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SURFACE FLAMMABILITY MEASUREMENTS BY THE RADIANT-PANEL METHOD

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Synopsis

The flammability of solids may be considered as a function of the ratio of heat release rate to critical ignition energy of the material being studied. The radiant-panel flammability test method, based on this concept, has shown its usefulness as a research tool. A review of previous studies made by this method is included.

Recently obtained experimental data are presented which illustrate the large changes in flammability that can occur with changes in the relative humidity of the ambient conditioning atmosphere. Data presented suggest that the subsurface heat-dissipation behavior of the material under test may have an important influence on flammability.

The paper concludes with the suggestion that, although the radiant-panel flammability test method has achieved some recognition, it would be a mistake to assume that it, or any other test method, would be ideal for prediction of the surface flammability hazard of all materials in all situations.

About ten years ago it became increasingly clear that, with the adoption by the ASTM of the tunnel flammability fire test method,[2] manufacturers and the technical public would have ever-increasing need for a simpler laboratory scale method of measuring the surface flammability of materials. The radiant-panel flame-spread test method was developed to meet this need. Perhaps one measure of its success in satisfying the demand for such a measurement method is the degree to which it has been used. There are 20 existing installations of the equipment and at least an equal number are currently being installed. This paper is intended to present a brief review of the research findings that influenced development of the method. It will also serve to review some of the experimental data resulting from its use.

Radiant-Panel Method

The radient-panel test method[3] was developed with the specific objective of providing a relatively simple and reproducible method of measuring the surface flammability of solids. It was expected that if such a test method could be provided it would be widely used for research and for quality-control purposes during manufacture of building finish materials. It was not originally intended

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[1] Chief, Fire Research Section, National Bureau of Standards, Washington, D. C.

[2] Method of Test for Surface Burning Characteristics of Building Materials (E 84), 1961 Book of ASTM Standards, Part 5.

[3] Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source (E 162), 1962 Supplement to Book of ASTM Standards, Parts 5, 9, and 11; see also "Flame-Spread Properties of Materials," Interim Federal Standard 00136a, June, 1961.

to replace other methods of test, although in some situations this may become desirable.

The 1954 edition of the *NFPA Handbook of Fire Protection* defines a flammable material as one which is "easily ignited and burns with unusual rapidity." Simple analytical reasoning suggests that two factors should be of great importance in characterizing flammability: (1) flammability must be an inverse function of the critical ignition energy of the material in question, and (2) it must be directly related to the rate of heat liberation after ignition. This point is shown diagrammatically in Fig. 1.

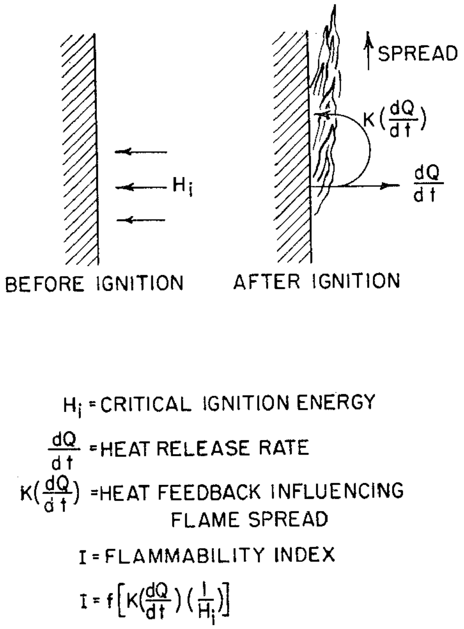
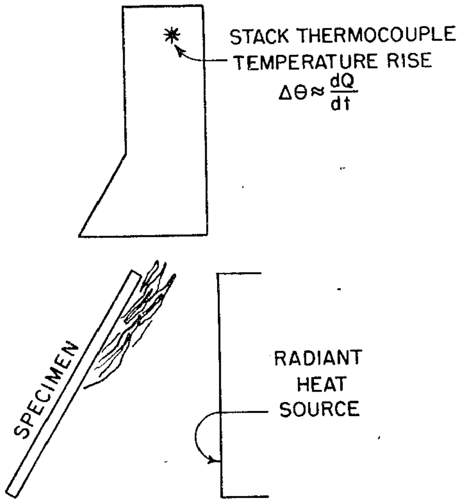


FIG. 1.—Heat Balance Influencing Flammability Measurements.

The radiant-panel test method permits separate measurement of these two properties during a single test. Figure 2 illustrates in diagrammatic fashion how this is done. A radiant heat source operates with a controlled heat-flux rate at its surface similar to that of a blackbody at a temperature of 1238 F (670 C). The specimen being tested is mounted in a standardized position to face the panel but inclined at a 30 deg angle to it in such a manner that the upper portions are most severely exposed. The stack and the associated thermocouples placed above the specimen serve as a heat-flux meter for measuring the rate of heat release.



Since irradiance varies along length of specimen, the time progress of ignition serves to measure critical ignition energy, H_i.

FIG. 2.—Diagrammatic Drawing of Radiant-Panel Test Method.

The time of arrival of the flame front at 3-in. positions along the length of the specimen during exposure to the prescribed incident heat flux serves as a measure of the critical ignition energy of the material. Figure 3 shows the form the test equipment assumes. In use, measurements are made of the position of the flame front on the exposed surface of the specimen as a function of time, and the maximum temperature rise of the stack thermocouples. These two measurements are combined to give the flame-spread index, I_s.

Some discussion of the reasons for adoption of the type of index used may be desirable. As suggested previously, it was assumed that any useful index should be directly related to the rate of heat release of the burning material and inversely related to the critical heat for ignition. The test is actually performed in such a manner that a whole series of these measurements is made. The time progress of the flame front during exposure to the prescribed irradiance serves as a measure of the way in which the critical heat required for ignition varies along the specimen length. Similarly, the temperature-time curve of the stack thermocouples serves to characterize the heat-release behavior of the specimen.

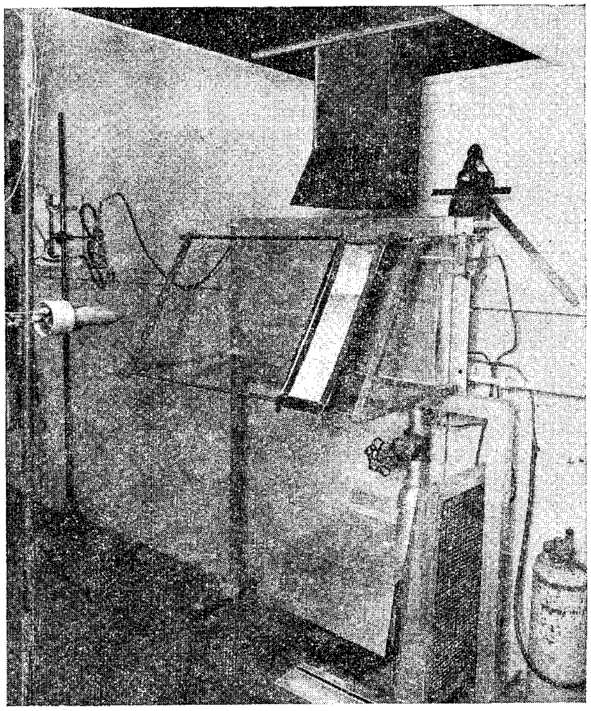


FIG. 3.—Equipment Used for Radiant-Panel Flammability Test Method.

Since the flammable behavior of materials during practical use will be largely influenced by size, geometry, orientation, and other parameters, it appeared unprofitable to attempt to determine the magnitude and character of the feedback factor K in Fig. 1. It seemed necessary, therefore, to express the flammability in the form of an empirical index rather than a uniquely characterized property of the material. This decision eliminated the need for strict dimensional conformance. The index first used was:

$$I = \Delta\theta \left[0.1 + \frac{10}{t_3} + \frac{100}{t_{12}} \right]$$

where $\Delta\theta$ was the maximum stack thermocouple temperature rise in deg Celsius above the maximum experienced when an asbestos cement board was exposed as a test specimen, and t_3 and t_{12} were the times, in seconds, after exposure for arrival of the flame front at distances of 3 and 12 in. from the upper end of the specimen, respectively. Thus the resulting index was obtained by multiplying a factor representing the maximum heat release rate by an ignition factor comprising essentially the sum of two factors, $10/t_3$ and $100/t_{12}$, representing the reciprocal of the critical ignition energies of the specimen at 3 and 12 in. along its length. The constant 0.1 was included to avoid assignment of an index of zero to specimens which released significant quantities of heat but did not show flame spread to the 3-in. mark. This index appeared to provide a means of ranking many materials in order of relative flammability. It will be observed, however, that large differences in indexes might result depending on whether the flame just reached or failed to reach the 12-in. position. Because of the evident need to provide a more discriminating assessment of flame propagation as well as a more direct measurement of the maximum rate of heat release, a new index was defined (**1**)[4] as:

$$I_s = \frac{0.1\Delta\theta}{\beta}\left[1 + \frac{1}{t_3} + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}\right]$$

where $\Delta\theta$ is the maximum stack thermocouple temperature rise above the maximum experienced when an asbestos cement board was exposed as a test specimen; the symbols $t_3 \cdots t_{15}$ correspond to the times in minutes from specimen exposure until arrival of the flame front at a position $3 \cdots 15$ in., respectively, along the length of the specimen; and β is a calibration constant for the stack and thermocouple assembly (**1**) obtained by the substitution of an auxiliary calibrating burner for the flammable specimen.

This is the current form of the index recommended for flammability classifications. As before, it results from the product of a heat generation term, Q, involving the ratio $\Delta\theta/\beta$ and an ignition sensitivity term, F_s, included within brackets. This latter provides a constant to penalize those materials producing heat but little or no flaming, a factor determined by measuring the critical heat for ignition (the term $1/t_3$), and a series of terms to characterize the manner in which flame propagation occurred. The proportionality constant 0.1 used was selected to provide some measure of agreement between the resulting index and that derived from the ASTM tunnel test method E 84.[2] It should be noted that the experimental equipment is calibrated in terms of heat-flux measurements rather than continual use of a reference material such as red oak.

The interest of building and code officials in the flammable behavior of interior finishes results primarily from the need for some measure of the hazard to life presented in the early stages of a building fire. However, our present understanding of the relative emphasis that should be placed on the properties measured (maximum heat generation rate and critical ignition energy) is not adequate to dictate a uniquely appropriate method for defining flammability. In spite of this uncertainty, our experience to date with the method indicates that there is a general consistency between the flame-spread index and the flammable behavior of materials during fires. Additionally, the method provides the distinct advantage of permitting future alternative combinations of the properties measured, without the necessity of retesting all materials previously studied.

The classifications resulting from use of the tunnel and radiant-panel methods should not be expected to be identical, but they are, we believe, sufficiently simi-

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper.

lar that, for many materials, the use of one method provides a good indication of the classification likely to be achieved when the other method is applied. While only limited data are available to justify it, Fig. 4 indicates the general form of the correlation between the radiant panel test method and both the ASTM E 84 tunnel and the 8-ft tunnel method (2) developed by the Forest Products Laboratory. The three methods should be expected to yield somewhat similar results over the range of flame-spread indices of about 10 to 150. Above and below this range there may be quite marked differences. As an example, there appears to be no evidence that highly flammable materials tested by the 8-ft tunnel method can show classifications above 180.

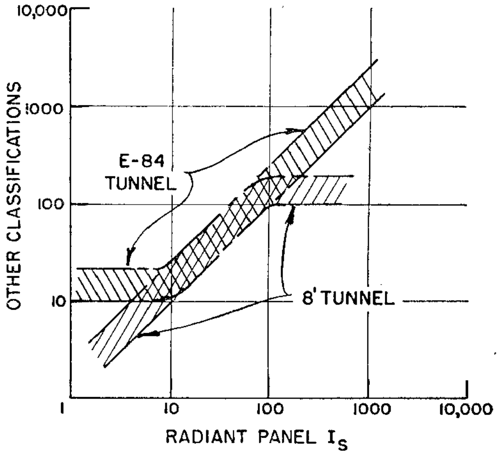


FIG. 4.—General Form of Correlation Which Appears to Exist Between Radiant-Panel and Tunnel Flammability Tests.

TABLE I.—INFLUENCE OF SURFACE TREATMENT IN REDUCING FLAMMABILITY OF CELLULOSE FIBERBOARD.[a]

	Surface Treatment of Unfinished Fiberboard	Flame-Spread Index, I_s
Specimen 8	unfinished	236
Specimen 13	alkyd paint 250 sq ft per gal	107
Specimen 9	factory finish (class D)	83
Specimen 12	fire-retardant paint 250 sq ft per gal	59
Specimen 11	same as specimen 12 but at 125 sq ft per gal	27
Specimen 14	oxychloride cement spray applied 32 sq ft per gal	3.4
Specimen 15	oxychloride cement trowel applied 13 sq ft per gal	1.2

[a] Data from Table II of reference (1).

PREVIOUS RESEARCH

The following brief review of some of the studies that have been performed by use of the radiant-panel method may be useful. The first of these was made in connection with development of the method (1). A group of finish materials was studied which, on the basis of information from other sources, would be expected to show a wide range of flammabilities. Actually, the results showed flame-spread index data over the range of 0.6 to 336 for materials varying from fiber glass formboard to unfinished cane fiber insulation board, respectively. As a part of this study, a cellulose fiberboard insulation material was tested in unfinished form, and also after application of a variety of finishes, with the results shown in Table I. It will be observed that the surface finish treatment has a profound effect on flammability.

A second study (3) presents a very comprehensive investigation of the influence of 23 different surface finish treatments in modifying the flammability of three different base materials—exterior grade ¼-in. Douglas fir plywood, ½-in. factory-finished (class D) fiberboard, and ⅜-in. gypsum wallboard. This investigation, besides supplying one of the most complete lists currently available of the influence of different finishes on wall boards, provided an interesting indication of the importance of surface finish thickness in determining resulting flammability. Figure 5 (reproduced from Fig. 3 of reference (3)) shows the ratio of flammability of the finishes studied as applied to fiberboard and gypsum board base materials. It is evident that as long as

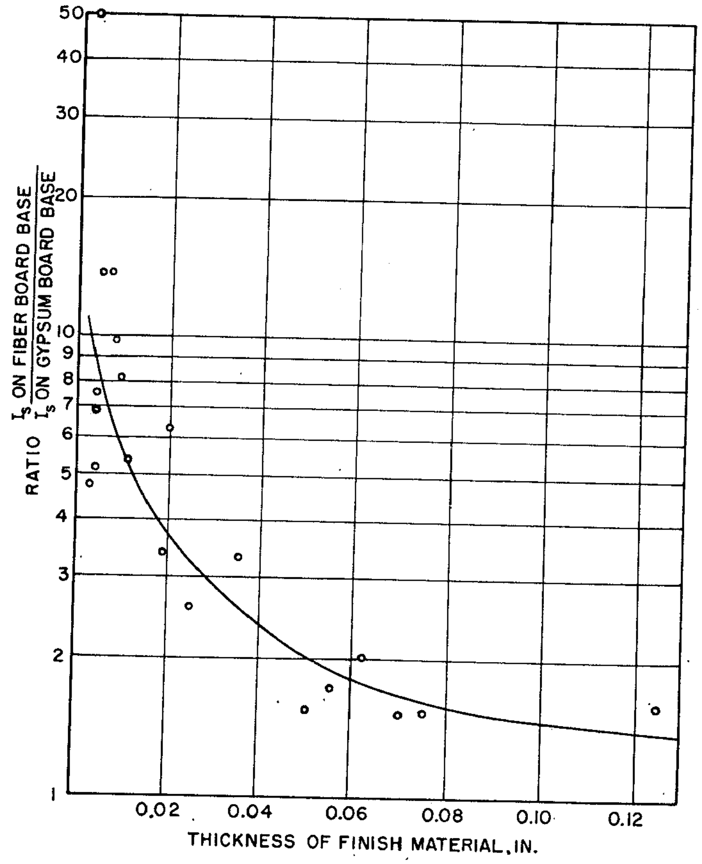


FIG. 5.—Influence of Coating Thickness on Flammability of Assembly.

this ratio differs greatly from unity the behavior of the base material significantly influences the flammability of the assembly. Inspection of this figure shows that this ratio drops to 2 for finish thicknesses of about 0.05 in. and to about $1\frac{1}{2}$ for thicknesses of about 0.10 in. It is apparent, therefore, that for surface finishes of greater than about 0.10-in. thickness, the flammability measured by the method is largely influenced by the finish applied, provided delamination during fire exposure is not a problem. There are some exceptions to this generalization that are experienced during use of both this and other test methods. As an example, the use of a highly reflective 0.003-in. aluminum foil bonded to exterior type Douglas fir plywood can result in surfaces of unusually low flammability.

This same paper (**3**) reports flammability data for twelve different plastic films, laminates, or panels. This study was performed at the request of ASTM Committee D-20 on Plastics, and the results indicate flame-spread indices varying from 2 for a fire-retardant treated tile to over 300 for polystyrene and acrylic sheet materials.

Recently a study was made for the Society of Plastics Industries of the behavior of cellular foamed plastics when tested by this method. Typical results are tabulated in Table II. It is evident that the effectiveness of fire-retardant treatments can vary widely. It also ap-

TABLE II.—SOME RESULTS OF FLAMMABILITY TESTS OF FOAMED PLASTICS.
All were of nominal 2 lb per cu ft density

	Material	Flame-Spread Index, I_s
Number 3	flexible polyether urethane (FR)[a]	10
Number 8	polystyrene (FR)	13
Number 7	polystyrene	114
Number 6	rigid polyether urethane (FR)	880
Number 1	flexible polyester urethane (FR)	1000
Number 2	flexible polyester urethane	1490
Number 5	rigid polyether urethane	2220

[a] The term FR denotes the incorporation of fire-retardant chemicals or treatments.

TABLE III.—FLAMMABILITY OF HARDBOARD PANELS COATED WITH CONVENTIONAL AND FIRE-RETARDANT PAINTS.

Coating	Description	Spreading[a] Rate, sq ft per gal	Flame-Spread Index, I_s
...	uncoated hardboard substrate	none	150
Number 3	flat alkyd wall paint	125	28
Number 6	styrene-butadiene (latex) emulsion wall paint	125	42
Number 8	flat alkyd wall paint	125	28
Number 1	fire-retardant paint C	125	29
Number 2	fire-retardant paint conforming with TT-P-26a	125	75
Number 4	fire-retardant paint B	125	37
Number 5	fire-retardant paint D	125	33
Number 7b	fire-retardant paint A	206	6

[a] Paint was applied in two coats, at 250 sq ft per gal each, to a substrate primed at a spreading rate of 450 sq ft per gal. Paint 7b involved application of two different paints to the primed substrate, the first at 350 sq ft per gal and the second at 500 sq ft per gal.

pears that the flammability of the untreated polyurethane materials may exceed that of the polystyrenes by a factor of ten or more. These very high flammabilities of low-density untreated polyurethane materials have also been observed in some tests by the ASTM tunnel method E 84 (4).

Studies have also been made of the effectiveness of fire-retardant and conventional paints in reducing the flammability of wall panels (5). In performing this study, with one exception all paints were applied at the same spreading rate, two coats at 250 sq ft per gal per coat or an effective spreading rate of 125 sq ft per gal. This application rate was selected as being representative of rates frequently recommended for fire-retardant paints. However, the results seem to indicate that conventional latex or alkyd-base paints, when applied at the spreading rates recommended for listed fire-retardant coatings, are of comparable effectiveness to many of the fire-retardant coatings in reducing surface flammability of the hardboard finish panel. A summary of some of the results obtained is shown in Table III. This finding is not too surprising when it is noted that the performance requirements of Underwriters' Laboratories for listing paints as fire retardant are simply that they reduce the flammability of the substrate by at least 30 per cent and that the reduced flammability result in a flame-spread classification of not more than 70.

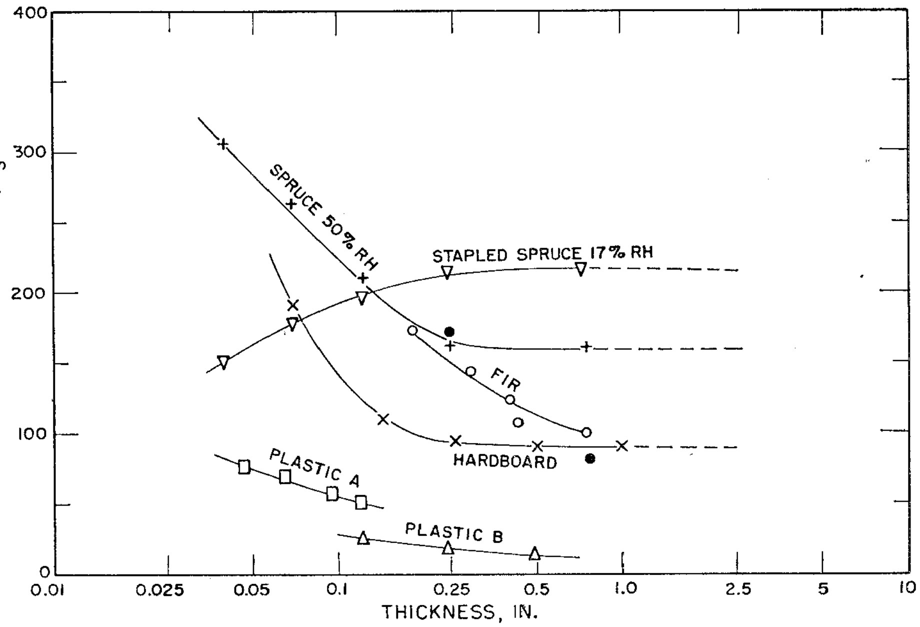


FIG. 6.—Influence of Specimen Thickness on Flammability of Several Materials.

Further work reported by Gross and Loftus (5) showed that the flammability of hardboard panels was not a sensitive function of paint spreading rate over the range of 125 sq ft per gal to 30 sq ft per gal, corresponding to a thickness range of 4 to 18 mils, for both a flat alkyd and a latex-base paint.

RECENT FINDINGS

Shortly after the initial development of the test method, some studies were performed to determine the minimum specimen thickness for which the flame-spread index would not differ greatly from that of thicker specimens. The conclusion reached was that this minimum thickness was, for a number of woods, on the order of $\frac{1}{4}$ in. However, it has recently been observed that the flame-spread index of $\frac{1}{4}$-in. Douglas fir plywood was about twice that for $\frac{3}{4}$-in. solid Douglas fir boards. Consideration of this behavior suggests the possibility that it might result from differences in the manner of heat absorption and distribution within the two forms of the wood. These observations have prompted further review of the influence of specimen thickness on flammability.

Figure 6 presents some flame-spread index data as a function of specimen thickness for a variety of materials. With the exception of the data marked "stapled spruce," for which the specimens were stapled to an asbestos millboard backing, all results on woods were obtained by application of the standard test procedure in which the specimens are backed but not fastened or cemented to asbestos millboard. The data for plastic A developed at the National Bureau of Standards were obtained in a similar manner but with the use of an intermediate sheet of aluminum foil between specimen and backing. No details of specimen mounting were reported in reference (6) from which the data for plastic B were obtained. The data for spruce plotted in this figure represent averages of four determinations. The remainder represent averages of less than the four determinations required by the standard procedure.

In general, the data presented support the original observation that the flame-spread index is relatively independent of thickness for specimens thicker than $\frac{1}{4}$ in. This behavior does not appear to hold, however, for the data on Douglas fir. Both the open-circled data for solid fir and the closed circles representing previously published data for fir plywood and $\frac{3}{4}$-in. solid fir indicate that the behavior of this material differs in some manner from that of the other more homogeneous materials. As yet, we are uncertain about the reason for the greater sensitivity of the flame-spread index of fir as thickness is varied in the range of $\frac{1}{4}$ to 1 in. We believe, however, that it is associated with the very wide variation in density, and thus the thermal properties, of the annual rings.

The data for spruce indicate that the rising flammability with decreasing specimen thickness resulted from an increase of the F_s term as specimen thickness was reduced. During test of these specimens it was observed that they showed a tendency to bow outward, losing contact with the backing material. Accordingly, another series of specimens was prepared and those less than $\frac{1}{4}$ in. thick were stapled to the backing material. These were tested after conditioning at 17 instead of 50 per cent relative humidity. The downward trend of I_s, as specimen thickness was reduced, resulted primarily from a reduction of Q, the F_s factor remaining essentially constant. The higher flame-spread index of the stapled spruce for thicknesses greater than $\frac{1}{4}$ in. was due to its lower moisture content.

These results indicate the importance of both the specimen thickness and the character of the thermal contact with the backing material. They also suggest that the heat capacity and thermal conductivity of the backing material for thin specimens has a significant influence on the flammability.

Some studies have recently been made of the influence of the relative humidity of the atmosphere in which the specimens

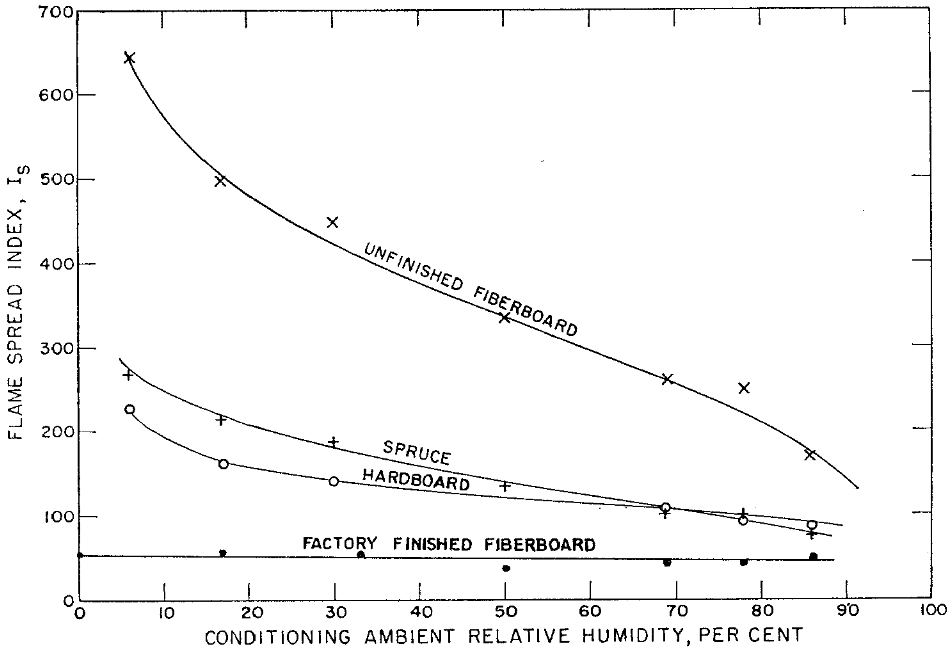
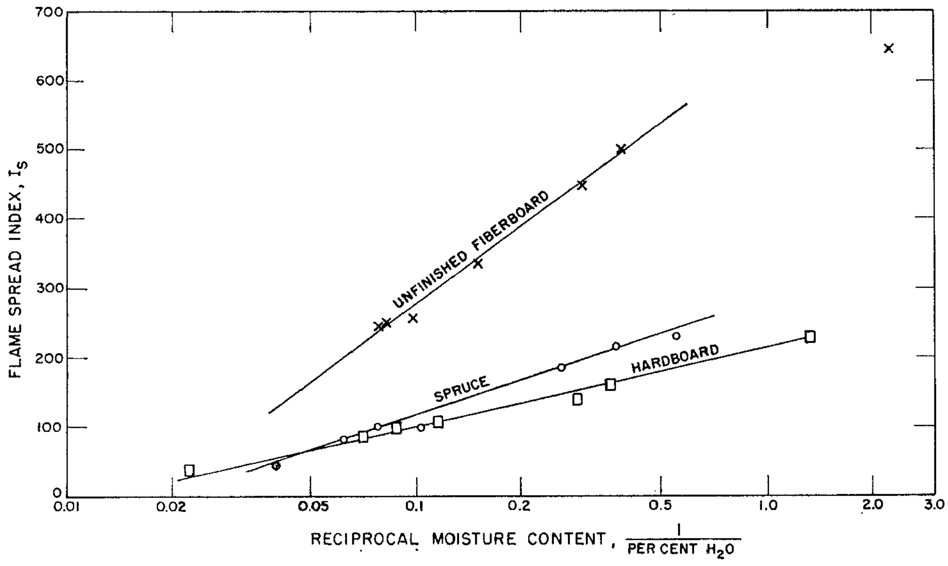


FIG. 7.—Influence of Relative Humidity of the Ambient Atmosphere During Conditioning of Specimen on Flammability of Several Woods.



Moisture contents are based on oven-dry weight basis.

FIG. 8.—Flame-Spread Index as a Function of Reciprocal Moisture Content of Several Woods

were conditioned on the flammability. The results are presented in Fig. 7 for three unfinished and one finished material. The data marked unfinished fiberboard, in this figure, were obtained during test of building board specimens from which the finish had been removed. The curves for the unfinished materials are of such a form as to suggest that flammability is an inverse power function of the moisture content of the specimen on an oven-dry weight basis. The extent to which this is true may be observed in Fig. 8 where semilogarithmic plots of the data are presented as a function of the reciprocal of specimen moisture content.

The data in Fig. 7 marked factory finished fiberboard were obtained during test of a building board reported as complying with class F by Commercial Standard CS-42-49 (ASTM Specification C 208[5]). It is evident that a good finish can both significantly reduce the flammability and also almost eliminate the influence of moisture on flammability of this fiberboard material.

Although data similar to those of Fig. 7 are not currently available for plastic materials, it appears very likely that in their nonhygroscopic forms they will not exhibit any significant variations in flammability after conditioning over the full ambient relative humidity range. It would be of interest to explore this possibility as well as the extent to which surface coatings of other types can be effective in reducing flammability variations resulting from changes in relative humidity of the atmosphere in which cellulosic materials are conditioned.

SUMMARY

In conclusion, it seems fair to suggest that use of the radiant-panel flammability test method has provided a considerable increase in our understanding of the flammable behavior of solids. There still remains, however, much research to be done on this property of materials. In addition to fundamental research in connection with clarification of the physical and chemical mechanisms of fire spread in solid fuels, there still exists the real need to conduct a carefully planned research study of the pertinence of the flammability classification systems currently being used to the hazard presented by use of flammable building finish materials during actual building fires. It seems premature, prior to the conduct of an inclusive research study of this type, to assume that this or other flammability measurement methods are capable of classifying the flammability of materials in a fashion directly related to the hazard presented during their exposure in an actual building fire. It also seems desirable to point out that it is unlikely that any flammability test method is uniquely qualified for prediction of the surface flammability hazard of all materials in all situations.

Acknowledgment:

It is desirable that credit be given J. J. Loftus and D. Gross who were primarily concerned with securing and interpreting the data reported.

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[5] Specifications for Structural Insulating Board Made from Vegetable Fibers (C 208), 1961 Book of ASTM Standards, Part 5.

face Flammability," ASTM BULLETIN, No. 230, May 1958, p. 61.
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(6) S. S. Feuer and A. F. Torres, "Flame Resistance Testing of Plastics," *Chemical Engineering*, April 2, 1962, p. 138.

DISCUSSION

MR. DAVID COUNTRYMAN.[1]—Were tests of plywood from material matched with the finished lumber? Was it exterior type? What was the moisture content?

MR. A. F. ROBERTSON (*author*).—In the case of plywood, we used "Exterior" grade $\frac{1}{4}$-in. material. The other fir data represented by open circles in Fig. 6 of the paper were obtained with the use of solid fir. These specimens were prepared by taking slices of varying thickness from a single fir plank. All the fir specimens mentioned were conditioned in air at 50 per cent relative humidity.

MR. E. J. REICHMAN.[2]—Has consideration been given to using an arithmetic scale in place of the present one that is used with the radiant panel? The values obtained by the present method of computing surface flammability result in relationships that are somewhat logarithmic. An empirical relationship was derived to equate radiant panel data to a value of 100 for materials such as red oak, which form the basis of the rating for the 25-ft tunnel. Materials with a low rate of surface flammability have values less than 10 by the radiant panel computation. This is appreciably lower in most cases than the same material would yield if tested under the 25-ft tunnel. A conversion to an arithmetic scale would bring the values into line for the range of values obtained by the tunnel method.

MR. ROBERTSON.—I believe it would be possible to modify the character of the flame-spread classification scale. The possibility of doing this at a later time, when we have achieved a better understanding of the relationship between flammability hazard and classification, is one of the attractive features of this method. We believe that if this becomes desirable, we can accomplish it by the simple process of combining the measured properties by use of a different flame-spread index formula. With respect to the "logarithmic" character of the classification scale, we are not prepared to say just now whether we consider the flame-spread index scale more appropriate than that achieved by the E 84[3] classification method. We do not want to make a change until there is good technical justification for it.

MR. J. R. ALLEN[4] (*presented in written form*).—We agree with the author's conclusion that there is no single ideal test method for predicting the surface flammability hazard of all materials in all situations. However, there is a vital need for a relatively simple and small-scale laboratory test method for measuring surface flammability. Such a procedure can play an important role in the study of unclassified materials and the development of new products.

We installed radiant panel test equipment over four years ago, and it has been used very extensively. In correlating results with other methods of test, we have experienced both agreement and

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[1] Douglas Fir Plywood Assn., Tacoma, Wash.

[2] Simpson Timber Co., Seattle, Wash.

[3] Method of Test for Surface Burning Characteristics of Building Materials (E 84–61), 1961 Book of ASTM Standards, Part 5, p. 1178.

[4] Engineering Service Division, E. I. duPont deNemours & Co., Wilmington, Del.

disagreement. The need for absolute conformance with prescribed details of construction, calibration, and operation should be emphasized. In review of the test method, it may be of interest for the author to explain the reasons for selecting a radiant panel temperature of 670 C. Also, as a result of our experience, we suggest that a method be considered to avoid assignment of an index of zero to specimens that show significant flame spread, but do not release sufficient heat to be measured by the subject apparatus.

Data presented in this paper, and confirmed by our experience, illustrate the necessity for an accurate description of the material or combination of materials that constitute the specimen.

The radiant panel method for measuring surface flammability has been a valuable tool in our work as both a consumer and producer of materials. Mr. Robertson and his group are to be complimented on their fine work in expanding our knowledge in this field. We concur that further research is needed to establish the relationship between fire hazard or flammability test results and the hazard presented in an actual fire.

MR. W. P. ELLIS[5] *(presented in written form)*.—Our laboratory would agree with the author's observation that the radiant panel method is satisfying the demand for a convenient yet significant method meeting research requirements for evaluating surface spread of flame. We have been operating the radiant panel apparatus for more than four years. During this period the apparatus has been in frequent use for the measurement and comparison of the surface spread of flame on organic coatings of many types and over varied substrates. The availability of this method has facilitated real progress in the investigation and development of fire-resistive coating materials.

A criticism sometimes heard of the radiant panel method is that the fire intensity developed in such a small-scale method cannot approach that obtained in larger apparatus and therefore the results cannot be representative of phenomena occurring during actual building fires. No data have been presented in support of this opinion.

The design and operation of the radiant panel method permit more precise observation of flame front progress than in other methods. Both the tunnel method and the radiant panel method are designed to measure only surface spread of flame. Other methods which involve combustion of the substrate cannot isolate the surface flammability effect and accordingly do not lend themselves to scientific study of flame spread.

On the subject of correlation between the radiant panel test method and the ASTM E 84 tunnel method, the relationship has been reasonably well established for cellulosic materials. We believe, however, that for other organic solids the relationship between the two methods is of a different order. In a brief series of tests in which identical coating materials were evaluated for surface spread of flame by both methods, we found indication that the same phenomena of combustion are not being measured in each case. In our opinion a lengthy program of cross-checking will be needed to establish the order of correlation between the methods for a variety of building materials.

In the course of our work with the radiant panel method we have compared the effect of thermal conductivity and heat capacity of different materials under organic coatings on the flame spread of the assembly. The materials used ranged from high-density asbestos-cement board to low-density, low-conductivity thermal insulating materials such as fibrous glass and foamed plastics. Coated thermal insulating materials

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[5] Benjamin Foster Co., Philadelphia, Pa.

generally showed higher flame-spread index values than did incombustible substrates of relatively higher thermal conductivity.

We strongly endorse the author's closing statement emphasizing the need for further research into the relationship between flammability classification systems based on present test methods and the actual hazard presented during field fire exposures. Only through better understanding of the chemical and physical factors involved in surface spread of flame can manufacturers improve materials, resulting in improved fire safety.

MR. ROBERTSON.—We appreciate the remarks made by Messrs. Allen and Ellis. It is always a pleasure to learn that one's work is considered useful.

The safe operating temperature of the radiant panel is specified by the manufacturer to be limited to 850 C. When we first set up our equipment, we decided to keep the surface temperature of the unit below 800 C; this is roughly the maximum surface temperature at which the units are currently operating. However, because of the limited emissivity of the refractory surface the radiant output of the panel was found to correspond to that of a blackbody source operating at 670 C. Considerable preliminary work was carried out with the equipment operating at this level. In standardizing the test procedure, there appeared to be little basis, other than that of rounding off the number, for selecting another value.

The recently adopted revision of ASTM Method E 136[6] contains an improved procedure for classification of materials that do show flame spread but at the same time liberate very little heat. The methods of doing this may not satisfy all needs but they are a considerable improvement over those previously used.

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[6] Method of Test for Determining Noncombustibility of Elementary Materials (E 136 – 59 T), 1961 Book of ASTM Standards, Part 5, p. 1147.