Flame Spread Properties of Building Finish Materials

By DANIEL GROSS and JOSEPH J. LOFTUS

In the specification of materials for the interior finish of buildings and other structures, the flame-spread behavior of the material may be as important as strength, ease of application, appearance, durability, or other qualities. The previous lack of a simple and relatively inexpensive method of evaluation has delayed the comprehensive study of this fire characteristic of materials. Completion of the development of the radiant panel flame spread test method[1] at the National Bureau of Standards has now made this study possible. Data have been obtained on a wide variety of interior wall finishes applied to several common wall base materials, as well as on other interior and exterior lining materials. The numerical index appears to classify materials in an order generally consistent with information currently available on their behavior during fires. Additional data obtained from full scale and model testing are required to determine the relationship between the radiant panel flame-spread index of a material and the actual fire hazard involved with a structure lined with this material.

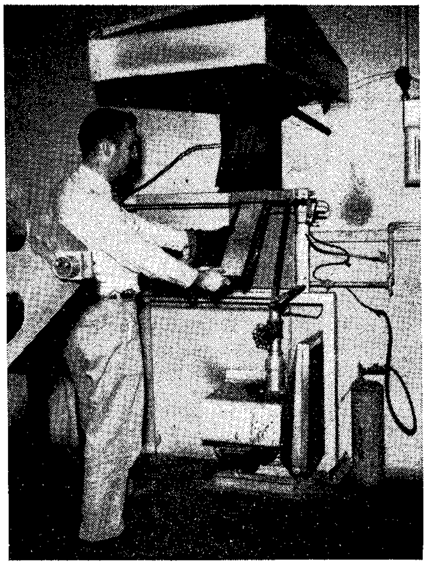


Fig. 1.—Radiant panel test apparatus.

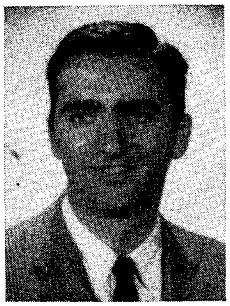
Method of Test

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

Briefly, the radiant panel consists of a cast iron frame enclosing a 12 by 18-in. 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, providing 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 combustion and smoke.

The test specimen, measuring 6 by 18 in., was placed in a metal holder and backed up with a $\frac{1}{2}$-in. sheet of asbestos

DANIEL GROSS has concentrated on ignition and flame-spread phenomena since joining the Fire Protection Section of the National Bureau of Standards in 1950. During the past three years, he worked on the development and application of the radiant panel test method for flame-spread evaluation.



JOSEPH J. LOFTUS since joining the Fire Protection Section of the National Bureau of Standards in 1954 has focused his attention on a test method designed to evaluate the flame spread characteristics of materials.

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[1] A. F. Robertson, D. Gross, and J. Loftus, "A Method for Measuring Surface Flammability of Materials Using a Radiant Energy Source," *Proceedings*, Am. Soc. Testing Mats., Vol. 56, pp. 1437–1453 (1956).

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millboard of 60 lb per cu ft density. At time zero, the specimen was placed in position on the supporting frame facing the radiant panel and inclined 30 deg to it. Observations were then made of the progress of the flame front, the occurrence of flashes, etc. A pilot igniter fed by an air-acetylene mixture served both to initiate flaming at the upper edge of the test specimen and to ignite combustible gases rising from the specimen. An electrical timer calibrated in minutes and decimal fractions to hundredths was used for recording the time of occurrence of events during the tests. The test duration was 15 min or until sustained flaming had traversed the entire 18-in. length of specimen, whichever time was less.

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

$$I_s = F_sQ$$

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 . . . . t_{15} correspond to the times in minutes from specimen exposure until arrival of the flame front at a position 3 . . . . 15 in., respectively, along the length of the specimen)

and

$Q = 0.1\Delta\theta/\beta$.

The constant 0.1 was arbitrarily chosen to yield a flame-spread index of approximately 100 for red oak. $\Delta\theta$ is the observed maximum stack thermocouple temperature rise in degrees Fahrenheit over that observed with an asbestos-cement board specimen, and β is the maximum stack thermocouple temperature rise for unit heat input rate to the calibration burner, in units of degrees Fahr per Btu per min.

Materials

The specimens comprised a wide variety of representative finish materials including liquid coatings, films, sheets, panels, and plastics (see Table I). One series of interior finishes was applied to the smooth finished side of three common wall base materials: plywood, fiberboard, and gypsum board. The finish materials were applied to the base material employing standard application materials and methods and following manufacturers' suggestions wherever practical.

The following procedures of specimen preparation were used for the series of plastic materials designated 1 to 12:

1. Opaque (to infrared radiation) materials of greater than $\frac{1}{16}$ in. thickness were not applied to any base material.
2. Opaque materials of $\frac{1}{16}$ in. thickness or less were applied to a $\frac{3}{8}$ or $\frac{1}{2}$-in. thick gypsum board base material (flame-spread index approximately 10 to 20).
3. Transparent or translucent materials of any thickness were not applied to any base material but were backed by a sheet of highly reflective aluminum foil.

The assemblies prepared as indicated were air dried for not less than 72 hr. They were then cut into 6 by 18 in. specimens and placed in a room maintained at 75 F and 50 per cent relative humidity for not less than one week's conditioning prior to testing.

Procedure and Results

Previous work[1] had indicated that variations in specimen structure, such as orientation of grain, pores, laminations, variations in the thickness, and bond of the finish or protective coating may appreciably affect the flame-spread behavior of a material. Data dispersion as indicated by the coefficient of variation had ranged from 5 to over 60 per cent. One phase of this study involved an analysis of part of the data to obtain a statistical measure of the variance assignable to finish material, base material, the constancy of differences among the materials, and a measure of the random errors inherent in the measurements.

To test for the existence of "order within a day" and "day-to-day" effects as well as to estimate the extent of the testing program necessary, a series of tests of eight finish materials on each of four base materials in duplicate was performed in an ordered sequence. Statistical analysis of these preliminary results indicated that variations due to the testing order during the day (that is, whether tested in the morning, noon, or afternoon) and variations due to testing over a period of time (day or weeks) were not significant as compared with variations observed between duplicate specimens. A random testing procedure was therefore adopted for all subsequent tests.

The average flame-spread index values are given in Table II. The weight of the smoke deposit reported is the average for replicate specimens and is based upon at least three determinations except in the instances where a smoke deposit of less than 1.0 mg was obtained in the first two determinations.

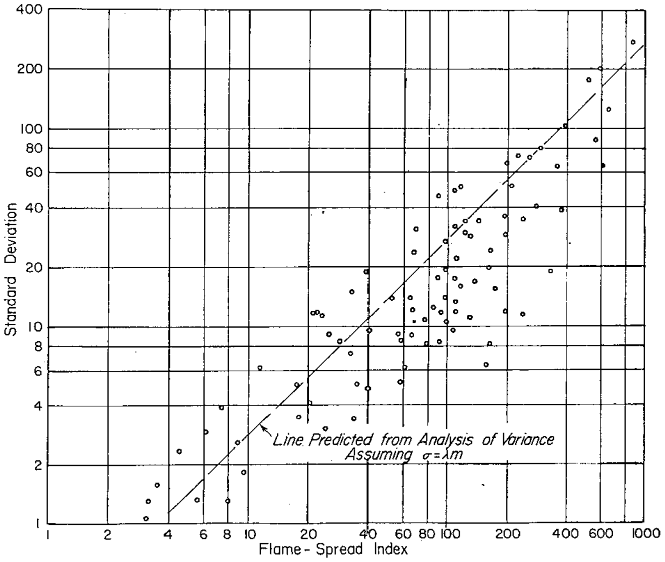

Fig. 2.—Standard deviation as a function of mean flame spread index.

Statistical Analysis

Figure 2 is a plot of the standard deviation as a function of the average flame-spread index for the finish materials tested. These standard deviations are based on four repeat determinations and, bearing in mind the uncertainty of standard deviation estimates based on 3 degrees of freedom, there is the suggestion that the standard deviation is proportional to the mean.

In order to combine the information on reproducibility from such widely varying standard deviations in analysis of variance procedures, it is necessary that all standard deviation estimates be estimates of the same quantity. If it can be assumed that the standard deviation σ, is in fact proportional to the mean, m, say $\sigma = \lambda m$, a logarithmic transformation of the flame-spread values will produce values that have a common standard deviation.[2]

This assumption of the proportionability of standard deviation to the mean appeared to be a satisfactory approximation for these data and the subsequent statistical analyses were carried out in the transformed scale. One thus obtains an estimate (the error term in the analysis of variance) of the proportionality constant λ, by which the variability of a measure-

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[2] M. S. Bartlett, "The Use of Transformations," *Biometrics*, Vol. 3, pp. 39–52 (1947).

ment is expressed as a fraction of its mean. This indirect estimate of 0.278, which is the slope of the broken line in Fig. 2, is in fair agreement with the direct estimate, 0.246, of the value of λ based on the untransformed data. Thus a standard deviation of 27.8 per cent of the mean was obtained for individual observations and a standard deviation of 13.9 per cent of the mean ($1/\sqrt{n} \times$ standard deviation of individual determination) for averages of four determinations.

In the analysis of variance[3] the differences among the averages for the several materials were compared with the agreement among repeated determinations on the same material. The analysis indicated that (1) for a given base material, there was a considerable difference in the performance of the finish materials, (2) for a given finish material, there was an appreciable difference in performance when applied to the various base materials, and (3) there was a significant difference in performance attributable to the combined effect of finish and base materials.

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[3] O. L. Davies, "Design and Analysis of Industrial Experiments," Chapter 4, Oliver and Boyd, London (1954).

TABLE I.—MATERIALS LIST.

Symbol	Material	Description	Thickness, in.	Density, lb per cu ft
		BASE MATERIALS		
I	Plywood	Exterior type Douglas fir grade A-C	¼	39.0
II	Fiberboard	Building board class D finish	½	19.4
III	Gypsum board	....	⅜	50.5
		FINISH MATERIALS APPLIED TO BASE MATERIALS I, II, III		
A	Aluminum wall tile	Linked wall tile; 4 in. sq, light green	0.020	161.5
B	Enameled wall covering	Enamel baked on felt backing; 4½ in. sq tile design, green with dark green border	0.055	64.9
C	Fabric wall covering	Baked enamel on cotton muslin, light green	0.009	80.9
D	Wallpaper	Polyvinyl coated, light green	0.008	40.3
E	Wallpaper, 5 coats	Embossed paper, light green	0.035	41.8
F	Wallpaper, 1 coat	Embossed paper, light green	0.007	41.8
G	Wood veneer	Random-grade oak wood veneer on cotton muslin	0.019	54.5
H	Cork tile	Standard weight tile, 6 by 12 in., natural color	0.125	30.8
I	Wall cloth	Plastic coating on cotton muslin, light green	0.011	70.3
J	Burlap	Imported jute fiber, natural color	0.025	30.4
K	Polystyrene	Wall tile, 8½ in. sq, light green	0.075	65.4
L	Plastic-coated wall covering	Clear plastic coating on felt backing, 4½ in.	0.050	66.9
M	Vinyl film	Self-adhesive, knotty pine design	0.004	56.6
N	Vinyl counter top	Vinyl surface on felt backing, turquoise	0.070	83.0
O	Vinyl counter top	Vinyl surface on felt backing, Caribbean turquoise	0.062	79.8
P	Melamine	Baked melamine finish on masonite hardboard plain surface tileboard, April green	0.150	71.8
Q	Poly(vinyl chloride)	Transparent film	0.003	69.2
R	Melamine	Melamine-surfaced high-pressure laminate on hardboard; linen finish, green	0.150	78.3
T	Linoleum tile	Laminated tile, 9 in. sq, marbleized gray	0.125	86.0
U	Latex paint	Flat interior finish, dado green, 1 primer coat, 2 paint coats	0.004[a]	86.5[b]
V	Alkyd paint	Flat, aqua, 1 primer coat, 2 paint coats	0.003[a]	100.0[b]
W	Oleoresinous paint	Flat, white, 1 primer coat, 2 paint coats	0.004[a]	97.5[b]
X	Alkyd paint	Gloss, light green, 2 primer coats, 2 paint coats	0.005[a]	77.5[b]
Y	Varnish	Interior varnish, clear color, 3 coats	0.004[a]	55.0[b]
Z	Shellac	White, 3 coats	0.006[a]	57.6[b]
		OTHER MATERIALS		
a	Aluminum foil	Glued to plywood	0.003	41.6[c]
b	Cellulose-mineral board	....	0.875	47.8
c	Paint, oil base	On cement asbestos board	0.010	...
d	Paint, oil base	On steel	0.010	...
e	Acoustic tile	Mineral base	0.750	19.3
f	Fire retardant paint	On plywood	0.006	42.3[c]
g	Red oak	Plain sawed, select grade, 2¼-in. face	0.750	40.0
h	Acoustic tile	Perforated fiberboard	0.500	16.7
i	Hardboard	Smooth side exposed	0.218	59.8
j	Fiberboard	Unfinished	0.500	18.0
		PLASTIC MATERIALS		
1	Rigid poly(vinyl chloride)	Gray	0.147	86.0
2	Rigid poly(vinyl chloride)	Retardant treated, dark gray	0.147	88.0
3	Phenolic laminate[d]	Dark gray	0.063	76.4
4	Linoleum tile[d]	Retardant treated, white and black	0.065	131.0
5	Acrylic	Retardant treated, milky white	0.125	75.0
6	Polystyrene[d]	Extruded sheet, impact grade, white	0.066	58.2
7	Polystyrene tile[d]	4¼ in. sq, cream	0.068	64.6
8	Poly(vinyl chloride)[d]	Retardant treated film on cotton, white	0.018	60.4
9	Poly(vinyl chloride)[d]	Film on cotton, gray	0.021	74.5
10	Glass reinforced polyester	27 per cent glass, translucent	0.085	87.0
11	Glass reinforced polyester	27 per cent glass, retardant treated, translucent	0.095	97.6
12	Glass reinforced polyester	21 per cent glass, translucent	0.062	81.7

[a] Estimated.
[b] Liquid density.
[c] Bulk density.
[d] Gypsum board base.

Discussion of Results

The base material as well as the surface finish material (and associated application materials) were important factors in the flame-spread behavior of composite test assemblies. While a thick finish material almost completely masked any base material effect, the base material behavior predominated in those test assemblies with thin vinyl, M, or poly (vinyl chloride) Q, films.

Paints U, V, W, and X, and other thin coverings C, F, in the thickness range 0.003 to 0.010 in. considerably reduced the flame spread index obtained with the bare base materials I, II, and III. In the thickness range 0.010 to 0.050 in., higher flame-spread index values were obtained with these finish materials on a fiberboard base than on the other base materials. This may be attributed to the thermal insulating effect of the fiberboard base. The base material had considerably less effect upon the flame-spread index of an assembly in which the finish material thickness was greater than 0.050 in., B, H, K, L, N, O, P, R, T.

Since highly reflective finishes do not absorb as much radiant energy as dull, black surfaces, they spread flame less rapidly. Due to its high reflectance and impermeable char-

TABLE II.—FLAME SPREAD AND SMOKE DEPOSIT DATA.
Effect of Base Material—Average of 4 Tests

Symbol	Finish Material	Plywood Base			Fiberboard Base			Gypsum Board Base		
		Flame-Spread Index	Coefficient of Variation, per cent	Smoke, mg	Flame-Spread Index	Coefficient of Variation, per cent	Smoke, mg	Flame-Spread Index	Coefficient of Variation, per cent	Smoke, mg
Base material		195	15.0	0.8	110	11.9	0.5	22	54.3	0.1
A	Aluminum wall tile	33	22.3	1.7	39	48.8	3.4	6.2	46.8	0.0
B	Enameled wall covering	110	20.1	6.0	116	43.8	4.9	67	35.5	2.1
C	Fabric wall covering	29	29.6	0.5	25	36.2	0.5	3.1	34.5	0.1
D	Wallpaper	98	14.4	0.6	193	18.9	0.2	20	20.5	0.1
E	Wallpaper, 5 coats	61	10.1	0.6	116	13.7	0.5	35	14.3	0.0
F	Wallpaper, 1 coat	64	21.7	0.9	76	14.2	0.2	5.6	23.8	0.0
G	Wood veneer	163	14.8	0.7	197	6.1	0.3	58	14.1	0.4
H	Cork tile	642	19.3	1.5	560	15.8	1.7	610	10.6	1.7
I	Wall cloth	18	19.2	1.9	24	12.2	2.1	4.5	51.2	0.5
J	Burlap	163	5.2	0.0	279	14.6	0.0	108	16.2	0.3
K	Polystyrene	590	33.1	13.7	520	33.9	20.1	335	5.7	17.5
L	Plastic coat wall covering	293	27.4	8.2	394	27.2	8.7	253	28.2	7.0
M	Vinyl film	128	22.4	2.4	144	36.8	2.2	21	55.9	1.1
N	Vinyl counter top	40	12.1	7.7	52	27.5	7.7	34	10.0	8.1
O	Vinyl counter top	121	24.6	7.9	196	34.3	8.3	97	27.9	7.6
P	Melamine	90	19.8	6.4	80	10.4	5.7	57	16.2	4.1
Q	Poly(vinyl chloride)	209	24.5	0.9	109	12.3	0.1	23	46.9	0.0
R	Melamine plastic	92	9.2	3.5	122	28.3	4.7	84	14.9	3.0
T	Linoleum tile	129	8.6	10.1	172	9.4	13.1	106	8.9	8.5
U	Latex paint	93	12.7	1.3	66	18.6	0.4	8.9	28.9	0.3
V	Alkyd paint flat	69	45.4	0.4	40	23.8	0.2	0.8	25.3	0.0
W	Oleoresinous paint	58	9.0	1.0	18	28.9	0.4	3.5	44.5	0.0
X	Alkyd paint gloss	97	20.0	1.7	108	29.7	0.5	8.0	16.3	0.6
Y	Varnish	162	12.2	0.6	...	...	...	...	...	...
Z	Shellac	832	35.3	0.2	...	...	...	...	...	...

Symbol	Material	Number of Tests	Flame-Spread Index	Coefficient of Variation, per cent	Smoke, mg
	OTHER MATERIALS				
a	Aluminum foil on plywood	4	1.0	73.3	0.1
b	Cellulose mineral board	5	1.3	38.5	0.2
c	Paint on cement asbestos board	5	2.0	29.0	0.0
d	Paint on steel	5	7.4	51.9	0.0
e	Acoustic tile, mineral base	5	11.5	54.0	0.0
f	Fire retardant paint on plywood	6	33	45.4	1.2
g	Red oak	5	99	10.7	0.3
h	Acoustic tile, fiberboard	5	116	13.6	0.3
i	Hardboard	5	136	12.4	4.1
j	Fiberboard, unfinished	9	236	5.0	0.2
	PLASTIC MATERIALS				
1	Rigid poly(vinyl chloride)	4	9.6	18.2	28.9
2	Rigid poly(vinyl chloride) treated	4	3.2	40.0	10.5
3	Phenolic laminate	5	107	45.3	1.1
4	Linoleum tile	4	2.1	39.9	15.2
5	Acrylic treated	4	376	10.3	40.6
6	Polystyrene extruded	4	355	18.3	23.0
7	Polystyrene tile[a]	4	224	32.7	10.6
8	Poly(vinyl chloride) treated	5	4.5	57.6	1.1
9	Poly(vinyl chloride)	5	89	51.1	3.9
10	Glass 27 per cent reinforced polyester	3	154	4.2	18.4
11	Glass reinforced polyester treated	4	66	13.7	22.3
12	Glass 21 per cent reinforced polyester	3	239	14.6	15.9

[a] Specimen supported by metal strip to prevent dropping.

acter, a thin (0.003-in.) sheet of aluminum foil provided an unbroken protective surface and reduced the flame-spread index of plywood to 1.0.

The flame-spread indices of the plastics group tested ranged from below 10 for representative polyvinyl materials to over 200 for polystyrene and acrylic type plastics. The poly(vinyl chloride) films on cotton exhibited flashing tendencies.

It can be seen from Table II that the flame spread indices for most finish materials on gypsum board were significantly lower than on the other base materials, with the index for finish materials on fiberboard generally the highest. One measure of the effect of base material is given by the ratio of the flame-spread index for a given finish material as applied to two different base materials. The correlation with finish material thickness when applied to fiberboard and gypsum board base materials is evident from Fig. 3.

Smoke measurements furnish an indication of the interference to be expected in fire-fighting or evacuation procedures during a fire rather than of fire intensity or rapidity of flame spread. A smoke deposit of 1.0 mg or less was generally obtained with materials which did not evolve appreciable quantities of smoke according to visual observations. Over half the assemblies tested evolved less than 1.0 mg of smoke deposit. It was observed that finish materials on a fiberboard base generally produced greater smoke deposits than the same finish materials on plywood or gypsum board bases. Polystyrene tile K, evolved a very heavy quantity of sooty smoke, and considerable smoke was also produced by linoleum tile, T, plastic-coated wall covering L, the vinyl counter top materials, N, O, and nearly all the plastic materials.

It should be emphasized that the method of test measures the flame-spread properties of the exposed surface of the test assembly only. Where assemblies of this type are used for application directly to studs or over other enclosed open spaces, it appears highly desirable to consider the flame-spread properties of the interior stud space lining as well.

Summary

Flame-spread data, as measured by the radiant panel method, have been obtained for a wide variety of materials including representative composite assemblies of interior finishes applied to common wall base materials. The base material as well as the surface finish material are important factors in the flame-spread behavior of a composite assembly. For the materials tested, the effect of the base material upon the flame-spread index of an assembly decreases as the finish material thickness increases. The standard deviation of a single observation was found to be approximately 27.8 per cent of the mean flame-spread index for many materials but considerable variation was observed.

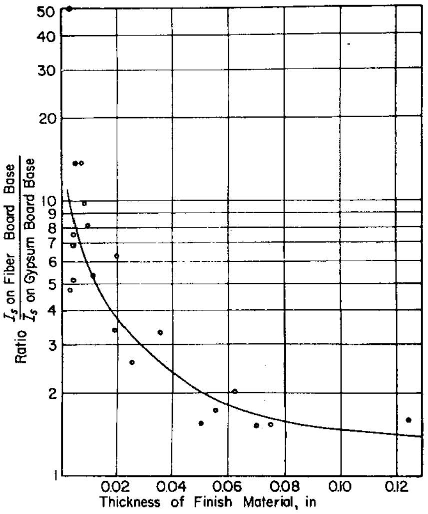

Fig. 3.—Effect of finish material thickness upon flame spread index ratio for two base materials.

Acknowledgment:

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