Effect of calcium silicate substrate on thermal barrier fire testing

Technical note

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Abstract

A recent revision of the ICBO building code specified the use of a calcium silicate substrate in the fire testing of thermal barriers for foam plastics. Twelve small-scale vertical ASTM E 119 fire exposure tests were conducted on specimens of 1/2-inch gypsum board or 5/8-inch plywood as the thermal barrier and 1/2-inch calcium silicate board or l-inch aluminum foil-faced foam plastic as the substrate. Both the plywood and the gypsum board had a fire resistance of 15 minutes when tested over calcium silicate versus 12 minutes when tested over foam plastics.

With the widely increased use of foam plastic insulation, building codes have required foam plastics to be fire protected from the interior of the building by a thermal barrier. The thermal protection provided by wood-based panelings has been investigated (8). Since completion of those tests, the ICBO uniform building code (UBC) (5) has been changed to specifically require that the protection provided by such thermal barriers meet an index of 15 when tested over a substrate of calcium silicate (4).

The index is defined as the time, in minutes, at which the surface of the substrate being protected from fire reaches either an average temperature rise of 250°F or a single maximum rise of 325°F as the assembly is subjected to specified fire exposure (ASTM E 119 time-temperature curve (1)). The same temperature-rise criteria are also referred to as the finish rating (7) or the protective membrane performance (1).

To determine the effects of the calcium silicate substrate on the thermal barrier test results, our recent study (8) was extended to evaluate the heat transmission performance of the 5/8-inch thick plywood and the 1/2-inch thick gypsum panels with calcium silicate board behind them.

Materials and methods

Specimens were tested in the Forest Products Laboratory (FPL) small vertical furnace which has a 20-inch square opening on its side for placement of test panels. Inside the furnace, a single iron-capped thermocouple was located 2 inches from the center of the fire-exposed surface of the panel. The gas supply was regulated so the furnace temperature followed the ANSI/ASTM E 119 time-temperature curve (1).

Each 20- by 20-inch specimen consisted of the panel produce (either 1/2-in.-thick gypsum board or 5/8-in.-thick plywood) and the substrate (either 1/2-in.-thick calcium silicate board or 1-in.-thick foam plastic) attached to a wood frame (Fig. 1). For the specimens with calcium silicate substrate, a second calcium silicate board was also attached to the unexposed side of the frame in accordance with UBC Standard No. 17.3 (5).

The 5/8-inch-thick five-ply Douglas-fir plywood was grade-stamped "A-C, Group 1, Exterior, PS 1-74, APA" and had a moisture content of 8.5 percent. The 1/2-inch-thick gypsum board was a regular gypsum wallboard without any markings related to fire performance. Both were conditioned at 73°F, 50 percent relative humidity (RH). The foam plastic insulation was a glass-reinforced polyisocyanurate core with aluminum foil facings (2). Calcium silicate board is a noncombustible board used in fire testing in place of asbestos-containing boards (6). Material properties are listed in Table 1.

A vertical joint was located down the middle of the panel products. For the gypsum board, the joint was taped with paper tape and two coats of joint compound.

Nine thermocouples were emplaced at the fire-exposed panel-substrate interface. The 30-gauge iron-constantan thermocouples were symmetrically located (Fig. 1) and attached to the panel with 3-inch-square pieces of duct tape. Three of the thermocouples were placed near the edges of the joint.

Fire exposure was maintained until the thermocouples at the panel-substrate interface recorded an

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TABLE 1. — *Material properties.*

Material	Thickness (in.)	Density (pcf)	R-factor (hr. × ft.^{2} × °F/Btu)
Plywood	0.620 - 0.626	33.2 - 35.3[a]	—
Gypsum board	0.481 - 0.501	39.8 - 42.6[a]	—
Foam plastic[b]	1	2	7.2
Calcium silicate[c]	0.5	46	0.6

[a]Mass and volume as tested after conditioning at 73°F and 50% RH.
[b]Ref. (2).
[c]Ref. (6).

TABLE 2. — *Time to 250° / 325°F temperature criteria.*

Item	Time for each specimen type			
	Plywood and		Gypsum board and	
	Calcium silicate	Foam plastic	Calcium silicate	Foam plastic
	(min.)			
Test 1	14.5	12.5	14.0	12.4
2	14.5	12.2	16.1	12.8
3	14.8	12.8	15.4	11.4
Mean	14.6	12.5	15.2	12.2
Standard deviation	0.2	0.3	1.1	0.7
95% confidence region	14.2-15.0	118-13.2	12.5-17.8	10.4-14.0

average temperature rise of 250°F or maximum temperature rise of 325°F. Three tests were conducted for each of the four types of specimens.

Results and discussion

Results with the calcium silicate substrate were significantly better than those with the foam plastic substrate. For the calcium silicate substrate, the 250° / 325°F temperature-increase criteria were met after 14.5 to 14.8 minutes with the plywood and 14.0 to 16.1 minutes with the gypsum board (Table 2). For the foam plastic substrate, the criteria were met after 12.2 to 12.8 minutes with the plywood and 11.4 to 12.8 minutes with the gypsum board (Table 2).

Because calcium silicate has higher thermal conductivity than the foam plastic, it allows more heat transfer away from the panel-substrate interface, resulting in a slower accumulation of heat and slower temperature rise at the interface.

Differences between the mean values for the gypsum and the mean values for plywood were not significant. The statistical t-test comparisons of the means for the two groups resulted in α values of 0.46 and 0.57 for the calcium silicate substrate and the foam plastic substrate, respectively. (An α of 0.05 or less is generally considered sufficiently strong evidence to reject the hypothesis that there is no difference between the two mean values.) Thus, the possibility that there is no difference between the group means cannot be rejected.

There was greater variability among tests with the gypsum board than with the plywood. The coefficient of variation (COV) for the gypsum board was 6 to 7 percent compared with 1 to 2 percent for the plywood. This variability was apparently due to the performance of the taped joints. In some cases the thermocouple readings for those under the taped joint lagged behind the other thermocouples readings and, in other cases, they increased sooner. On the basis of only the six thermocouples under the solid gypsum board, mean values for the times for the critical temperature rise were only slightly different (11.9 min. vs. 12.2 min. for the foam plastic substrate and 15.5 min. vs. 15.2 min. for the calcium silicate substrate (Table 2)) and the variability was reduced to 2 to 5 percent.

The presence of the joint did not affect the results for the plywood. During the period of critical temperatures, the thermocouples under the joint recorded temperatures consistent with the rest of the thermocouples. On examination of the thermocouple data and of the specimens after the test, it appeared that the joint became tight at the base of the panel for a period before later opening up. This may have been due to moisture being driven from the fire-exposed surface (9) and causing swelling of the plywood near the panel-substrate interface. In some tests, thermocouples near the joint did record significantly higher temperatures than the rest of the thermocouples during the period when the temperatures were less than 212°F. It is not known whether this behavior of the plywood joint would occur in the field or in a large-scale test.

The mean value for the plywood over the foam plastic was 12.5 minutes and is greater than the 10.6-minute mean value obtained before (8) for 5/8-inch-thick plywood conditioned at 73°F, 50 percent RH. In the previous tests, that plywood had a moisture content (MC) of 6.0 percent versus the 8.5 percent in this study. The difference in MC was probably due to the desorption-adsorption hysteresis behavior of wood. The equilibrium MC for a given conditioning depends upon whether the MC is being increased or decreased. In the previous tests, 5/8-inch-thick plywood conditioned to 8.7

percent MC (80.0°F, 65% RH) lasted an average 12.4 minutes, which is comparable to the value obtained in these latest tests. An increase in MC of a panel was found to significantly increase the times to achieve the 250° / 325°F rise in temperature on the unexposed side of the panel (8).

Commentary

The purpose of both the small-scale vertical-exposure furnace test of this report and the UBC Standard No. 17.3 small-scale horizontal-exposure furnace is to evaluate the heat transmission performance of the thermal barriers. Testing for thermal transmission with the calcium silicate backing as specified in UBC Standard No. 17.3 is not representative of actual use of the thermal barriers because of the higher conductivity of the calcium silicate board. The UBC test is intended, however, to provide an equivalent and uniform basis for determining the equivalence of various thermal barriers as alternatives to 1/2-inch regular gypsum wallboard.

Because the FPL furnace test used here is not equivalent in all aspects to the UBC furnace test, the results are not necessarily equivalent to the index classification of the UBC furnace. Nor are small-scale furnace results necessarily equivalent to the finish rating for panels on a full-scale assembly. Neither test determines how long the membrane would stay in place in a large-scale test.

Reproducibility between furnaces that satisfy UBC Standard No. 17.3 may be poor. UBC Standard No. 17.3 is essentially a small-scale ASTM E 119 test. Fifteen minutes is a short time for the conduct of an ASTM E 119 test, which is generally used to obtain ratings of 1 hour or more. Neither UBC Standard No. 17.3 nor ASTM Standard E 119 specify the heating characteristics (e.g, fuel used, type of burners, and ratio of air-to-fuel input) or the furnace chamber characteristics (e.g., properties of all materials forming the boundaries of the chamber). Harmathy (3) considers ASTM E 119 fire tests of relatively short duration (less than 1-1/2 hr.) to be very sensitive to the heating characteristics; the shorter the fire endurance, the poorer is the commensurability. If an ASTM E 119-type test is to be used to detect small differences in fire resistance, the reproducibility between furnaces should be investigated.

While there are possible problems, both small-scale test methods, however, provide valid information in comparing performance of different materials.

Conclusion

In tests of 5/8-inch-thick plywood and 1/2-inch-thick gypsum wallboard panels, times to achieve the 250° / 325°F rise in temperature at the panel-substrate interface for the calcium silicate substrate were significantly higher than those for the foam plastic substrate. For both substrates, differences in the mean values for the gypsum wallboard and the plywood were not significant.

With average results rounded off to the nearest integral minute, both the plywood and the gypsum board had a resistance of 15 minutes when tested over calcium silicate and 12 minutes when tested over foam plastic.

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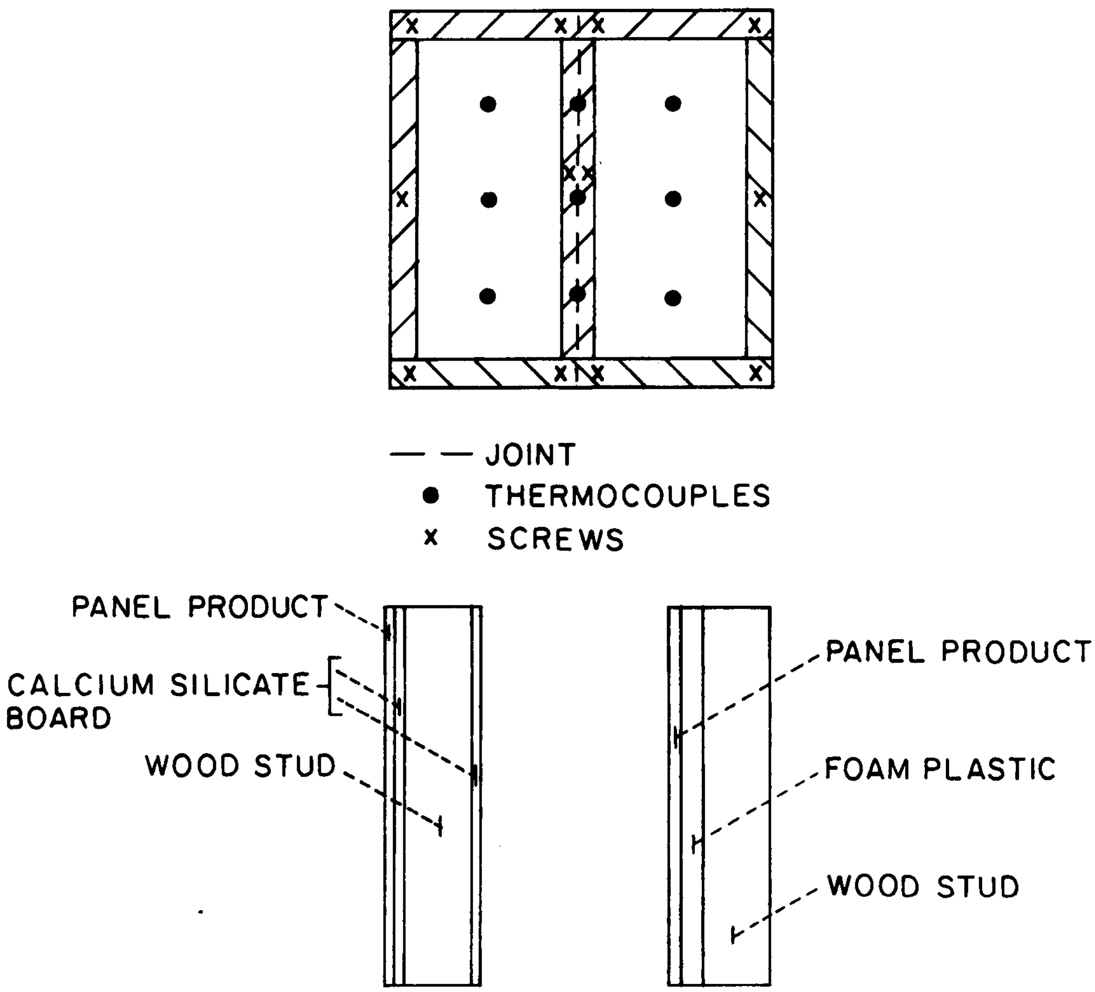

Figure 1.--Diagram of test specimens.