FLAMESPREAD VARIABILITY OF CANDIDATE WOOD-BASED REFERENCE MATERIALS

Susan L. LeVan

Forest Products Laboratory
U.S. Department of Agriculture, Forest Service
Madison. WI 53705

ABSTRACT

We determined the flamespread variability of four wood composite panel products that were being considered as possible standard reference material. We examined the effect of density, moisture content, heating rate, thermal conductivity, and specific heat on this variability. Of these, density has the greatest effect on variability. Of the four types of materials tested, material C had one of the smallest density variabilities. We recommend that this material be used in ASTM E 84 tests to establish its use as a standard reference material for flamespread tests, and that material selection and statistical design procedures outlined in this paper be followed.
Keywords: Standard reference material, flamespread, variability, particleboard, hardboard, medium-density fiberboard, density, thermal conductivity, specific heat.

INTRODUCTION

WOOD PERFORMANCE UNDER FIRE CONDITIONS IS SOMETIMES THE reference point used in building codes for specifying the flamespread of other building materials. However, performance variability of wood is not properly characterized for this purpose. We investigated the flame spread variability of four wood composite products and examined the parameters necessary for proper selection of a suitable standard reference material (SRM).

Two wood-based reference materials have been used in the past. Red oak flooring has been used as the reference material for comparing the

0734-9041/85/03 0208–16 $04.50/0

flamespread values of various materials and for checking the calibration of the tunnel in the ASTM Standard E 84 [1]; presently, it is used just to check the operation of the tunnel. A hardboard, NBS SRM 1002b [2], is used in a small-scale flamespread test, ASTM E 162 [3], for checking operational and procedural details of this standard.

The objective of this work is to examine potential wood-based candidates as a possible calibration replacement for the red oak flooring. The disadvantages of the red oak flooring are the high cost and the time required to assemble a test specimen. The advantages of a wood panel product are lower costs and simplified handling procedures.

Any wood-based materials considered as possible SRM's would have to meet the following criteria:

- Reasonably priced
- Available in sufficient quantity
- Widely used as a building material
- Uniform in fire performance within acceptable variability limits.

Many wood-based materials meet the first three criteria. However, to meet the fourth criterion a procedure is needed to determine fire performance of the material and its variability. We used the ASTM Standard [4] E 286 (8-ft tunnel) to determine flamespread variability of four wood panel products. Since the performance of wood materials in fire depends on density, moisture content (MC) and equipment variability, all these variables influence flamespread variability. By determining the variability of flamespread and its dependence on other related properties, we could screen potential candidate SRM's and propose procedures to select the material to be evaluated in the ASTM E 84 flamespread test [1].

BACKGROUND

A study by Holmes and Chudnoff [5] examined the use of red oak as an SRM for flamespread testing. They evaluated red oak on the basis of present usage, forest resource, growth variability, and fire performance variability in ASTM E 286. Using statistical techniques they determined that 58% of the variation in flamespread travel time was due to density variations. Because of the high cost associated with red oak, they felt the variability encountered warranted the use of other materials and suggested the use of a reconstituted wood product.

The advantages of a reconstituted wood product such as particleboard or medium-density fiberboard are:

(1) more uniform product
(2) availability in large production lots
(3) ease of handling panel-size material
(4) low-cost product.

Groah [6] used a particleboard with an average density of 43 lb/ft^3 and 3/4 inch thick to study influence of certain operating and specimen variables on results in the 25-foot tunnel test, ASTM E 84. The particleboard was selected because it was relatively homogeneous and because 3/4-inch-thick material did not burn through during the lo-minute duration of the test. The data supported the premise that reproducibility of results can be obtained when furnace variables are kept under tight control and when a homogeneous material is used.

MATERIALS AND METHODS

To determine the flamespread variability of four types of wood panel products, we measured the flamespread of 32, 32, 18, and 20 specimens for materials A, B, C, and D, respectively. We also monitored burning pattern, density, MC, heating rate of the gas, panel orientation, specific heat, and thermal conductivity.

Materials

We evaluated four types of commercial wood composite boards: two particleboards, a medium-density fiberboard, and a hardboard. Material characteristics include resin type, thickness, species, and density (Table 1).

We obtained eight 4- by 8-foot panels (all from the same manufacturing lot) for each type of product. Due to MC irregularities in data, replicate tests were conducted on materials A and B. For replicate tests, we obtained an additional four panels for each product from a different lot than the previous eight panels.

We used two 13-3/4-inch by 4-foot sections to make up our 13-3/4-inch by 8-foot flamespread test specimen. (Previous testing indicated no differences between a continuous 8-foot specimen and two

Table 1. Panel characteristics.

Material	Resin	Thickness (inches)	Species	Additives	End Use
A Particleboard	Urea formaldehyde	1/2	Western hardwoods mix	Yes	Flooring underlayment
B Medium-density fiberboard	Urea formaldehyde	1/2	Southern yellow pine	No	Furniture, cabinets
C Particleboard	Urea formaldehyde	1/2	Douglas-fir	Yes	Flooring underlayment
D Hardboard	Phenolic	7/16	Pine, hardwoods mix	Yes	Siding

4-foot sections joined end to end.) We cut three specimens (Figure 1) from each of four panels and used them to measure flamespread variability in the cross-panel direction. To measure flamespread variability as affected by panel orientation, we cut two specimens from each of the remaining four panels (Figure 2).

For thermal conductivity tests, we cut four 12- by 12- by 1/2-inch specimens from remaining panel materials.

Specimens for specific heat utilized remaining scrap material. They were ground in a Wiley mill, 16-mesh size, and kept in plastic zipper-lock bags until used.

Methods

Flamespread.–We measured values for flamespread in an 8-foot tunnel furnace [3]. This test method uses a 13-3/4-inch-wide, 8-foot-long specimen. The specimen is heated by a graduated level of radiation emitted from the partition plates that divide the firebox from the

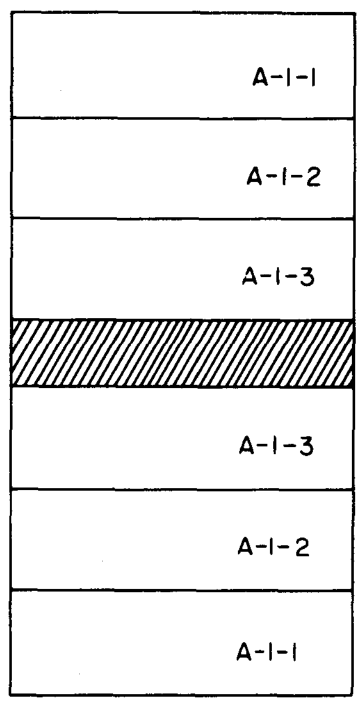

Figure 1. Schematic of cutting diagram for determining effect of flamespread variability. Letter indicates panel type; first number is panel number; and second number identifies specimen and position in the panel.

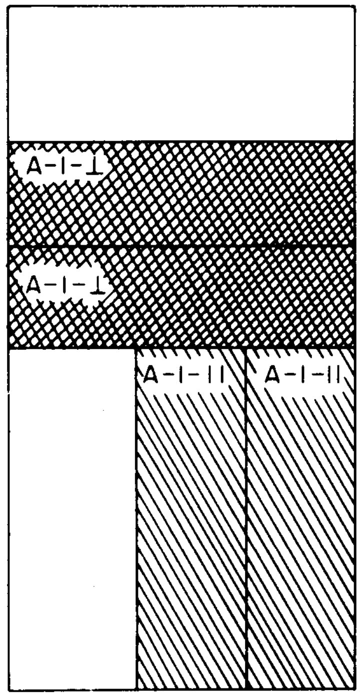

Figure 2. Schematic of cutting diagram for determining effect of panel orientation. ⊥, / / represent perpendicular and parallel, respectively.

specimen combustion chamber. The furnace is run under natural draft conditions and time for the flames to travel 87 inches is recorded. The total amount of gas consumed and its heating value are also recorded. From this information, we could then calculate the heating rate of the gas. Variation in heating rate is a primary source of experimental variability.

We followed the ASTM procedure E 286-69 with some modifications to the tunnel:

- We replaced the stainless steel plates with cast iron plates, 15-1/4 by 1/4 by 12-1/4 inches, to improve durability.
- We replaced original asbestos board lining with 1/2-inch calcium silicate board to eliminate the health hazard associated with asbestos.
- We increased the British thermal unit (Btu) rate from 3,400 to 4,000 Btu/ft^3, and used a 3-minute preheat time to obtain the same heating profile with the cast iron plates as with the stainless steel.

For flamespread tests, we stored specimens in our 73°F, 50% RH room to obtain an MC of about 7%. To determine when the panels reached equilibrium moisture content (EMC), we monitored the weight of the panels at periodic intervals. When no apparent weight change occurred, we conducted the flame-spread tests. We used the ovendry method on blocks cut from each specimen to measure MC.

Because of MC irregularities in data from materials A and B, we repeated tests on material from different lots. To ensure EMC for repeat tests we coated the edges of some scrap material with a wax and proceeded as follows:

1. We weighed panels to be fire tested along with scrap material weekly.
2. When fire test panels appeared to reach a stable weight, we cut the MC specimen from scrap material and determined MC by the oven-dry method.
3. We waited another week and repeated step 2.
4. When MC's from scrap material were consistent, we conducted the flamespread test.

Prior to the flamespread test, we measured the length, width, and thickness of each board in several places to find the average volume. We calculated the density of each specimen by dividing the ovendried weight by the average volume.

We tested 12 panels of each product according to the design in Table 2. Day 1 tests, which used three specimens from one panel, estimated within-panel variation. This estimates the equipment variation if it is assumed that each individual 4- by 8-foot board is homogeneous within itself. Test method variabilities are compared across product type. Day 2 through 4 tests were used to try to compute variance components for board-to-board variation, day-to-day variation, a variation due to sequence of the test, and a residual variation.

Panel orientation.–For determining the effect of panel orientation, we tested four type-A panels with one perpendicular and one parallel sample from each panel, looking for differences due to panel direction between specimens from the same board. Using statistical techniques,

Table 2. Experimental design for each product, example of panel type A. *

Day	First Test	Second Test	Third Test
1	A-4-1	A-4-2	A-4-3
2	A-1-1	A-2-1	A-3-1
3	A-3-2	A-1-2	A-2-2
4	A-2-3	A-3-3	A-1-3

*Letter indicates panel type; first number is panel number, and second number identifies specimen and position in panel we examined the effect of panel orientation on flamespread, density, MC, and heating rate. Since we tested a small sample population, we only looked for obvious trends in the results.

Specific heat.–We used a Mettler TA3000 DSC 20[1] differential scanning calorimeter to determine the specific heat of 5-mg samples; specific heats were measured in the range of 315°K to 345°K. The specific heat can plateau outside these bounds but is reasonably linear within these bounds. Prior to testing, the specimens were conditioned in the 73°F, 50% RH room. We scanned the samples from 26°C to 78°C at a heating rate of 5°C/min. Aluminum oxide (sapphire) standard with known specific heats served as our reference standard. We took three samples from each panel of each board type.

Thermal conductivity.-For determining the thermal conductivity of the specimens, we used a Dynatech Corp. Rapid-K Thermal Conductivity Instrument, Model TCHM-F4.[1] The apparatus measures steady-state thermal transmission properties using a heat flow meter and operates in accordance with the requirements of ASTM C 518-76 [7]. Prior to testing, the specimens were ovendried overnight. Temperature gradients of about 12°C existed between the hot face and cold face. Mean specimen temperature was 20°C. The heat flux through the specimen was 35 W/m.

RESULTS AND DISCUSSION

Because of our limited number of tests, we looked only for trends in the influence of certain variables-burning pattern, density, heating rate of gas, panel orientation, specific heat, and thermal conductivity-on flamespread. Only density proved to show significant trends.

Burning Patterns

Visual observation indicated that the burning patterns were not all the same for the various materials. Some materials tended to recede at the 43-inch mark, then after about 30 seconds they would proceed as normal to the remaining 87-inch distance. Material A burned evenly with a blue-orangish flame but receded during some of the tests. Material B burned with a very blue flame and during all tests the flamefront receded. Material C burned in a manner similar to that of material A but did not recede during tests. Material D burned with a

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

blue flame, receded during all tests, and produced extremely high heats.

Overall, the variability associated with flamespread for a given lot of a particular panel product is small. For all six lots, the coefficient of variation (COV) is less than 5% (Table 3). In Table 3, the first series for materials A and B corresponds to information from the first lot; the second series corresponds to information from the second lot. Pooled data are also shown.

The flamespread variability between lots 1 and 2 of material A is small, with standard deviation of 0.63 and 0.60, respectively, and pooled standard deviation of 0.66. A two-sided t-test indicates significant differences between the two lots of material A with P = 0.028.

The flamespread variability between lots 1 and 2 of material B is large, with a standard deviation of 0.68 and 0.90, respectively, and standard deviation of 1.06. A two-sided t-test indicates highly significant differences in flamespread of the two lots at P = 0.000.

Since only one lot of materials C and D were tested, we could not compare flamespread variability of these products between lots. Within a lot, material C had small variability with a standard deviation of 0.48 and a COV of 2.0%. Material D also showed small variability within a lot with a standard deviation of 0.47 and a COV of 2.0%.

A statistical analysis of variance on flamespread by panel types indicates no significant difference in flamespread between panel types at the 95% confidence interval. Analysis of variance on flamespread by different lots indicates significant differences between lots at the 95% confidence interval with an F-test value of 14.41. By pooling the data from two different lots of the same material, we obscured the differences between lots. These results indicate that lot-to-lot differences are greater than we expected.

The estimated variance components for within-board, board-to. board, day-to-day, and time-of-test were not stable for the four different materials due to small sample sizes involved; therefore they are not reported. No one source of variation was constantly larger, so these effects are combined under the particular independent variable in the rest of the report.

Density

Of all the factors that we evaluated, density variability has the greatest impact on variability in flamespread data. For the two different lots of materials A and B that we tested, density differences between lots did occur (Table 3). A two-sided statistical t-test indicates significant differences between lots 1 and 2 of materials A and B. The standard deviations for material A are 1.11 and 0.50 for lots 1 and 2, respectively. For material B, the standard deviation is 1.14 and 2.56,

Table 3. Variability of test specimens.

	Flamespread			Density			Moisture Content		
	Mean (min)	Standard Deviation	Coefficient of Variation (%)	Mean (lb/ft^3)	Standard Deviation	Coefficient of Variation (%)	Mean	Standard Deviation	Coefficient of Variation (%)
A1	24.02	0.63	2.6	41.75	1.11	2.7	8.30	0.58	7.0
A2	23.50	.60	2.6	40.40	.50	1.2	7.24	.08	1.1
A pooled	23.82	.66	2.8	41.24	1.13	2.7	7.90	.69	8.7
B1	23.20	.68	2.9	42.69	1.14	2.7	7.10	.62	8.7
B2	24.72	.90	3.6	45.57	2.56	5.6	7.65	.14	1.8
B pooled	23.77	1.06	4.5	43.77	2.27	5.3	7.31	.56	7.7
C	23.77	.48	2.0	41.66	.76	1.8	7.31	.18	2.5
D	23.26	.47	2.0	53.05	1.73	3.3	7.52	.96	12.8

for lots 1 and 2 respectively. We can conclude that densities between lots 1 and 2 of material B are more variable than densities between lots 1 and 2 of material A.

In order to evaluate which parameters affected flamespread, we applied statistical correlations between the independent variables (density, MC, and heating rate) and the dependent variable flamespread. The high correlation between flamespread and density exists for various panel products. For material A we obtained a pooled correlation coefficient of 0.34 with a density range from 39.7 to 43.5 lb/ft^3 (Table 4). For material B, with the widest range of density values, the pooled correlation coefficient is 0.77. For material C, we could not determine any significant correlation (Table 4) because of the narrow density range evaluated. For material D, the correlation coefficient is 0.61. For the other independent variables there were no significant correlations.

The materials that showed large variability in flamespread also showed large variability in density. When comparing the data from two different lots of material B (Figure 3), this becomes particularly evident. The density variability associated with each board and within each lot is given in Table 5. Density was uniform in the first lot of material. In the second lot it was not. Density variation between the two lots is also significant. When one compares differences in flamespread between the two lots, a similar pattern in variation and significant differences in means exists. Since density variations affect flamespread variability, a suitable SRM would have to have a very narrow density range within a lot and small variation between lots.

Moisture Content

Ensuring the MC of all specimens is difficult. Simply weighing the individual panels until no further weight loss occurred did not ensure

Table 4. Correlation by material between flamespread and density.

Material	Correlation Coefficient	Density Range (lb/ft^3)
A1	0.13	39.7-43.5
A2	.32	39.7-41.6
A pooled	.34	39.7-43.5
B1	.34	41.3-45.4
B2	76	40.9-48.3
B pooled	.77	40.9-48.3
C	-.07	39.7-42.7
D	.60	49.9-56.1

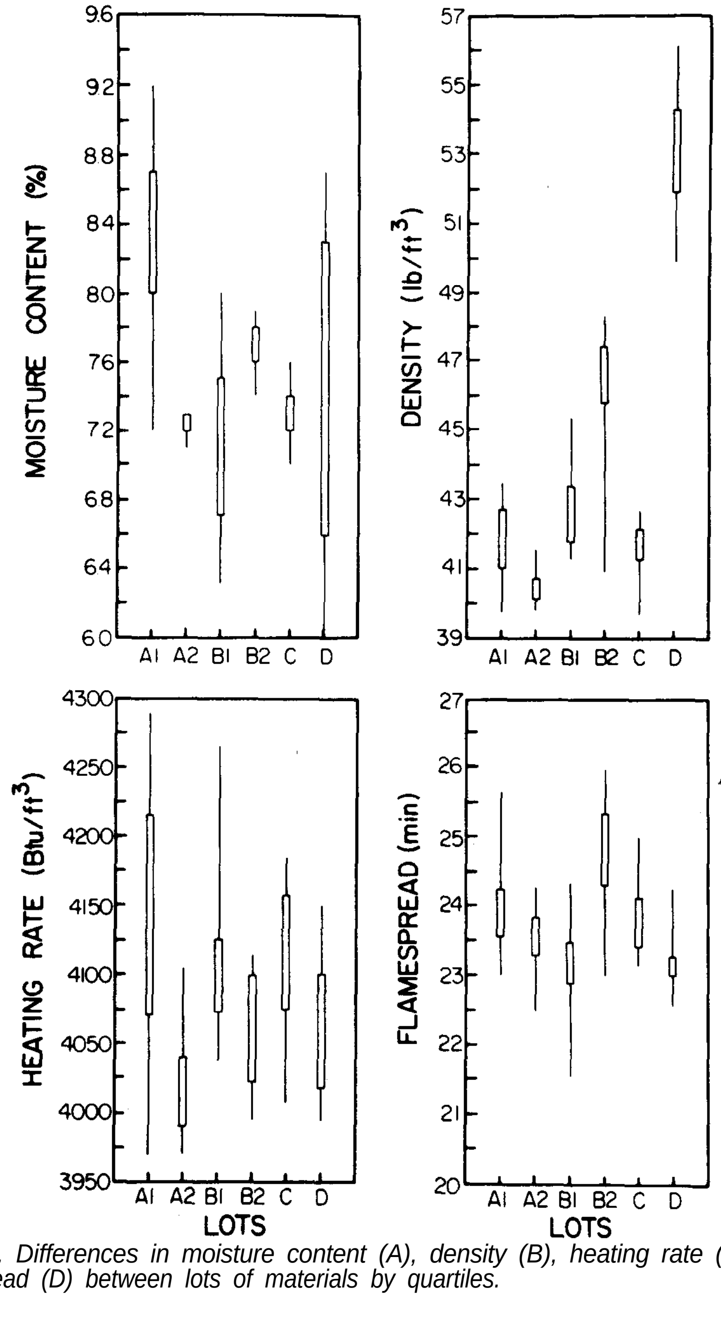

Figure 3. Differences in moisture content (A), density (B), heating rate (C), and flamespread (D) between lots of materials by quartiles.

Table 5. Density profile of material B.

Board/Lot	Mean (lb/ft^3)	Standard Deviation	Coefficient of Variation (%)
B1-1	41.7	.56	1.3
B1-2	42.3	.78	1.8
B1-3	43.4	.50	1.2
B1-4	41.6	0.20	0.4
Entire lot 1	42.7	1.14	2.7
B2-1	41.5	.57	1.4
B2-2	47.3	.39	.a
B2-3	46.1	.36	.7
B2-4	47.4	0.87	1.8
Entire lot 2	45.6	2.56	5.6

that all specimens were at the same EMC. Differences were probably due to discrepancies in weighing precision between large 1- by 4-foot pieces and smaller 2- by 2-inch pieces used for MC determination. The technique used on the repeat tests of materials A and B proved to be a much more effective method for ensuring that all specimens were at the same MC. With the second technique, we reduced the MC standard deviation from 0.58 for lot 1 to 0.08 for lot 2 of material A and from 0.62 for lot 1 to 0.14 for lot 2 of material B.

The effect of MC on flamespread variability appears to be minor compared to the effect of density. Statistical correlations applied to MC and flamespread indicated no significant trends. Although the correlation data for material A suggested a slight correlation, with a coefficient of 0.50, it also might be attributed to density effects. Since material D had the greatest MC standard deviation of 0.96 yet the smallest flamespread standard deviation (0.47), it appears that MC might have minimal effect on flamespread. Our data are inconclusive. However, ensuring uniform MC reduces concern for its influence on variability.

Heating Rate of the Gas

For all materials, a negative correlation existed between flamespread and heating rate (Table 6). Although none of the individual correlations are significantly different from zero (due to small sample sizes) the trend is in the expected direction. The more heat applied to specimen the quicker the flame travel time. This is as expected. Statistical analysis of variance on the heating rates indicates no significant difference in results when material is grouped together by

Table 6. Heating rate values and correlation coefficients between flamespread and heating rate.

Material	Mean (Btu/min)	Standard Deviation	Coefficient of Variation (%)	Correlation Coefficients	Range of Heating Rate (Btu/min)
AI	4125	102.0	2.4	-0.51	3972-4323
A2	4023	47.0	1.2	-.90	3969-4106
A pooled	4087	98.0	2.4	-.25	3972-4323
B1	4109	67.0	1.6	-.12	4037-4265
B2	4058	43.0	1.0	-.12	3996-4115
B pooled	4090	63.2	1.6	-.45	3996-4265
C	4106	50.5	1.2	-.21	4008-4186
D	4069	51.4	1.3	-.35	3973-4151

panel type or by lot. The overall variability of heating rate is only about 2%, indicating good control over experimental variability.

Panel Orientation

Only material B appeared to show a slight difference in density for the cross-panel versus along-panel direction. Overall, orientation had no significant effect on flamespread, density, MC, and heating rate.

Specific Heat

Using overall regression analysis, we determined specific heat equations as a function of temperature within our temperature boundary. Our specific heat values are considerably higher than values reported in the literature [10], almost by a factor of 2. Moisture may have been retained in the sample capsule, which would account for the higher values.

Thermal Conductivity

Thermal conductivity values for the four materials are very similar and agree with values obtained in the literature (Table 7) for the various densities [8,9]. For wood-based materials, the thermal conductivity is affected mostly by density and MC. There is insufficient data to assess the influence of thermal conductivity data on flamespread. A larger sample size is necessary to assess the influence of thermal conductivity on flamespread.

Table 7. Thermal conductivity and specific heat.

Material	Thermal Conductivity (W/m°K)	Specific Heat" (J/gK°)
A	0.1013	C_p = -19.4 + 0.068T
B	.1004	C_p = -18.9 + 0.067T
C	.1050	C_p = -19.8 + 0.070T
D	.1103	C_p = -20.8 + 0.074T

'Overall regression analyses with temperature in °K

Selection Procedure for SRM

The results indicate that selecting a material with uniform density is the major criterion for reducing flamespread variability. The ASTM E 286 standard calls for densities between 37 and 42 lb/ft^3 for the red oak calibration material. ASTM E 84 does not specify the density. From the work here, we recommend tighter requirements be placed on density variability. Of the four materials tested, particleboard from lot 2 of material A and material C displayed the more uniform density; however material A tended to recede during burning. Material D had little flamespread variability, yet large MC variability; it also burned with extremely high heats. Material B had both large density and flamespread variability and therefore is not suitable as a candidate SRM. The recommended density range should be kept within ± 1.0 lb/ft^3. It is assumed that from a large lot of material, boards within this narrow density range could be selected.

After choosing the boards of appropriate density, the moisture content must be brought to EMC. The second technique outlined in the methods section is recommended to ensure uniform MC among test specimens.

As previously mentioned, the overall variability between materials in our 8-foot tunnel (ASTM E 286) is small, with a COV of less than 5%. One disadvantage of using the 8-foot tunnel is that it does not distinguish between similar wood materials. The fire exposure to the specimens is not as severe as in the 25-foot tunnel (ASTM E 84) and the time to reach the end of the 8-foot tunnel is usually longer than the time for the same material to reach the end of the 25-foot tunnel. Since we propose the selection of an SRM to be based on density uniformity, there is no advantage to further testing in the B-foot tunnel. Any additional work must be conducted in the 25-foot tunnel. Therefore, flamespread measurements by ASTM E 84 method are necessary to provide variability information to establish allowable flamespread range. To do so we have to ensure the following:

- Select material of uniform density.
- Choose panels from a given lot that fall in narrow density range.
- Condition material to equivalent MC.
- Test panels according to ASTM E 84 and experimental design outlined previously in this paper.

We believe such a procedure could be used to systematically verify a suitable SRM for flamespread testing. We also recommend material C as a potential candidate.

CONCLUSION

We determined the flamespread variability of four wood composite materials in the 8-foot tunnel test and examined the influence of density, moisture content, and heating rate on the variability. Flamespread variability for all materials is small, with a coefficient of variability of less than 5%. Density had the greatest influence on this variability. We found significant differences in flamespread values between lots of one product to correspond to density differences between the two lots. The effect of moisture content differences on flamespread variability is minor compared to the effect of density. Heating rates are uniform between tests and contribute little influence to flamespread variability.

The 8-foot tunnel test does not distinguish between the various products. Therefore, to implement the selection procedure outlined in this paper further tests in the 25-foot tunnel are necessary. We recommend that selection procedures, as outlined, should be followed to establish variability and allowable flamespread range in the ASTM 25-foot tunnel.

ACKNOWLEDGEMENT

The author thanks Mr. Thomas McKarn, Mettler Instrument Co., for performing the thermal analysis for specific heats and Dr. Carol Link, statistician at Forest Products Laboratory, for experimental design and data analysis.

REFERENCES

1. "Standard Test Method for Surface Burning Characteristics of Building Materials," ASTM E 84-79a, ASTM, Philadelphia, PA (1984).
2. Cali, J. P., Mears, T. W., Michaelis, R. E., *et al.*, "The Role of Standard Reference Materials in Measurement Systems," NBS Monograph 148, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C. (January 1975).

3. "Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source," ASTM E 162-78, ASTM, Philadelphia, PA (1981).
4. "Standard Test Method for Surface Flammability of Building Materials Using an 8-Foot Tunnel Furnace," ASTM E 286-69 (reapproved 1975), ASTM, Philadelphia, PA (1975).
5. Holmes, Carlton A. and Chudnoff, Martin, "Candidate Wood-Based Standard Reference Material for Fire Testing—Red Oak," Res. Pap. FPL 404, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI (1981).
6. Groah, William J., "A Study of Certain Operating and Material Variables of the 25-Foot Tunnel Flamespread Test," *Forest Products Journal*, 23(12), pp. 39–45 (1973).
7. "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter," ASTM C 518-76, ASTM, Philadelphia, PA (1976).
8. Lewis, Wayne C., "Thermal Conductivity of Wood-Base Fiber and Particle Panel Materials," Res. Pap. FPL 77, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI (1967).
9. Ward, Robert J. and Skaar, Christen, "Specific Heat and Conductivity of Particleboard as Functions of Temperature," *Forest Products Journal*, 13(1), pp. 31–38 (1963).
10. Beall, F. C., "Specific Heat of Wood—Further Research Required to Obtain Meaningful Data," Res. Note FPL-0184, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI (1968).