Transition from Room Corner Fire to Flashover in a Compartment with Combustible Walls and Noncombustible Ceiling

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ABSTRACT

Two series of full scale experiments were conducted to analyze the mechanism of the transition to flashover in a room with plywood walls and noncombustible ceiling. Burn tests using a 12.25m x 2.60m x 2.54m(high) enclosure with a propane burner at a corner suggest that the transition is caused by the heating of walls by smoke layer and the smoke layer excess temperature around 350K is the criteria. Measurement of heat release distribution from walls using a 1.65m x 1.65m x 2.50m(high) open-corner apparatus suggest that corner wall of wood in such configuration could generate comparable energy with that from the source, and heat release from the top of wall-corner may become significant enough after the ignition by the strong radiation from the corner ceiling.

1. INTRODUCTION

Lateral flame spread along ceiling or wall is one of the most representative processes of the transition of a room fire from local combustion to full involvement of the room by fire. Control of the combustibility of lining material is important for life safety in buildings. However, at the same time there is considerable needs to use wood for interior linings, especially for walls, for acoustic performance, thermal comfort and aesthetics. In order to develop a guide for fire safety design with wooden walls in buildings where the Japanese regulation requires fire protective materials for both walls and ceiling, effectiveness of the use of noncombustible material to the ceiling is examined by experiments. The study consists of two series of experiments, full-scale room fire tests and open-corner fire tests, both with wood as the wall surface and a 0.3m square propane burner as the ignition source. The room fire tests intended to clarify general mechanism of the transition to full involvement of enclosure by fire in such configuration. The open corner tests intended to characterize the heat release from wooden wall in a corner fire configuration. Before each experiment, the specimen was conditioned at 50± 5 % relative humidity and 23± 2℃ temperature.

2. ROOM CORNER EXPERIMENTS

(1) Experimental Description

The experiments were conducted in a 12.25m x 2.60m x 2.54m(high) enclosure(Figure 1). All walls and ceiling were built with 15mm thick cement boards. The burner was placed at one corner of the room. The two walls adjacent to the burner were covered with 12mm (nominal) thick combustible material; while the tests were made on various products,

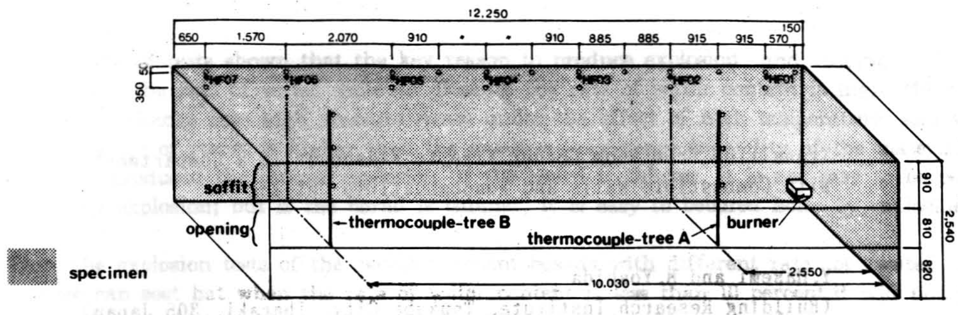

Figure 1 Test enclosure and mesurement arrangements(● : heat flux gage, o : thermocouples)

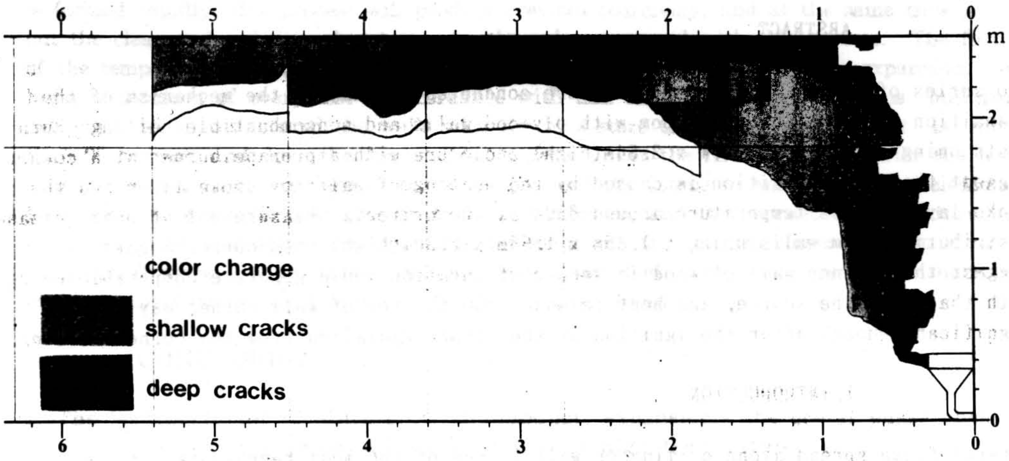

Figure 2 Ultimate burn pattern(plywood)

description will be made mostly on lauan plywood. The longer wall apart from the burner had a 0.81m high opening with the same width as the wall; the height of the soffit above the opening was 0.91m. At the design of the experiments it was intended that smoke layer comes down to the upper edge of the opening. Heat release rate(assuming complete combustion) from the gas burner was 100kW from the ignition to 10 minutes and 300kW from 10 to 20 minutes. It has been reported that flashover takes place at around 2 minutes after the ignition at the ISO Room Corner Test which uses the identical heat input for the ignition source.[1,2] Temperature of the wall- and ceiling-surface and air, and heat flux were monitored with type K thermocouples and Gardon-type heat flux gages respectively on the wall 50mm beneath the ceiling. Each heat flux gage was cooled with 60～65℃ water to prevent dew generation on its surface. Visual observation was made both with eyes and video camera during each test. Ultimate burn pattern was recorded after each test.

(2) Experimental Results

Figure 2 shows the ultimate burn pattern for lauan plywood; in this test, flame did not develop to the another end of the longer wall. It should be noted that thick char was not observed beneath the height of the upper edge of the opening except for the wall close to the burner. According to visual observation during the test, it seems that the charred surface with small and large cracks in Figure 2 was covered by thick flame; the

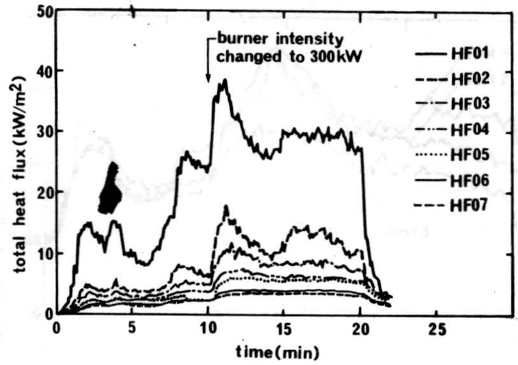

Figure 3 Heat flux to the wall surface(plywood)

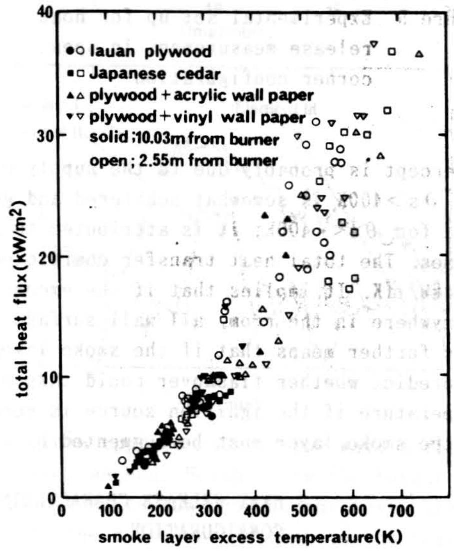

Figure 4 Correlation between total heat flux to the wall surface and smoke layer temperature (summary from all tests)

limit of the cracked surface should be a measure for the limit of the area which fed the flame with combustible gas. Figure 3 shows time histories of heat flux. The first peak at 1.5 minutes after the ignition at HF01 is due to the ignition of the corner wall, and the second notable rise at HF01 at around 8 minutes is probably due to the penetration of the plywood board by thermal wave. It is noteworthy that crack was observed only on the surface where heat flux exceeded continuously 14kW/㎡. Therefore, the value, 14kW/㎡, should be appropriate as rough estimate for the critical condition for the lateral flame spread of this material in such configuration. This value is close to the critical heat flux for ignition and somewhat greater than the flame spread criteria for this material estimated from LIFT apparatus. The critical value for Japanese cedar estimated similarly seems to be slightly smaller, around 12kW/㎡, probably due to its smaller $k\rho c$ value. The fact that flashover did not take place in the present tests implies the general effectiveness of noncombustible ceiling.

Figure 4 shows the correlation between the heat flux and excess temperature of the smoke layer , θs, summarized from all tests conducted. In every experiment, there was considerable difference in the air temperature at the same height between the two thermocouple trees; the heat flux and the smoke layer temperature measured at the same distance from the shorter wall adjacent to the burner were used for the correlation. The heat flux to the wall surface exposed to the smoke layer is almost proportional to θs for $\theta s < 400K$ with the intercept with the horizontal axis at around 80K; this

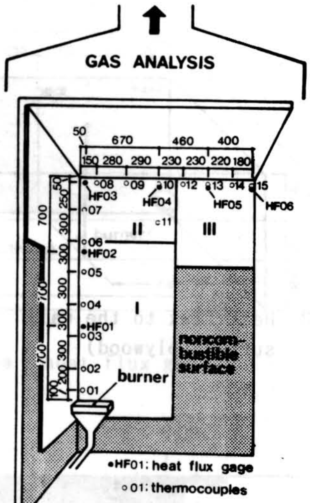

Figure 5 Experimental set-up for heat release measurement in open corner configuration

intercept is probably due to the supply of hot water to the heat flux gages. Heat flux for $\theta s > 400K$ is somewhat scattered and generally larger than extrapolation from the data for $\theta s < 400K$; it is attributed to the contiguity of the surface to intermittent flames. The total heat transfer coefficient for $\theta s < 400K$ is estimated as $K = \partial q / \partial \theta s \fallingdotseq 0.04 kW/m^2K$. It implies that if the excess temperature of the smoke layer exceeds 350K everywhere in the room, all wall surface exposed to the smoke layer may get ignited. This further means that if the smoke layer temperature is calculated it become possible to predict whether flashover could take place. Flashover may occur at lower smoke layer temperature if the ignition source is more sooty, since the heat transfer coefficient of the smoke layer must be augmented by soot.

3. HEAT RELEASE CHARACTERISTICS OF WOODEN WALL IN CORNER-WALL CONFIGURATION

Chapter 2 suggests that the heat balance around the somke layer is the key problem in the evaluation of the criticality. Among many components of the heat balance, it is undoubtedly the heat release from lining material at the wall-corner that is the most poorly understood.[3, 4] There are numbers of zone models to estimate the smoke layer temperature in a burn room, however most of such models assume noncombustible linings or use experimental data of heat release as a given condition. In order to characterize release behavior of wall fires in the corner-wall configuration, a trial was made to measure time history and distribution of heat release due to the combustion of lining material in an open corner configuration.

(1) Concept of the Measurement of Heat Release Distribution

Despite the importance of the information on the heat release distribution, its direct measurement is virtually impossible. However, if it is assumed that the heat release characteristics of any part of the lining is not affected by the pyrolysis from any part downstream of that point, heat release distribution can be measured indirectly by repeating heat release measurement by decreasing the combustible surface gradually from the downstream and then taking differences of heat release.

(2) Experimental Description

Figure 5 shows the experimental set-up; the walls and ceiling was built with cement

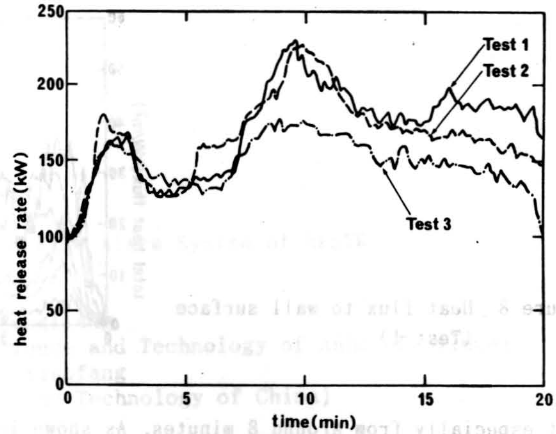

Figure 6 Heat release records from the three tests

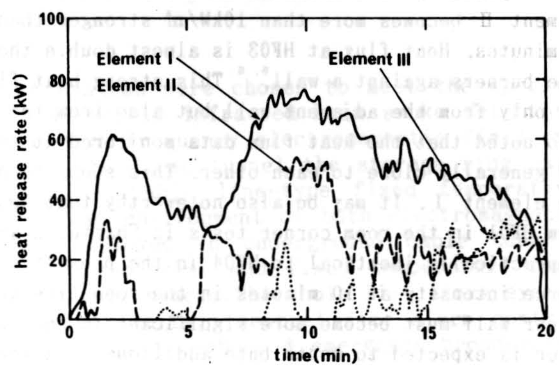

Figure 7 Estimated heat release rate from each element

board, and 12mm(nominal) thick lauan plywood was then applied only to the wall surface. Heat release rate was measured by oxygen consumption method. Height from the burner surface to the ceiling was arranged to become identical to the room corner test. The wall was divided into three elements, according to the relative location to the height of the flame from the propane burner measured at a preliminary test with noncombustible walls, element I beneath the solid flame height near the corner, element II up to the ceiling, and element III for the part where the flame spreads only laterally just beneath the ceiling. Heat release measurement was repeated by decreasing the surface elements one by one. Heat release rate from the burner was 100kW±7kW. Surface temperature and heat flux to the wall surface were measured similarly with Chapter 2.

(3) Experimental Results

Figure 6 summarizes the heat release records. It is noteworthy that heat release from the plywood is comparable to the heat source intensity; this suggests the general importance of the combustion of lining material as heat input to the smoke layer. Figure 7 shows the heat release from respective elements of the plywood estimated from Figure 6. Strong peaks of heat release from element I starting at 1.5minutes and at 7.5 minutes should be due to ignition by the burner flame and penetration of the specimen by thermal wave respectively. Similar characteristic two peaks are seen also at element II, but it is important to note that the strong heat flux plateau from 9.5 minutes to 11 min is only slightly smaller than the whole heat release from element I although element II is farer from the burner than element II and the ultimate burnt area in element II was only 40% the area in element I. This significant heat release from the top corner implies importance of the combustion of the top part of corner walls for energy balance of the smoke layer and is probably due to the strong heating of this

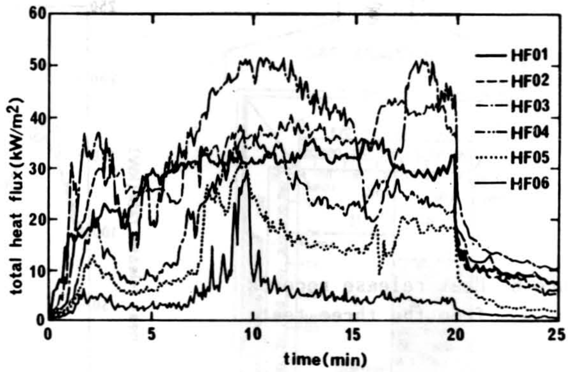

Figure 8 Heat flux to wall surface (Test 1)

part especially from around 8 minutes. As shown in Figure 8, heat flux at HF03 in element II becomes more than 10kW/m² stronger than the values at element I at around 10 minutes. Heat flux at HF03 is almost double the reported value for wall fires and line burners against a wall.[5,6] This strong heat flux is clearly due to the radiation not only from the adjacent wall but also from the ceiling at the corner. It should be also noted that the heat flux data monitored at two different height in the element I are generally close to each other. This seems to endorse relatively uniform heating in the element I. It may be also noteworthy that heat flux at HF04 is close to the data from HF01 in the room corner tests in Chapter 2 whose relative location to the burner is practically identical to HF04 in the present test until the change of the ignition source intensity at 10 minutes in the room fire tests. Heat release from the top of a corner wall must become more significant in room corner configuration, since smoke layer is expected to contribute additional heating to this part of the wall.

4. CONCLUSIONS

While the experimental conditions were quite limited, the following conclusions could be drawn on fires in an enclosure with wood walls and noncombustible ceiling.

1. Use of noncombustible ceiling is effective for delay or even prevention of the occurrence of lateral flame spread along the walls.
2. Heating of the wooden walls by smoke layer is the key process leading to the lateral flame spread along the walls. The total heat transfer coefficient is $K \fallingdotseq 0.04 kW/Km^2$.
3. In the fire scenario with a fire source in a room corner, combustion of the wooden lining has significant influence on the temperature rise in the smoke layer.
4. Heat release from the top part of a wall corner may become important by the radiation from ceiling even if it is not directly heated by the ignition source.

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