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Use of Coatings to Improve Fire Resistance of Wood

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ABSTRACT Currently used tire retardant coatings for wood products reduce flame spread; they are not designed specifically to provide fire resistance. Fire resistive coatings designed for steel and foam plastics generally are not recommended for wood. Small nonload-bearing fire resistance tests were conducted in this study to determine the fire resistance of eight commercially available fire retardant and fire resistive coatings when applied to a wood product.

Coated plywoods over a foam plastic substrate were tested in a small-scale vertical exposure furnace in accordance with ASTM Fire Tests of Building Construction and Materials (E 119-82). The results were the times for the temperature rise to reach an average value of 139°C (250°F) or a maximum value of 181°C (325°F) at the plywood/foam-plastic interface. Uncoated plywoods were tested as controls.

Fire retardant coatings improved the times for plywood specimens by up to 900 s, and fire resistive coatings showed a 240- to 2640-s improvement over uncoated plywood. Coatings significantly improved the tire resistance of a wood product. The fire resistance data reported in this paper should aid in future considerations of fire resistive coatings in wood construction.

KEY WORDS: fire resistant coatings, fire retardant coatings, fire resistance, fire tests, wood, plywood

The fire resistance of traditionally designed structural wood members has been sufficient to meet code requirements because of wood's low thermal conductivity; production of an insulative char layer as it burns; the solid, generally rectangular, cross section of the structural wood member; and the generally conservative nature of traditional wood construction. However, progress in wood engineering and better understanding of the basic properties of wood has improved wood utilization in structural wood assemblies. Examples of these products are glued laminated beams, wood trusses, sand-

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with panels, glued plywood beams, and prefabricated wood joists [*1*]. In these and similar applications, there may be a need to improve fire endurance. In addition, changes in the occupancy of a building or new requirements in the building codes may increase the required fire resistance rating in an existing structure.

Fire resistive coatings add fire resistance to the substrate. Fire resistance is the property of a material to withstand fire or give protection from it. Fire resistance of elements of buildings is characterized by the ability to confine a fire or to continue to perform a given structural function or both. Commercial coatings have been available for some years to improve the fire resistance of structural steel. More recently, they have been developed for foam plastics. However, no coatings specifically designed for improving the fire resistance of wood are currently available. Fire retardant coatings provide comparatively low flammability or flame spread properties to the substrate. Flashover, or the sudden simultaneous ignition of most combustibles in a room, signals the start of a fully developed fire. Existing coatings for wood are fire retardants that reduce flame spread in the preflashover fire mode, as opposed to fire resistant coatings that improve fire endurance of the protected substrate beyond the time of flashover.

Existing published data on the fire resistance of coated wood are limited and inconclusive. Coated wood beams or columns have been tested in Europe and Japan to determine the effect of coatings on rate of charring [*2-5*]. Sandwich panels with and without mastic fire resistive coatings have been tested for fire endurance [*6*]. In Canada, a wood floor and ceiling assembly coated with cementitious material on an expanded metal lath and a mastic coating have a 1½-h unrestrained assembly rating [*7*]. In most cases, only one specimen of a given coating was tested. Thus, statistically reliable data that conclusively evaluate the effect of fire retardant or fire resistive coatings on the fire resistance of wood are not available in the published literature.

In recent years, building codes have required foam plastics to be fully protected from the interior of the building by a thermal barrier. This thermal barrier must limit the average temperature rise of its unexposed surface to 139°C (250°F) for at least 900 s of fire exposure in accordance with ASTM Fire Test of Building Construction and Materials (E 119-82). This study on coatings is a follow-up to a previous study on wood-based panel products as possible thermal barriers [*8,9*].

The objective of the work reported here was to obtain performance data showing the effect of coatings applied to a wood product in improving the fire resistance. Four fire retardant coatings and four fire resistive coatings (Table 1) were evaluated for their ability to improve the fire resistance of plywood. All coatings were commercially available. It is hoped that the results of this work will encourage the development of fire resistive coatings specifically formulated for wood.

Designation	Coating
	FIRE RETARDANT COATINGS
A	flat, latex emulsion, intumescent coating, applied at Forest Products Laboratory
B	high build, two-component, catalytic, epoxy, intumescent coating, applied at Forest Products Laboratory
C	catalytic polyurethane intumescent varnish over one coat of a clear single-component sealer, applied at Forest Products Laboratory
D	flat, alkyd, intumescent coating, applied at Forest Products Laboratory
	FIRE RESISTANT COATINGS
E	water-based, single-component asbestos-free flexible mastic coating, troweled on at Forest Products Laboratory
F	sprayable, ablative, catalyst-cured coating using a polymer binder and containing no free water, sprayed on by manufacturer
G	mineral fiber and binder, sprayed on by manufacturer
H	ablative, epoxy, room temperature curing, two-component intumescent mastic coating approved for exterior use, sprayed on by manufacturer
NC	no coating

Procedure

As in previous tests [8], the plywood was tested over a foam-plastic substrate in a small vertical furnace. Satisfactory performance was based on the times until the 139/181°C (250/325°F) temperature rise criteria of ASTM Method E 119-82 were satisfied at the interface of the plywood and the foam plastic.

Different thicknesses of coatings were tested on three thicknesses of plywood as shown in Table 2. Most tests were replicated three times. The original experimental design included:

(1) one thickness of four fire retardant coatings on nominal 16-mm (⅝-in.) plywood,

(2) two thicknesses of four tire resistive coatings on nominal 16-mm (⅝-in.) plywood,

(3) one thickness of one fire retardant coating on nominal 6- and 19-mm (¼- and ¾-in.) plywood,

(4) one thickness of one fire resistive coating on nominal 6- and 19-mm (¼- and ¾-in.) plywood, and

(5) uncoated nominal 6-, 16-, and 19-mm (¼-, ⅝-, and ¾-in.) plywood.

Preparation of the Specimens

Plywood specimens were conditioned to equilibrium moisture content at 23°C (73°F) and 50% relative humidity before coatings were applied. After

TABLE 2—*Average test results for fire retardant coatings.*

					Time to 139/181°C[a]		
					Total		
Coating Designation	Number of Tests	Number of Coats	Dry Coating Thickness, mm	Dry Coating Weight, g/m²	Mean, s	COV[b], %	Improvement[c], s
			6-MM (¼-IN.) PLYWOOD				
NC	3	0	0.0	0	210	7	0
A	3	5	0.5	720	350	3	150
D	1	1	0.1	130	360	...	140
D	1	2	0.2	300	390	...	180
D	1	3	0.3	460	470	...	260
D	1	4	0.4	600	450	...	230
D	1	5	0.5	760	480	...	290
			16-MM (⅝-IN.) PLYWOOD				
NC	6	0	0.0	0	670	2	0
A	3	1	0.1	140	820	1	160
A	3	5	0.5	670	1040	6	370
B	3	1	0.1	260	780	1	120
B	3	5	0.5	920	1160	4	500
C	3	8	0.6	910	1260	1	590
D	3	5	0.5	920	1580	3	920
			19-MM (¾-IN.) PLYWOOD				
NC	3	0	0.0	0	870	2	0
A	2	1	0.1	120	990	9	120
A	3	5	0.5	670	1270	3	400
D	2	1	0.1	190	1310	2	440

[a] Time for unexposed surface of plywood to reach average of 139°C (250°F) or maximum of 181°C (325°F) above initial temperature.

[b] Coefficient of variation.

[c] Improvement over the time for uncoated plywood. Calculations are based on the individual test results; this may not be the same as the difference in average times.

the coatings were applied, specimens were reconditioned for a minimum of 30 days. The differences in weight and thickness between the specimen before coating and the coated specimen at the time of testing were recorded as the dry coating weight and the dry coating thickness.

The 508- by 508-mm coated-plywood specimen and a foam-plastic slab were screwed to a wood frame (Fig. 1). Five 30-gage iron-constantan thermocouples were attached to the unexposed side of the plywood. Thermocouples were located at the center of the panel and at the center of each quadrant.

Materials

The eight coatings[2] are described in Table 1. Coatings were selected so a range of different types of coatings was tested. Coatings A through D are fire

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[2] **The use of commercial products in this study was for the convenience of the government. 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.**

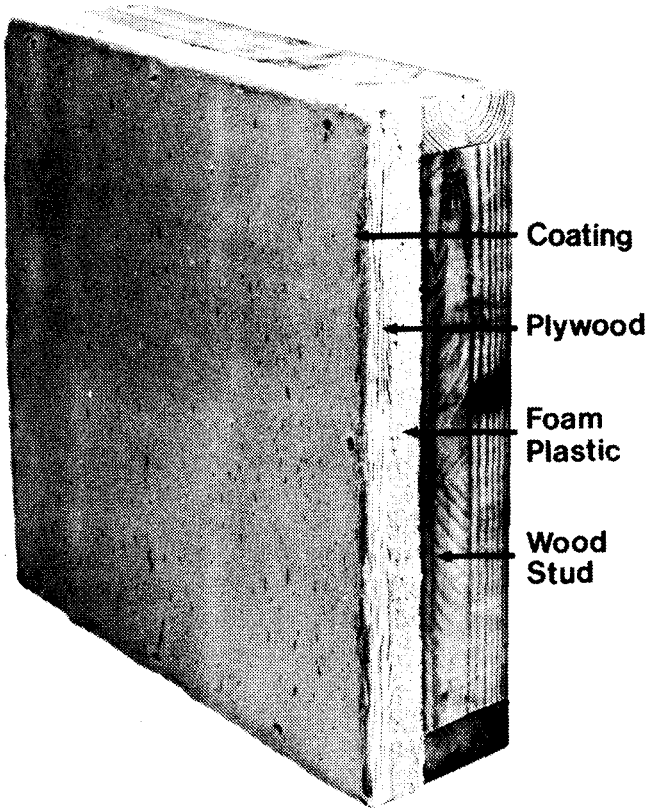

FIG. 1—*Coated test specimen on wood frame.*

retardant coatings designed to reduce the flame spread of wood substrates as measured in the ASTM Test for Surface Burning Characteristics of Building Materials (E 84-77). The fire resistive coatings were designated as Coatings E through H. Coating E is designed to halt fire propagation in grouped electrical cables. Coatings F, G, and H are designed to provide thermal or fire protection to steel or foam plastics.

The sanded southern pine plywood was graded "PS 1-74, Exterior, A-C, Species Group 1." The average measured thicknesses of the nominal 6-, 16-, and 19-mm (¼-, ⅝-, and ¾-in.) plywood panels were 7.3, 16.2, and 19.1 mm, respectively. The plywood had an oven-dry density of 460 ± 60 kg/m^3 and moisture content of 8.7 ± 0.7%.

The foam-plastic slabs were cut from nominal 25.4-mm (l-in.) foam-plastic sheathing. The sheathing had a glass-reinforced polyisocyanurate foam-plastic core with aluminum foil facings, The foam-plastic sheathing had an R-value of 1.3 m^2· K/W and density of 32 kg/m^3.

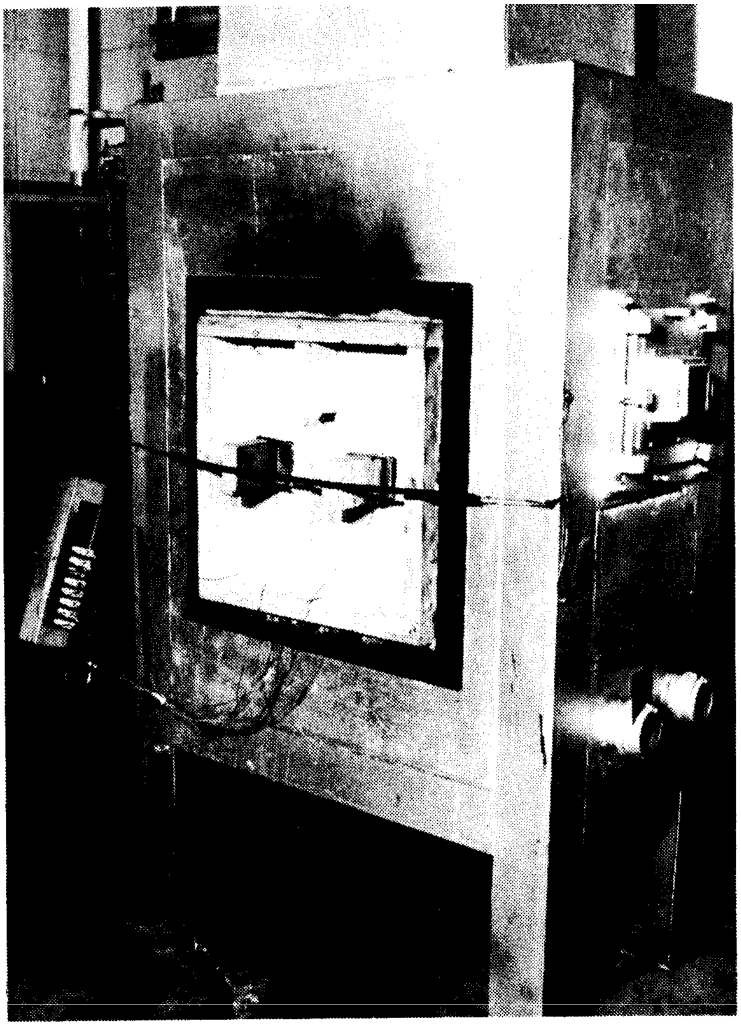

FIG. 2—*Small vertical furnace.*

Equipment

The vertical furnace (Fig. 2) has a 508-mm square opening into which the specimen was inserted. The furnace is equipped with pipe outlets for discharging natural gas into the furnace. Air for combustion was admitted by natural draft through vents at the bottom of the furnace and was distributed with a baffle. A single iron-capped time-temperature curve monitoring thermocouple was located inside the furnace opposite the center of the specimen and 51 mm from the exposed surface of the specimen. The thermocouple was located closer to the specimen than the 152 mm specified in

TABLE 3—*Average test results for fire resistive coatings.*

				Time to 139/181°C[a]		
				Total		
Coating Designation	Number of Tests	Dry Coating Thickness, mm	Dry Coating Weight, g/m²	Mean, s	COV[b], %	Improvement[c], s
			6-MM (¼-IN.) PLYWOOD			
NC	3	0.0	0	210	7	0
F	3	2.9	4940	730	8	530
			16-MM (⅝-IN.) PLYWOOD			
NC	6	0.0	0	670	2	0
E	3	1.4	2010	930	4	250
E	3	6.0	8720	1890	6	1220
F	3	1.9	3320	1070	6	400
F	3	2.8	4840	1300	1	640
G	3	12.7	1640	1230	6	560
G	3	34.8	6120	3320	10	2640
H	3	2.6	3550	1690	7	1020
H	3	6.4	8640	3100	3	2420
			19-MM (¾-IN.) PLYWOOD			
NC	3	0.0	0	870	2	0
F	3	2.6	5000	1610	1	740

[a] Time for unexposed surface of the plywood to reach average of 139°C (250°F) or maximum of 181°C (325°F) above initial temperature.

[b] Coefficient of variation.

[c] Improvement over the time for uncoated plywood. Calculations are based on the individual test results; this may not be the same as the difference in average times.

ASTM Method E 119-82. This was necessary if the thermocouple was to be located between the specimen and the natural gas pipe outlets. It was assumed that this has no appreciable effect on the results.

Test Procedure

The gas supply of the furnace was regulated so the temperature of the iron-capped thermocouple followed the ASTM Method E 119-82 time-temperature curve during the test. The test was continued until all of the thermocouples at the plywood foam-plastic interface had recorded at least a 139°C (250°F) rise in temperature. An average rise of 139°C (250°F) is one of the limiting performance criteria. The specimen was observed during the test through the two observation ports on the sides of the furnace (Fig. 2).

Results

Numerical Results

For each test, the time was noted when the five thermocouples attached to the unexposed side of the plywood recorded an average temperature rise of 139°C (250°F) and when any one thermocouple recorded a 181°C (325°F) temperature rise. The lesser of the two times is reported as the total time. The mean total times for the four fire retardant coatings on 16-mm (⅝-in.) plywood ranged from 780 to 1580 s (Table 2). The mean total times for the four fire resistive coatings on 16-mm (⅝-in.) plywood ranged from 930 to 3320 s (Table 3). The coefficients of variation for the replicated tests were 10% or less. On average, the coated specimens have a significantly higher total time than the uncoated specimens. Individually, all the coated specimens except the single coat of Coatings A or B were significantly better than the uncoated control specimens. The uncoated 16-mm (⅝-in.) plywood had an average time of 670 s.

The difference between the endurance time for the coated specimen from the time for the uncoated specimen, which was cut from the same sheet of plywood, was calculated as the improvement caused by the coating. For the four fire retardant coatings, the average improvement with respect to the uncoated 16-mm (⅝-in.) plywood ranged from 120 to 920s (Table 2). The improvement for the four fire resistive coatings on 16-mm (⅝-in.) plywood ranged from 250 to 2640 s (Table 3).

The average improvements of coated over uncoated plywood increased with the thickness of the plywood.

Visual Observations

Observations of the specimens during the tests were difficult because the natural gas flames from the burner often obscured the view of the specimens. The fire retardant coatings were intumescent coatings that expanded to a thick foamy **layer when** exposed to heat. For the thicker multiple coated specimens, an increase in thickness up to 75 mm was observed, When the expansion was substantial, the foam would sometimes slip from the top to the bottom of the vertical specimen or fall off the specimen. While substantial parts of the foam sometimes fell off, the base of the foam layer remained attached to the plywood. After continued exposure to the fire, the rest of the foamy layer burned away or fell off. Less expansion was observed on specimens protected with one coat. No expansion of Coating B was noticed when only one coat had been applied. In contrast, 75 mm of intumescence was observed with five coats of Coating B.

The main observation with some of the fire resistive coatings was failure of the adhesion of the coating to the plywood. Small blisters formed on the surface of Coating E, and the coating would crack and parts would come off as the test progressed. Coating F either came loose from the plywood or burned away. Coating G remained intact during the test but was not attached to the plywood when the specimen was removed from the furnace after the test. Coating H expanded and remained attached to the plywood.

5/8-in. plywood															
Coating designation	G	H	E	H	D	F	C	G	B	F	A	E	A	B	NC
Dry coating thickness, mm	34.8	6.4	6.0	2.6	0.5	2.8	0.6	12.7	0.5	1.9	0.5	1.4	0.1	0.1	0
Mean total time, s	3,320	3,100	1,890	1,690	1,580	1,300	1,260	1,230	1,160	1,070	1,040	930	820	780	670
Groups of equivalent mean total times	———														
		———													
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1/4 in. plywood								
Coating designation	F	D	D	D	D	D	A	NC
Dry coating thickness, mm	2.9	0.5	0.3	0.4	0.2	0.1	0.5	0
Mean total time, s	730	480	470	450	390	360	350	210
Groups of equivalent mean total times	———							
		———	———	———				
					———	———	———	
								———

3/4 in. plywood				
F	D	A	A	NC
2.6	0.1	0.5	0.1	0
1,610	1,310	1,270	990	870
———				
	———	———		
			———	
				———

FIG. 3—*Grouping of mean results that are not significantly different. (Duncan's multiple range test of uncoated and coated plywood results.)*

Comparison of Results

On average, the fire resistive coatings have a significantly higher total fire resistance time than the fire retardant coatings. The fire resistive coatings were thicker coatings than the fire retardant coatings. Fire retardant coatings are only expected to reduce flame spread. The Duncan's multiple-range statistical test was used to rank the total times for the different types of specimens (Fig. 3). Specimen types were grouped together if their mean results were not significantly different. Because the ranking depends upon the thickness of the coating, it is not a ranking of the different coatings.

Effect of Coating Thickness

Performance of a coating improved as the thickness of the coating was increased as shown in Figs. 4 and 5 and Table 4. For fire retardant Coatings A and B, and fire resistant Coatings E, F, G, and H, the increase in time per increase in coating thickness was calculated for replicated data at two thicknesses. The difference in the means for the two thicknesses was statistically significant for each of the coatings.

The increase for fire retardant Coating D is based on singular tests at five coating thicknesses. Based on the variability of other replicated 6-mm (¼-in.)

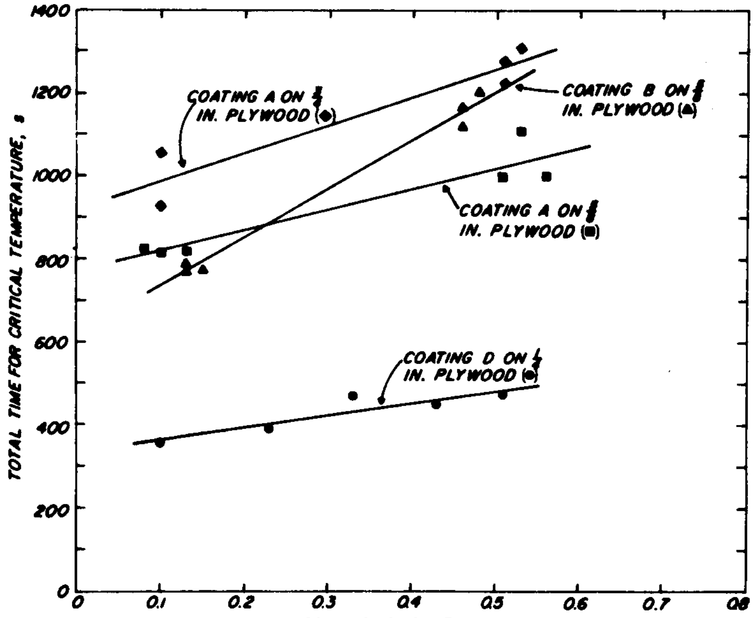

FIG. 4—*Total time versus fire retardant coating thickness.*

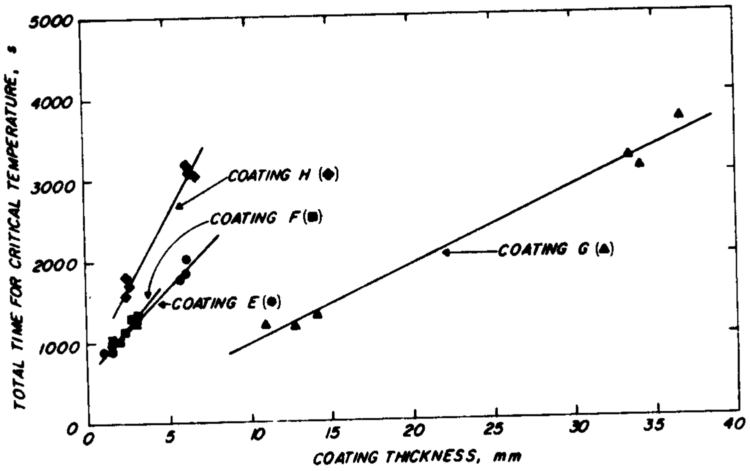

FIG. 5—*Total time versus fire resistive coating thickness.*

plywood tests, the difference between the 0.1-mm-thick and the 0.5-mm-thick Coating D is significant.

For comparison. the increase in time for the uncoated plywood was 70-s/mm increase in the thickness of the plywood.

Effect of Plywood Thickness

In the statistical evaluation of the total times, the plywood thickness by treatment interaction term suggested that the coatings behaved differently on different thicknesses of plywood. This is also shown in the data for the improvements obtained with the coatings. The improvement of the coated plywood with respect to the uncoated plywood increased with an increase in the thickness of the plywood (Fig. 6). See Table 5.

This is because the coatings provide an insulative layer over the plywood

TABLE 4—*Coating thickness.*

Nominal Thickness of Plywood, in.[a]	Coating	Increased Time per Millimetre Thickness of Coating, s/mm
5/8	A	495
...	B	1160
...	E	206
...	F	234
...	G	94
...	H	363
3/4	A	671
1/4	D	293

[a] 1 in. = 25.4 mm.

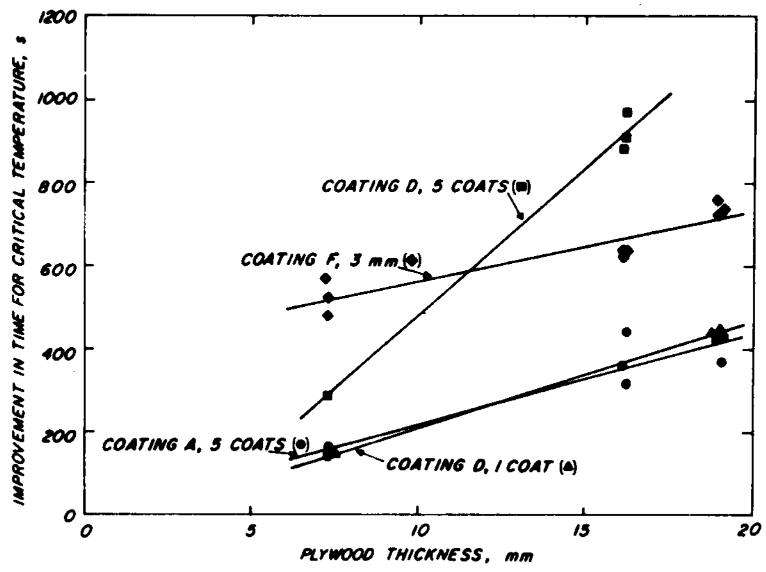

FIG. 6—*Improvement in time versus plywood thickness.*

in addition to delaying the ignition and charring of the plywood. An insulative layer will reduce heat transfer into the substrate. As a result, the time for a temperature rise at a given location in the substrate will be increased. The longer the total time, the longer the insulative layer will improve the performance of the specimen. Because the temperature is recorded at the unexposed side of the plywood, thicker plywood specimens increase the total exposure time. Thus, the improvement shown for insulative coating will increase as the thickness of the plywood is increased.

In addition to plywood thickness, other methodology factors, such as substrate, orientation of specimen, and size of specimen may affect the results. The amount and type of insulation behind the plywood has an effect on the results [*8*]. In previous tests, the results were greater for uncoated plywood when tested over calcium silicate than when tested over foam plastics [*9*].

TABLE 5—*Plywood thickness.*

Coating	Thickness of Coating, mm	Increased Time per Millimetre Increase in Thickness of Plywood, s/mm
A	0.5	22
D	0.1	26
D	0.5	71
F	2.9	17

Tests were conducted on vertical specimens only. Floor ceilings and other horizontal specimens are generally tested for fire exposure from below. Thus, a horizontal orientation of the specimen may have a detrimental effect on results for coated plywood when there is poor cohesion or adhesion of the coating. The 9-m^2 fire-exposed area required by ASTM Method E 119-82 for performance of protective membranes in wall assemblies would better test the ability of a protective membrane or thermal barrier to remain in place than did the small-scale tests performed in this study.

Discussion

Fire resistant coatings have potential for use in several situations. Coatings can be used to improve the fire endurance of the new structural wood products mentioned in the introduction. The coatings can improve the finish rating of panel products used as a thermal barrier for foam plastics. In addition, the development of analytical procedures for predicting the fire resistance of large-timber members should make it more feasible to obtain acceptance for fire resistive coated timber members when a specific fire rating is required.

In addition to the degree of thermal protection, there are other things to consider before using a fire resistive coating. These include properties in areas of (1) durability at normal temperatures, (2) durability at elevated temperatures, (3) smoke and toxic gas hazard, and (4) fire spread and structural stability [*10*]. ASTM test standards are being developed to determine the performance characteristics of sprayed-applied fireproofing [*11*]. Published standards include ASTM Tests for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members (E 605-77), Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 736-80), Effect of Deflection of Sprayed Fire-Resistive Materials Applied to Structural Members (E 759-80), Effect of Impact on Bonding of Sprayed Fire-Resistive Materials Applied to Structural Members (E 760-80), and Compressive Strength of Sprayed Fire-Resistive Materials Applied to Structural Members (E 761-80). ASTM Methods E 759-80 and E 760-80 are for a steel substrate. ASTM Methods E 736-80 and E 761-80 are for any rigid backing. Some considerations not directly related to thermal protection may be important in determining the practical feasibility of using coatings such as application temperatures, method of application, cure time, and water vapor transmission.

The small-scale tests did not involve an applied load on the specimens. Additional research is needed to determine performance of coatings on load-bearing assemblies. To obtain actual in-use performance, details of the total construction must be considered. Unprotected portions of the construction may lead to premature failure. The effect of joints in the membrane must be considered.

The development and use of fire resistive coatings in wood construction will depend upon their cost effectiveness. The economics of applying a coating versus increasing the member cross-sectional area may particularly limit the use of coatings on new products. Coatings are more likely to be an economical alternative when improving the fire resistance in existing buildings. It is hoped the fire resistance data reported in this paper will aid in future considerations of fire resistive coatings in wood construction.

Summary

Four fire retardant coatings and four fire resistive coatings applied to AC, Group 1 plywood were tested for fire resistance in a small vertical furnace using the ASTM E 119-82 time-temperature curve. The coated plywood was installed over a substrate of foam plastic. While a single coat of the fire retardant coatings only produced a minimum gain of 120 s, a gain of 920 s was achieved with multiple coats. With a 0.5-mm-thick flat, alkyd intumescent fire retardant coating, 16-mm (⅝-in.) plywood provided a 1580-s thermal barrier.

As expected, the fire resistive coatings provided more protection than the fire retardant coatings. A 6.4-mm ablative, epoxy intumescent mastic coating provided up to 2420-s improvement over uncoated plywood. With a 35-mm-thick mineral fiber coating on 16-mm (⅝-in.) plywood, a 3320-s thermal barrier (total time) was achieved.

The improvement in tire resistance provided by the coating depended upon the type and thickness of the coating and the thickness of the plywood.

Other performance characteristics and the cost effectiveness of coatings will need to be considered when evaluating possible applications in wood construction.

Acknowledgments

Avco Corporation, Carboline Company, Clark-Tectonics, Inc., Ocean Chemicals, Inc., and Stahl Industries, Inc., provided materials used in this study.

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DISCUSSION

F. G. Schway[1] (*written discussion*)—Can you characterize the fire resistive coating described as Contory H-epoxy? Is it a halogenated epoxy coating?

R. H. White (*author's response*)—Coating H is AVCO's Chartek 59. Chartek 59 coating is described as a filled amine-cured epoxy containing flame retardants. Its composition is considered to be proprietary information.

Neil Schultz[2] (*written discussion*)—What are the names of the manufacturers of the coatings for each type that was used in this project?

R. H. White (*author's response*)—The coatings are as follows:

A—Ocean Chemicals #320, Savannah, Ga.,
B—Ocean Chemicals #477,
C—Ocean Chemicals #777 and #776,
D—Ocean Chemicals #987,
E—Intumastic 285, Carboline, St. Louis, Mo.,
F—STAYTEX 4119A, Stahl Industries, Youngstown, Ohio,
G—Clark-Tectonics, Inc., Madison, Wis., and
H—Chartek 59, Avco, Lowell, Mass.

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[1] Coatings Research Group, Inc., Cleveland, Ohio.

[2] VTEC Laboratories, 540 Faile St., Bronx, N. Y. 01474.

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