Role of Initial Burning Objects in the Fire Growth in a Large Enclosure-Experiments for the Investigation of a Recent Timber Gymnasium Building Fire

D. Nam[1], Y. Hasemi[1], K. Kagiya[2], and T. Harada[3]

[1]Department of Architecture, Waseda University, Tokyo, Japan
[2] National Institute of Land Infrastructure Management, MLIT, Ibaraki, Japan
[3] Forestry and Forest Products Research Institute, Ibaraki, Japan

Abstract

The fire, occurring in October 2000 in Hiroshima Pref. Japan, is the first blaze in Japan that has totally burned a large-scale glue-laminated timber gymnasium. The fire also deserves close attention in terms of fire safety engineering because flashover rapidly occurred in only 9 minutes from the activation of the fire detector. The extent of char layer of the members was collected to estimate the process of the fire spread in gymnasium. A series of burning tests were conducted on the combustible objects suspected as the source of the extensive fire growth to clarify why the fire spread so rapidly in the gymnasium where a flashover had been least anticipated. The cause of the flashover was finally estimated by comparing the extent of the total heat release of respective specimens with the total heat release required to cause flashover in the whole arena. Any of countermeasures is indicated to reduce the hazard of fire anticipated in such gymnasium.

1. Introduction

The fire occurred in October 2000 at a gymnasium of a junior high school in Fukuyama City, Hiroshima Pref., Japan, and burned the whole building of a 979 m^2 large heavy timber construction. Although it did not cause any victims nor led to the collapse of the load bearing components, the fire is still very significant from scientific and technical points of view. The flashover occurred in only 9 minutes from the activation of pressure tube detector before the arrival of fire engines, and it is Japan’s first large fire in heavy timber construction. The rapid occurrence of flashover was surprising enough as such gymnasium had been believed not to cause flashover because of its rather small fire

Corresponding Author- Tel.: +81-3-5286-3851;
Fax: +81-3-3209-7214
E-mail address: nam@akane.waseda.jp

load. Photograph1 is a picture taken immediately after the arrival of the fire –fighting squad.

The fire did not cause casualty only because the fire took place during a lunch break. It is believed that if the building had been filled with children or even aged people as such country school gymnasiums are often used for local events, the fire would have caused large numbers of victims. Identification of the process of the fire growth is important, as there are numbers of very similar gymnasiums in the prefecture and other parts of Japan.

2. The building

The gymnasium, built in 1997, was composed of the reinforced concrete first floor and the heavy timber posts and arches (Figure 1). The floor, the wall and the ceiling of the arena were finished essentially with wood-based materials. Table 1 shows major inner finishes. The gymnasium, over 30m apart from other buildings of the school, is made with a total floor space of 979 m^2.

2.1 Source of the fire

Figure 2 is shown to the source of the fire and its surroundings. The fire began in the southeast corner of the gear supply storage on the east side of the second floor next to the stage. There were 15 tatami mats and one urethane mattress in the gear supply when the fire broke out. The urethane mattress was rested against the wall. The storage where the fire started was open to the stage side, and was surrounded by the plywood wall on the remaining 3 sides. The ceiling of the storage was enclosed by a cemented excelsior board and its floor was made of reinforced concrete (RC). The proscenium arch between the stage side, including the gear supply storage, and the indoor arena has plywood (5.5 mm thick) finish on the stage side and cemented excelsior board finish with vertical grids of glue-laminated timber on the arena side.

Photo1. Picture record of the fire (from the west side)

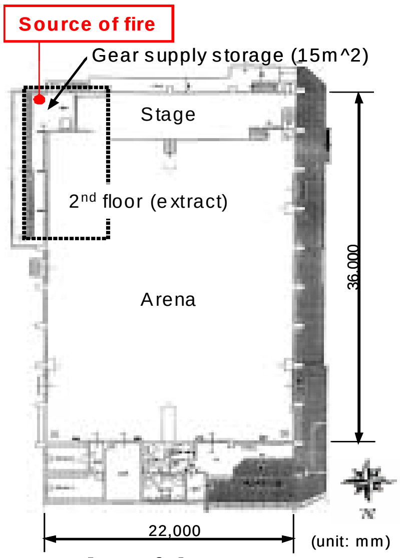

Figure1.Plan of the gymnasium

Table1.Major inner finishes (unit:mm)

	Floor	Frame	Wall	Ceiling
Arena	Gypsum board (12), Wooden flooring (15) with polyurethane resin coating	Glue-laminated timber (30)	Cemented excelsior board (30), Finishing plywood (12)	Cemented excelsior board (25) with paint
Stage	Gypsum board (12), Wooden flooring (15) with polyurethane resin coating	Timber (25)	plywood (5.5), mortar on concrete surface	Cemented excelsior board (25) with paint
Gear supply storage	Mortar (30)	Glue-laminated timber (30)	plywood (5.5)	Cemented excelsior board (25) with paint

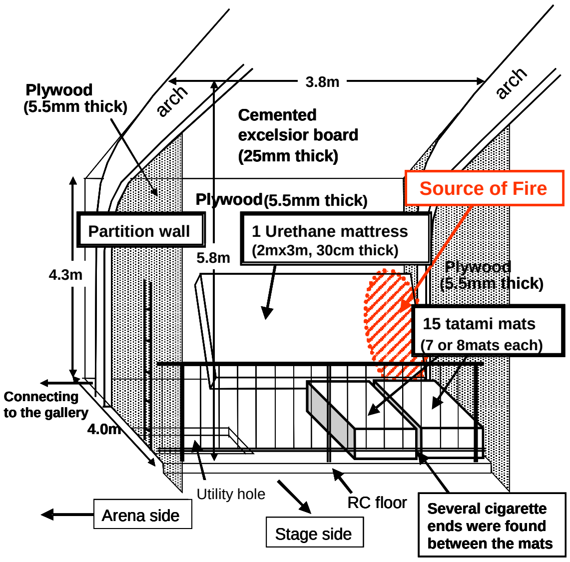

Figure2.Source of the fire and its surroundings

2.2 Time lapse of the fire

Table 2 shows the time lapse from the occurrence of the fire to its extinction based on the information obtained from hearings held at the site of the fire and in the municipal office as well as from newspaper articles about the fire.

Table2.Time lapse of the fire

Time	Event
12:30	A teacher found pupils gathering in the gear supply storage and picked up several cigarette ends from the gap between an urethane mattress and tatami mats. (Newspaper article)
12:49	Though teachers who noticed fire outbreak by fire detector, tried to suppress the fire, the fire already had reached the ceiling and too large for them to extinguish. (Newspaper article)
12:51	The windows broke and the flame was ejected from the stage side to opposite side of the gymnasium one after another in not so long time. (Newspaper article)
12:58	Fire brigade arrived and began to hose. (Fire department) The whole gymnasium went up in flames. (Fire department)
13:10	Fire was suppressed. (Fire department)

The fire reached flashover within 9 minutes after the activation of the pressure tube detector, and the post flashover fire lasted for 20 to 30 minutes irrespective of the efforts of the fire fighters. Almost all combustible objects and building components except for the heavy timber frames were lost, while the load bearing components including the reinforced concrete part survived without collapsing.

3. Estimation of the fire spread in the whole building

3.1 Investigation on the depth of char layers

The process of the fire spread was estimated from the char layers on the members of the fire-damaged building although the fire spread in the arena during the fire is not recorded sufficiently. Samples of the arch members were collected when the fire-damaged building was pulled down and then transported to the Forestry and Forest Product Institute for investigation. Figure 3 shows the position of the collected members. Because of the restriction on the period of the dismantling and maximum carrying capacity of the truck transport, 4 parts of members were collected for estimating the fire spread from the source of fire to whole building.

3.2 Estimation of the fire spread

Figure 4 illustrates the depth of the char layers. The deepest char layer is 18mm at the bended post on the east side of the storage (line number 2). The upper arch (block number 2) on the east side of the line number 3 was carbonized with the depth of 16 mm extensively. The lower arch and the whole arch of the west side in the line number 3, the upper arch of the line number 6 and the upper arch of the east side in the line number 9 were extensively carbonized with the depth of 12～14mm. In the upper stage of the line number 2 except for the bended post near the fire source, the depth of char layer is shallower than in the block number 2 of the line number 3.

In general, the conventional char layer growing velocity based on the fireproof heating test is estimated as 0.6 mm/min [1][2]. The carbonized speed of the glue-laminated timber in damaged-building was estimated as 0.67 mm/min, because the bended post of the line number 6 and 9 inspected from the outside during the fire was carbonized with the depth of 8 mm against the heating duration time of 12 minutes. This carbonized speed in damaged-building exceeds only 10 % against the conventional char layer growing velocity. Assuming that the carbonized speed does not change without relation to part of the timber, the flame from the fire source of the stage openings spouted out to the arena and spread to the arch of the line number 3. This flame after 3 minutes spread to the upper ceiling of the line number 6 at 16 m away from the wall of the arena, and this flame also spread to the upper arch of the east side in the line number 9 at 12 m away from the wall of the arena.

The stage and the wall of the arena was estimated to burn extensively and at the same time the ceiling of the arena was also burning extensively which means the process of the fire growth in the ceiling of the arena extensively was caused by the burning of the wall of the storage, because the depth of the char layer in the arch of the line number 2 is approximately the same to the upper arch of the line number 6 and the upper arch of the east side in the line number 9. Also the process of the fire growth in the arena was estimated to precede the east side near the fire source, because the arch of the east side is deep

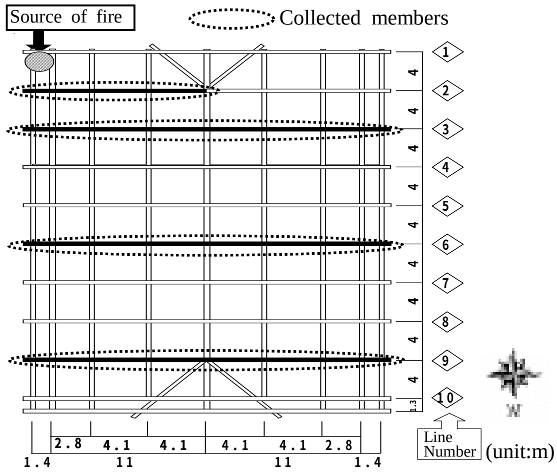

Figure3.Position of the collected members

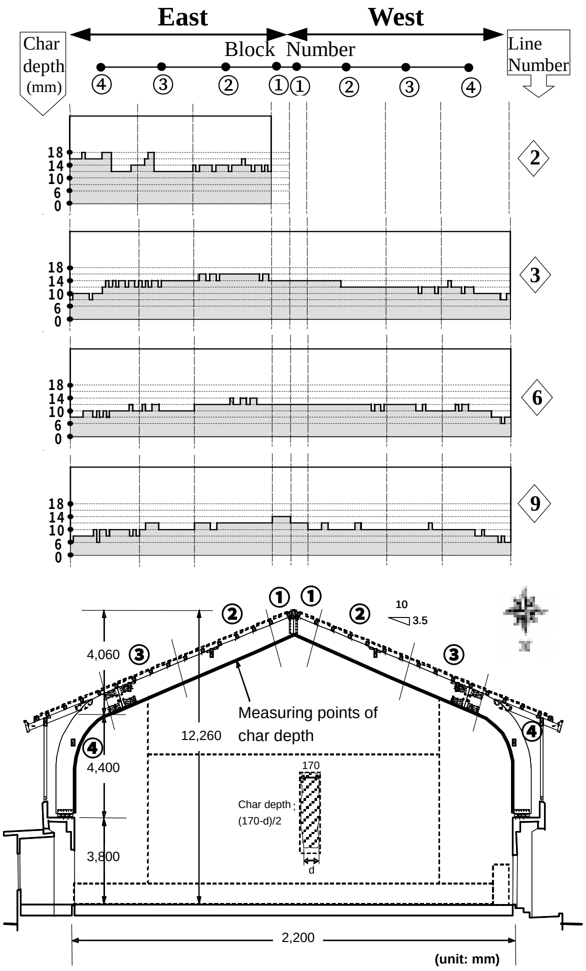

Figure4.Depth of char layers

against the arch of the west side on the depth of the char layer in the line number 9.

In the line number 3,6 and 9, the bended post near the storage openings was carbonized with the depth of approximately 8 mm but the upper arch was carbonized with the depth of approximately 12 mm. It is believed that the spouting flame from the storage openings took approximately 6 minutes from burning the lining of the ceiling in the arena. If the spouting flame from the storage openings was calculated backward from 12:58, the flame from the stage was estimated to spout out to the arena at 12:49, and the upper arena was estimated to burn extensively at 12:52 after burning the wall in the storage: it is comparable with the reported time lapse (Table 2).

In addition, the heating time of the structural members from Table 2 took approximately 20～30 minutes from the impossible phase of the fire fighting in the storage until the fire was suppressed. From Table 2 it took approximately 12 minutes in the arena from flashover until the fire was suppressed. The heating duration time is calculated for approximately 27 minutes, as the glue-laminated timber near the fire source was carbonized with the depth of 18 mm against 0.67 mm/min of the carbonized speed. The heating duration time near the fire source corresponds to 20～30 minutes from the fire record (Table 2).

4. Estimation of the mechanism to flashover

4.1 Experiments

Experiments have been conducted using mock-ups of combustible objects to verify the estimated causes and mechanisms for the fast flashover. Firstly, a series of burn tests were carried out on the urethane mattress and the tatami mat to obtain general information on the burning behavior of the main combustibles stored in the storage and to identify the first ignited object. Secondly, burning tests using a mock-up of the internal partition finished with plywood separating the storage and the arena were conducted in order to see the detailed process of the ignition and fire spread in the partition and estimate the scale of the fire after the wall was ignited. The wall specimen was built according to the original drawing of the building.

In the experiment, the major measurement item was heat release rate by the oxygen consumption method, and the data were recorded at every two seconds. In addition, the following were also carried out: visual observation of the surface and back surface of the specimens, thermocouples (wall test only) and the VTR image recorder. Table 3 summarizes the experiment condition.

Table3. Experiment condition

Experiment NO.	Specimen	Dimension (cm)	Propane		Remarks
			Flow rate (l/min)	Time (sec)	
1∗	Urethane mattress	100×50 ×30(1/12)	13	80	The urethane mattress was filled with polyurethane and was lined with cotton covering
2∗		100×100 ×30(1/6)	12	90	
3		100×100 ×30(1/6)	12	90	
4∗	Tatami mat	91×181 ×6	13	80	The tatami mat is composed of thin plywood in the center, foamed polystyrene slabs, and PVC
5	Partition wall	182×182 ×25.5	13	80	Figure7,8
6			25	until the burn-through	

∗： California State Bulletin 133, Furniture Burning Test

Urethane mattress

The same urethane mattress stored in the storage of the fire-damaged building was used for the tests. Since it was anticipated that a full burn test of the mattress make an extreme fire, a 1/12 of the original product measuring 100 cm× 50 cm was used as the specimen. In experimet1, a square pipe burner with injection holes (to be referred to a CSB133-Burner) was installed 3 cm above the center of the urethane mattress that was placed horizontally (Photo 2, Table 3, Figure 5). 13 L/min propane fuel was supplied for 80 seconds to make a 20 kW

Photo2.Urethane mattress

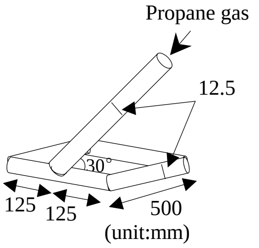

Figure5. CSB133-Burner

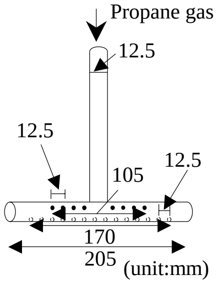

Figure6.T-Type burner

laminar flame. Two further experiments were carried out with a urethane mattress of 1/6 size used for the experiment. In experiment 2, CSB133-Burner was installed as the same position as at experiment1, with the specimen placed horizontally on the floor. In experiment 3, a “T” shaped pipe burner with injection holes along the 205 mm long front pipe (T-Type burner) was installed at a position 5 cm away from the lower end, with the specimen resting against the nonflammable wall (Table 3, Figure 6).

Tatami mat

The same tatami mat stored in the storage of the fire-damaged building was used for the experiment. CSB133-Burner was installed 3 cm above the center of the tatami mat that was placed horizontally (Photo 3, Table 3)

Photo3. Tatami mat

Partition wall

①Test specimen

The partition wall was framed by timbers and covered by a layer of 5.5 mm plywood on the storage side and wood fiber reinforced cement board on the arena side (Figure 7,8). Glued laminated timber sticks were perpendicularly stuck on the wood fiber reinforced cement board in the 10 cm interval. The studs were placed at the interval of 45 cm not to make gap between any of the cavity spaces. The top of the cavities of each specimen was left open as there were not any horizontal partition bars in the original wall. Concrete blocks were placed under the specimen and fireproof adhesive was applied in order to remove gaps between the wall and the blocks.

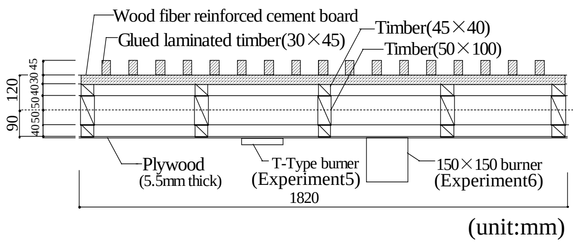

Figure7. Horizontal cross section

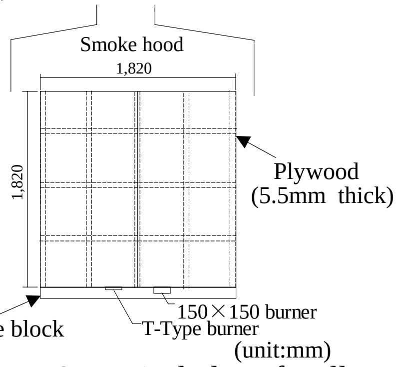

Figure8. Vertical plan of wall

②Test condition

Two experiments were carried out on the wall specimen.

In experiment 5, T-Type burner was located in front of the second left cavity of the specimen 10 mm below the bottom of the wall. 13 L/min propane fuel was supplied for 80 seconds. After confirming that no penetration had occurred into the cavity, the burner was reignited and the fuel was supplied at the same rate until the burn-through was confirmed. The experiment 6 was conducted with a 15 cm square diffusion burner in front of the second right cavity at the 10 mm below the bottom end of the wall. 25 L/min propane fuel was supplied throughout the experiment.

4.2 Experimental results

Urethane mattress

Experiment 1: The specimen began to burn actively with black smoke soon after the ignition. The top of the flame height reached 1.8 m after one minute, and 2.3 m after 2 minutes. Terrific flame was seen in 2 minutes after the ignition. During the test, the burning area spread radially on the specimen surface, and almost the whole specimen was finally burnt out in 6 minutes. Figure 9 shows time history of heat release rate (HRR) and total heat release (THR) for the urethane mattress of 1/12 size.

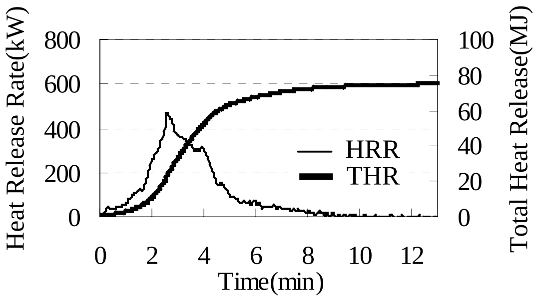

Figure9.Experiment 1(Urethane mattress 1/12, horizontal)

The heat release rate in the experiment reached the maximum, 463 kW, or 331 kW per surface area of the urethane mattress (m^2) at 2 minutes 36 seconds after ignition, resulting in rapid burnout. Since the specimen was a 1/12 of the original product, the heat release rate, 331 kW per surface area of the urethane mattress, could be interpreted that a full mattress could make a 2977 kW fire.

Experiment 2, 3: Figure 10 and Figure 11 respectively show the heat release rate and the total heat release at experiment 2 where urethane mattress was horizontally placed and at experiment 3 where it rested against the nonflammable wall.

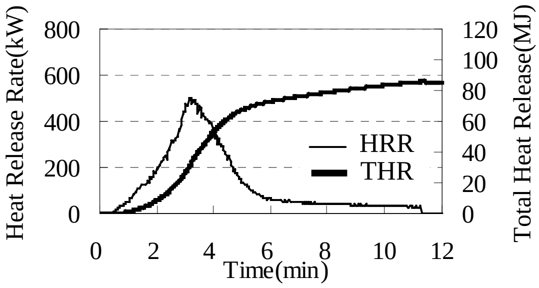

Figure10.Experiment 2(Urethane mattress 1/6, horizontal)

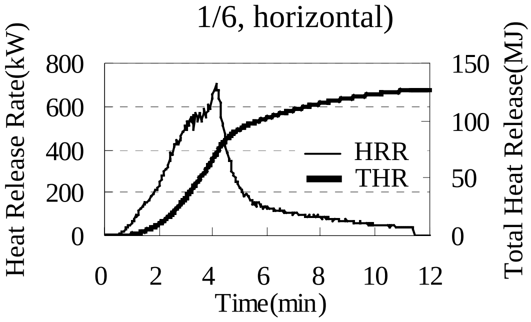

Figure11.Experiment 3(Urethane mattress 1/6, vertical)

As an experiment1, the specimen flared up into flames in a few minutes, but it is obvious that the peak heat release rate was greater than at experiment 1. The heat release rate was greater and the spread of the flames was faster at experiment 3 than at experiment 2. As far as the surface of the flammable materials is concerned, the difference is considered due to the faster spread of the flames on the wall surface than on the upward plane surface, as well as being responsible for the mechanism of the flames. The heat release rate in the experiment 2 reached the maximum, 501 kW, or 228 kW per surface area of the urethane mattress (m^2) at 3 minutes 10 seconds after ignition. Since the specimen was a 1/6 of the original product, the heat release rate, 228 kW per surface area of the urethane mattress, could be interpreted that a full mattress could make a 2050 kW fire.

Although the size of the specimen in the experiment 2 is two times of the specimen in the experiment 1, the peak heat release rate of the experiment 2 is lower than two times of the experiment1.

Tatami mat

Experiment 4: Figure 12 shows time history of the heat release rate for the tatami mat.

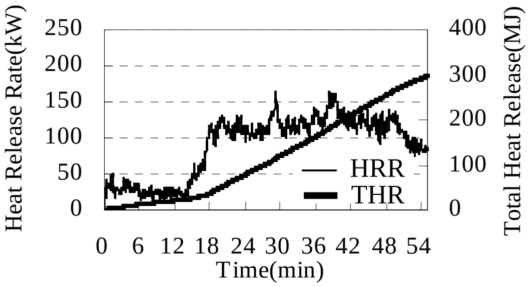

Figure12.Experiment 4 (Tatami mat)

The heat release rate remained at a low value for 15 minutes after the specimen caught fire. The heat release rate in the experiment reached the maximum, approximately 120 kW, or 61 kW per surface area of the tatami mat (m^2). The tatami mat demonstrates rather weak burning, and the low heat release rate and the time to the acceleration of burning longer than the reported flashover time in the fire indicate that tatami mat was not important in the growth of the fire.

Partition wall

Experiment 5: The wall surface started burning first when an ignition burner brought into contact with the wall, but there was no fierce flare-up. When heating was discontinued at 80 seconds thereafter, the fire faded away in approximately 40 seconds. When the specimen was reignited 5 minutes 40 seconds after the first ignition, the fames spread the upper end of the surface of the specimen. After the wall surface burned out in 6 minutes after the reigniton, the hollow section between studs that was in contact with the burner started burning out and the flames continued fiercely. The burner was taken off after 6 minutes 30 seconds from the reignition and the fire faded away again at 12 minutes. After the experiments, the inner part of the wall was examined and it was found that the fire did not spread horizontally beyond the studs, and there was no damage in the timber reinforced cement board on the reverse side.

Figure 13 shows time history of the heat release rate of the experiment 5. The heat release rate reached the maximum, 196 kW namely 436 kW per unit width of the wall (m), at 6 minutes 43 seconds after the reignition.

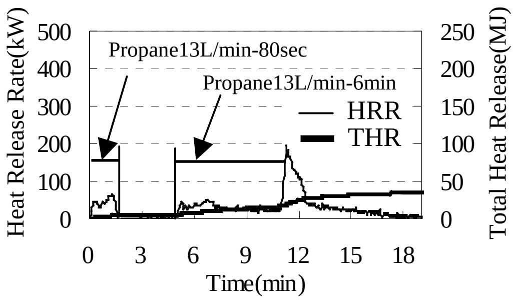

Figure13.Experiment 5 (Partition wall)

Experiment 6: while the ignition burner produced a 2.1 m tall flame along the burner, the wall began to burn only at 5 minutes after the ignition and continued to burn for 2 minutes. Black smoke appeared from the timber reinforced cement board in 21 minutes after the ignition. When the wall was examined after the fire had faded away at 33 minutes 30 seconds, it was found that the fire did not expand beyond the studs, but the timber reinforced cement board was slightly damaged. Figure 14 shows the heat release rate reached sharply the maximum, 407 kW namely 905 kW per unit width of the wall (m), in approximately 6 minutes after ignition.

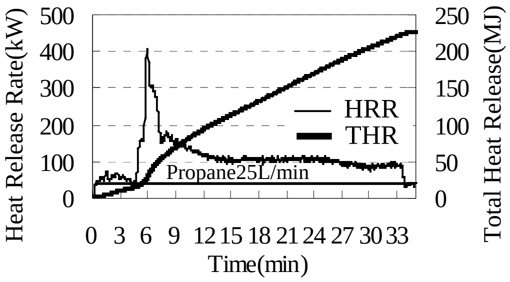

Figure14.Experiment 6 (Partition wall)

In experiment 5 and 6, while it took relatively long time until the wall surface was ignited, the plywood as penetrated into the cavity and burnt up quickly once it was ignited. The flaming remained within the 45cm wide cavity confined by studs in front of the fire source in both experiments. The delayed ignition to the surface is attributed to the rather weak intensity of the ignition source used for these tests. The peak of the heat release rate of experiment 6, in which the fire source intensity was bigger than experiment 5, appeared earlier than in the experiment5; it means that the greater the fire source is, the earlier the wall begins to burn.

4.3 Estimation of the mechanism of flashover

Now let us discuss the dynamics of the rapid growth of this particular fire on the basis of the experimental results. Although the restriction of the test facilities did not allow burn tests in the original size, the test results demonstrate notable difference of the combustion behavior among the objects and the building elements located near the estimated fire origin. We try to estimate the cause for the flashover by comparing the estimated extent of total heat release of respective objects with the energy required to cause flashover in the whole arena.

From experience in fire investigations and large scale burn tests, it is believed that, if the smoke layer temperature rises enough to ignite combustible floor or furniture on the floor by radiation, flashover may occur even if the ceiling is incombustible. So energy balance equation for the smoke layer in the arena is analyzed to estimate heat release necessary for the smoke layer temperature to reach this critical temperature, which is normally taken as 600℃. In order to relate the critical temperature directly with the energy necessary to cause flashover, G_f, the energy balance equation is integrated over time as Equation (1). In equation (1), convective heat loss through the ceiling and the upper walls are neglected for the uncertainty in the estimation and radiative fraction of heat release is assumed as 0.3, which is around the minimum in real fires. The energy to be projected from openings are ignored assuming the disclosure of the window before the flashover; while the last assumption is consistent with the witnesses, these assumptions should lead to underestimate of the energy actually released at the fire before flashover. Therefore, the energy calculated from equation (1) should be interpreted as the minimum energy necessary to cause flashover in the arena. No objects not releasing this estimate can alone cause flashover in the arena.

$$V_s \Delta T \ \rho_S C_p = \int_0^t (Q - Q_L)\, dt$$

$$= (1-r)\int_0^t Q dt$$

$$= (1-r)G \quad \cdots (1)$$

Where V_s is volume of the smoke layer [m^3], ρ_S is density of smoke [kg/m^3], C_p is specific heat of the air (=1.0kJ/kgK), Q is heat release rate [kW], Q_L is radiative fraction of heat release [kW], ΔT is temperature rise of the smoke layer [K], r is radiative fraction (0.3), and G is total heat release to time t [kJ]. ΔT is assumed to be 580K using a widely accepted ambient temperature 20 ℃.

Location of the smoke layer interface at the flashover is assumed at the lower edge of the windows of the arena, 4.6m above the floor. This is because the photographs taken at around the flashover show flame projection from almost whole windows. G_f is then calculated as 1.9×10^3 MJ. As pointed out earlier this G_f should be considered a minimum energy to cause flashover, it is important to note that a flashover will not occur unless integrated total heat release of flammable materials exceeds this level.

In this fire, flashover occurred in only 9 minutes from the activation of a fire detector. Assuming that the fire detector was activated in the very beginning of flaming, the total heat release for 9 minutes from the ignition for the respective specimens was compared to G_f. Since some of the experiments were conducted only on specimens cut out from original products, e.g. one-twelfth to one-sixth portion used for the urethane mattress comparison, the test data are multiplied by the “size ratio”, e.g. 12 or 6 for the mattress. Experiments using different size portions of the urethane mattress (experiments 1 & 2) endorse that this treatment of the test data result in overestimate of the heat release rate from a whole product. Also, the total heat release of the tatami mat was estimated by multiplying the total heat release of 1 tatami mat by 15 because there were 15 tatami mats in the gear supply storage (Figure 2).

The results on the partition walls (experiments 5 and 6) represent total heat release from 1 plot (45 cm) confined by studs and therefore the wooden partition wall (12 m long and 5 m high on average) in the vicinity of the fire source was individually converted to obtain estimated total heat release. Table 5 shows comparison between G_f calculated from equation (1), and measured total heat release of the urethane mattress, tatami mat and partition wall, as well as the estimated total heat release from respective objects considering the number and conditions at the building.

Table5. Comparison between experimental results

Experiment NO.	Specimen	Total Heat Release in 9 minutes (MJ)		G_f (MJ)
		Experiment Result	Real size (estimated by volume,area)	
1	Urethane mattress	74	**888**	**1.9×10^3**
2		82	**492**	
3		120	**720**	
4	Tatami mat	17	**255**	
5*	Partition Wall	30	**2430**	
6		70	**5670**	

Note: *start time: re-ignition time

The urethane mattress was quick to catch fire and flame up, with the resultant high total heat release. Though the estimated total heat release of one urethane mattress differed each experiment, it has been proven to be far smaller than G_f in either case. Therefore it is highly unlikely that flaming of one urethane mattress would cause a flashover in the gymnasium. The tatami mat continued burning at a steady heat release rate over a long time, but its total heat release is small. Even estimated total heat release of 15 tatami mats is still far short of G_f. Even if all the tatami mats burn together with the urethane mattress, still the total heat release does not reach G_f. The surface of the partition wall took some time before it was ignited, but the flames expanded rapidly after the burnout. It is clear that the estimated total heat release, when the whole surface area burned, exceed G_f. However, the flame does not easily spread horizontally in the hollow section, and the whole area is unlikely to flare up unless subjected to a large flame.

To summarize the above, the direct cause of the flashover which occurred in 9 minutes is attributed to the burning of the partition wall whose relatively wide surface was probably ignited by the burning mainly of the urethane mattress. The urethane mattress was not enough to cause flashover alone, but its role in the fire growth should have been important because without flaming of such a large combustible object the burning of the partition wall should not have become large enough to cause flashover.

Estimation results

The fire scenario from the ignition to the flashover is estimated as follows.

A small fire was initiated by cigarette left on the urethane mattress. After the stable ignition of the urethane mattress, the fire grew rapidly and made a large flame covering the surface of the partition wall in around 2-3 minutes. It is believed that the pressure tube detector was activated during the burning of the mattress. The mattress fire was perhaps large enough to ignite the wide area of the combustible walls of the storage in 4-5 minutes. The fire may also have ignited the curtains in the adjacent stage. The full burning of the walls of at least the storage and possibly its neighbor space and the curtains produced a hot gas layer in the arena hot enough to ignite the linings of the arena. The time from the stable ignition to the mattress to the flashover is thus estimated as 6-9 minutes: it is comparable with the reported time from the activation of the pressure tube detector to flashover at the fire.

5. Concluding remarks

Since there are abundant similar buildings across the country and the construction demand is still expected to continue, it is important to derive countermeasures to prevent such significant fires. Since it is believed that such a fast fire growth was caused by the combination of such a large fire source as the urethane mattress and combustible walls of the small compartment, any of the following countermeasures could reduce the hazard of fires anticipated in such building.

①To use noncombustible finish of the partition wall for the storage

②To install sprinklers in the stage and the storage

③To reduce combustibility of urethane mattress

It may be worth introducing that Hiroshima Prefecture decided to replace the plywood finish of the compartments of all the gymnasium similarly designed by noncombustible board materials accepting the recommendation after this investigation.

Acknowledgments

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References

1. Nakamura, K. and Miyabayashi, M., “Fire Resistance of Large Timber Construction”, Wood Industries, Vol.40, 1985(in Japanese)
2. Goetz,K.H.,Hoor,D., Moehler,K., NattererJ., Holzbau Atlas, Institut fuer Intermationale Architektur-Dokumentation, GmbH, Munich, 1980.
3. California State Bulletin 133, Furniture Burning Test