboard	3/16	Polyvinyl acetate latex-water emulsion	.004	3.04	25.2	77	12.2
4p	Hardboard	3/16	Intumescent starch-bound water paint, urea-formaldehyde plus overcoat finish 3b minus sealer and undercoat	.008	2.33	24.3	57	23.9
4o	Hardboard	3/16	Intumescent starch-bound water paint, urea-formaldehyde plus overcoat finish 3b minus sealer	.008	1.90	14.5	28	46.8
9a	Softboard	1/2	Fire-retardant paint, semi-gloss	.005	6.55	3.91	25	13.6
7c	Plywood, coachwood veneer	3/16	Mono-ammonium phosphate impregnation plus clear high-gloss lacquer	.002	5.06	2.70	14	58.6
31	Softboard	1/2	Water paint, alkyd-resin casein-bound with glue size sealer	.006	6.96	1.4	5.1	51.9
7a	Plywood, coachwood veneer	3/16	Mono-ammonium phosphate impregnation	-	1.00	2.53	2.6	94.2
9b	Softboard	1/2	Intumescent starch-bound water paint, urea-formaldehyde plus overcoat of casein-bound water paint type 3	.010	1.00	0.63	0.6	133.
5j	Softboard	1/2	Intumescent starch-bound water paint, urea-formaldehyde plus overcoat of casein-bound water paint type 4	.010	1.09	0.29	0.3	133.

exterior-grade Douglas-fir plywood as well as on an uncoated plywood control panel, The results are tabulated in Table 2. The finishes were applied by brush (or trowel) in accordance with normal procedures and specifications and with the usual variations in paint loadings obtained in practice.

Although all the flame-retardant systems tested (C through J) gave a decidedly lower flame-spread index than the conventional two-coat paint finish (B), the application of two coats of an intumescent interior fire-retardant paint (C) was particularly effective. It was considerably more effective than a two-coat application of exterior fire-retardant paint (D). The results for systems E and G indicate a relationship between the protection provided and the thickness of coating for this type of system and up to the thickness tested.

Australian Building Boards[6]: A number of coated and uncoated building boards were made available by the Australian Commonwealth Experimental Building Station in connection with a comprehensive study they performed on the fire hazards of combustible building boards and methods for their evaluation. A variety of conventional and fire-retardant coatings were applied in the conventional manner, that is, with the usual application of priming coats or undercoats and in a tradesman-like fashion so as to be representative of field application. The results are shown in Table 3. It may be seen that the flame-spread indices of the conventional paint coatings were generally lower than those of the uncoated building boards. These differences were more pronounced when the paint coatings were applied to the softboards than to the hardboards. However, boards with varnish and nitrocellulose lacquer coatings yielded higher flame-spread indices than did the uncoated building boards. The intumescent water paint and the impregnated mono-ammonium phosphate finishes were particularly effective, and resulted in considerably lower flame-spread indices although the application of overcoats to intumescent water paints generally reduced the efficiency of the retardant.

Attempts to correlate the radiant-panel test results with the Australian "spread of flame index" or "index of early fire hazard" on these materials were only moderately successful. Consideration should be given to the fact that the specimens tested at NBS were prepared subsequent to the tests in Australia, and that different specimen conditioning procedures were used. The importance of conditioning and careful control of the moisture content has been indicated previously.

Discussion

In the evaluation of the flame-spread properties of finish materials, consideration should be given to the following: Is the test finish representative of the finish in field applications? Are there variations in the composition, orientation, and density of the finish and substrate materials? What effect will moisture content have?

The results of the limited tests reported here have shown that variations in moisture content and mean density can have significant effects upon the results of surface flame-spread measurements on untreated material. It was also observed that variations due to the surface grain orientation and distribution in wood materials such as red oak can be quite appreciable. The use of wood as a standard for comparative flame-spread measurements would appear to involve close specifications of its type, density and moisture content, of the distribution and orientation of annual growth rings, of the type of sawed lumber (that is plainsawed or quartersawed) and so forth.

The importance of standardization of the test procedure and of assessing the magnitude of such variables has been shown. Careful evaluation is particularly necessary in the case of fire-retardant finishes. Since these are not always acceptable decorative finishes. overcoating with conventional paint finishes is frequently desirable. Some fire-retardant paints may cause breakdowns of the superimposed finishes. In addition, considerable variation in flame—spread properties is possible with intumescent water paints because they are adversely affected by atmospheric conditions, and they may deteriorate with age.

In the application of fire-retardants to wood, the most important aspect from the point of view of fire spread is the ability of the treatment to retard the development and spread of flame. Previous work[5] has indicated that the surface spread of flame is controlled primarily by the surface layer or coating up to a thickness of about 50 mils. Resistance to glow, afterglow, or smoldering combustion such as might be imparted by deep impregnation, is here considered of secondary importance. It should not be discounted, however, in its ability to retard the later growth of fire.

In a recent survey of wood combustion theories, Browne[7] concludes that no single theory completely describes the mechanism of the fire-retardance of wood. Theories based upon the maintenance of a surface coating bar-

[6] Ferris, J. E. 1955. Fire hazards of combustible wallboards. Special Report No. 18. Commonwealth Experimental Building Station, Department of Works, Sydney, Australia. D. V. Isaacs, Director of the Station, provided the specimens of typical Australian finish materials.

[7] Browne, F. L. 1958. Theories of the combustion of wood and its control. Forest Products Laboratory, Forest Service, U. S. Department of Agriculture. Report No. 2136.

rier and on chemical effects appear to be the most reasonable, however. The fact that ordinary oil paints, which are applied in comparatively small amounts to the wood surface, are somewhat effective indicates that the maintenance of an impermeable surface coating is important. On the other hand, the fact that many highly effective fire retardants are water-soluble suggests the operation of chemical rather than physical mechanisms for these materials. To date, the most effective fire retardants appear to be water-soluble paints that intumesce strongly, and produce a thick, relatively stable foam that provides an insulating surface barrier.

Summary

It has been determined by use of the radiant-panel flame-spread test method that variations in moisture content and mean density can cause appreciable differences in the flame-spread test results of the same material. For the same mean density and moisture content, it was observed that variations in the surface grain structure of untreated wood had an appreciable effect upon the flame-spread index. The importance of careful selection, specification, and conditioning of test material under well-standardized conditions has been demonstrated.

The test method has been used to evaluate a number of fire-retardant coatings applied to wood-base materials. The flame-spread indices of the fire-retardant-coated assemblies were considerably lower than those obtained with uncoated or conventionally coated materials, although significant differences between coated assemblies were observed. Water-soluble paints that intumesce strongly to produce a thick, surface-barrier foam are particularly effective fire-retardants, although there appear to be some drawbacks to their practical use.

A test method such as this can be used to advantage for the development and evaluation of effective and practical fire-retardant coatings for wood-base materials.