Experimental Study on Car Fire with Respect to Urban Fire Spreading

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ABSTRACT

In case of urban large fire spreading in a highly crowded areas of Japan, roads are usually considered to be effective in blocking the fire spreading between the buildings, together with parks, vacant spaces, rivers, and railway tracks, etc. However, especially when there is a car in a narrow road between two adjacent buildings, then it could be possible that fire spreading will be even accelerated by the burning car on a road, rather than the situation where a road will block the fire spreading. Both domestically in Japan and internationally, there have been many car fire researches based on experiments, but so far, most of them have been discussing the fire behavior of automobiles themselves, and not so many have been focusing on the car fire with respect to fire spreading between the buildings in case of urban fire spread, under the circumstances such as major earthquake or extremely high wind. Therefore, in this research, authors firstly conducted the full-scale fire experiment, where car is ignited by fire from the opening in a building façade, and observed how car is ignited by radiation and convection and then how fire is propagated in that car, and also incident heat fluxes were measured at surrounding places of the ignited car. Furthermore secondly, simple calculation model was proposed based on this car fire experiment, which was then applied to the parametric study for predicting the occurrence time of fire spreading to the adjacent building from the building of fire origin, with and without a car located between the two buildings. It was found that generally there was not great difference in time to fire spreading between the buildings dependent on the existence of car. But in an extreme situation where the distance between the two buildings is large, and also car is located quite close to the adjacent building (instead of the building of fire origin), there was a difference in calculation results dependent on the existence of a car, more specifically, the existence of car induced the occurrence of fire spreading between the buildings.

Keywords: Car Fire, Urban Fire, Full-Scale Fire Experiment, Façade Test, JIS A 1310, Incident Heat Flux, Fire Spread, Distance between the Adjacent Buildings.
1. INTRODUCTION

While roads are generally expected to be effective in controlling the spread of fire in case of urban fire spread, when there are cars on such roads, there is a possibility that the fire will be spread by burning cars. Many past studies on car burning, for instance [1-9], discuss the impact of burning of a car itself or the aftermath of its burning on the surroundings (buildings or other cars). Although they provide valuable data, there is actually not much experimental discussion made on the spread of fire from a burning building to a car. Under these circumstances, the authors conducted a full-scale fire experiment, in an environment where fire jetted out of an opening in a facade wall of a building under fire, to analyze the process of a car located close to that building catching fire and starting to burn and how the fire of that cars affects its surroundings. Former half of this paper provides a report on the outline of our experiment and discussion. Furthermore in the latter half of this paper, based on the results of this car fire experiment, the fire spreading time with and without a car between adjacent buildings was calculated, and the results of calculation were compared.

2. EXPERIMENTAL

2.1 Layout of the Specimen

A façade wall (4.095 m high × 1.82 m wide) and a combustion chamber (1.35 m high × 1.35 m wide × 1.35 m deep) specified by JIS A 1310 “Test Method for Fire Propagation Over Building Facades” [10], were installed under a large hood (8 m each side) in the Full Scale Fire Test Laboratory of Building Research Institute, and a car was located 1.5 m away from the outermost exterior of the façade wall. Heat flux meters were installed at four locations 1 m away from each corner of the car (at the same height as the vertical center of the car opening) in the direction facing the car. Heat flux meters were used to measure incident heat fluxes during the fire experiment. Since tires are expected to readily ignite from outside, the chamber opening and the rear tires of the car were laid out so that they directly faced each other (Figures 1 to 3).
**Figure 1** Layout of the specimens.
(The external frame is a hood measuring 8 m each side. ○ indicates a heat flux meter. “Fa” indicates a facade test instrument.)

Combustion chamber, facade and opening from JIS A 1310 facade test rig

**Figure 2** Photo showing a layout of the specimen.
2.2 Specifications of the Specimen

A test car selected for the test is a standard sedan type passenger car. It is a five-seater car with a total displacement of 1.99 liters and measuring 476 cm in length, 177 cm in width and 141 cm in height. A channel steel, calcium silicate board, and load cell are placed under each of the four tires, and the bottom of the tire is 300 mm above from the floor of the laboratory. For the facade, the bottom of the opening (910 mm each side) is positioned 455 mm above the soffit of the chamber and 780 mm above the floor of the laboratory. Noncombustible material (a calcium silicate board covered with a ceramic fiber blanket) is used for the facade, which means that there is a flame and plume spouted out of the façade opening but flame will not be further propagated by the ignition of any elements of facade. The heat flux meters, four installed in total, are set to a height of 1,400 mm above the floor of the laboratory.

2.3 Heating Method and Measurement Items

The combustion chamber of the facade test equipment, which generates heat, heated at 900 kW for 20 minutes after the start of the test, during which time a flame continually spouted out of the facade opening. After 20 minutes, heating was stopped, and the resulting changes and conditions were measured. It was preliminarily decided that when the car did not catch fire within 20 minutes, heating would further continue to the 30 minute point. However in the real fire experiment, a tire caught fire at 19 mins
and 34 secs, and chamber heating was stopped at the 20 minute point as scheduled. During the experiment, incident heat flux at four corners of the car was measured by the heat flux meters, the temperature in the car and the tire temperature measured by the thermocouples, changes in the mass were measured with load cells, and the heat generation rate was measured by the oxygen consumption method.

3. EXPERIMENT RESULTS

Still picture during the experiment, heat release rate, temperatures inside the car, and incident heat fluxes around the car are illustrated in Figures 4, 5, 6, 7, respectively.

After 19 mins and 34 secs from the start of chamber heating, two rear tires of the car caught fire. Chamber heating stopped at the 20 min point, and the burning of the car was measured. After the right rear tire took fire, burning spread to the tail lamp, the rear trunk, and the left half of the car. After 33 mins 23 sec, flames gushed out of the right rear window, and burning was further activated. After 37 mins 14 sec, the rear glass broke, and flames also jetted out of the rear of the car. After 39 mins 32 sec, a flame spouted out of the upper part of the front glass of the car. After 41 min 35 sec, almost the entire front glass collapsed, and flames emerged. The condition thereafter was that of a flashover. The heat release rate reached the maximum of 3,215 kW, in 44 mins 32 sec (Figure 5). The experiment indicated a tendency of slightly slower burning property compared with past experiments of forced ignition of fire in cars conducted in Building Research Institute of Japan such as [2].

For the impact on the surroundings (heat fluxes around the car), a small value of heat flux continued for a while after chamber heating stopped in 20 mins as shown in Figure 7. After the 30 minute point, the rear heat flux increased to over 10 kW/m². After the occurrence of the flashover, the heat flux, particularly the right and left flux, rapidly soared and finally exceeded 25 kW/m².
Figure 4  Experiment under way.
(After façade test chamber heating finished, the right rear tire of the car is burning.)

Figure 5  Heat release rate.
Figure 6  Temperature inside the car.

Figure 7  Incident heat flux around the car.  
(see Figure 1 for measurement points).
4. MODELLING FOR CALCULATING FIRE SPREAD TIME TO ADJACENT BUILDING

Based on the results of this car fire experiment, the fire spread time with and without a car between adjacent buildings will be calculated, and the results of calculation will be compared in the latter half of this paper. Firstly in this fourth chapter, modelling information for calculation will be described.

4.1 Modelling of Building of Fire Origin (Burning Building)

A flat vertical radiant plane measuring 6 m in height and 10 m in width is assumed. It is assumed that the temperature of the radiant plane follows a heating curve specified by JIS A 1301-1994 Method of fire test for wooden structural parts of buildings [11]. Class 1 should be used for a wooden building with no fireproofing, while Class 2 for a wooden building of a fire preventive construction.

4.2 Modelling of Fire-Receiving Building

It is assumed that a fire-receiving building has a wooden part at its outermost layer and that the wooden outermost surface receives the radiant heat from the burning building and the car (in the case with a car) and catches fire when its temperature reaches a temperature at which wood ignites. The height of the flammable material of the heat-receiving side is set to half the height of the burning building. The position of the fire-receiving building in the horizontal direction is defined by the distance from the burning building. In case an inflammable material is assumed to exist inside the building, it is assumed that glazing is provided in the opening and that, in this case, the heat flux from the radiant heat on the wooden surface is halved because of glazing.

The thermal property of the flammable material of the heat-receiving side is assumed to be wood (cedar). The surface temperature of the flammable material shall be calculated as a one-dimensional heat conduction problem using the forward difference method (0.5 cm in spatial grid interval and 1 sec in time interval) under the condition of rear thermal insulation of 5 cm in thickness. Loss of heat by radiation from the radiation heat to the surface and the surface temperature shall be considered, with the reference temperature being 10˚C, and loss of heat by radiation by convection shall also be considered.

4.3 Modelling of Car

It is assumed that the surface temperature of the upper part of a tire (0.6 m above the ground) increases and that the tire catches fire when the said temperature reaches a value where the tire kindles. After the car is ignited, heat is supposed to be generated from the car, according to the time-specific radiation receiving heat flux (equivalent to “left” in Figure 7) at a point 1 m away from the car fire. The thermal property of the tire
is based on natural rubber, and the tire surface temperature should be calculated under conditions equal to those of the heat-receiving side flammable material except for the thermal property.

The position of the car is defined by the distance from the flammable material of the heat-receiving side. When the distance from the fire-receiving building to the car is not 1 m, the receiving heat flux should be adjusted by dividing by the square of the distance. Screening of radiant heat from the burning building to the fire-receiving building by the existence of the car is not considered.

4.4 Calculation Time

The calculation time used is 2,700 seconds. After the lapse of 2,700 seconds, the surface temperature of the heat-receiving side flammable material is in the decreasing phase, and when the fire does not spread by 2,700 seconds, it should be judged that no fire spreading will occur.

4.5 Positional Relationship among the Building of Fire Origin, Car, and Fire-Receiving Building

A sectional view is shown in Figure 8. The distance from the building of fire origin to the fire-receiving building is $X$ m, while the distance from the car to the fire-receiving building is $Y$ m. Parameters are put together in Table 1.

![Figure 8](image-url)  
*Figure 8 Sectional view of the building of fire origin, car, and fire-receiving building.*
Table 1  Positional relationship among the building of fire origin, car, and fire-receiving building.

| X [m] | Y [m] | 0.45 | 0.5 | - | - | - |
|-------|-------|------|-----|---|---|---|
| 2.7   | 0.45  | 0.5  | -   | - | - | - |
| 4.0   | 0.5   | 1.0  | 1.2 | 1.5| 1.7| |
| 6.0   | 0.5   | 1.0  | 2.0 | 3.0| 4.0| |

5. CALCULATION RESULTS

5.1 Case of a Distance of 2.7 m between the Two Buildings (: X [m] in Figure 8 and Table 1)

The calculation results when the distance between the buildings (X [m]) is 2.7 m and the distance from the car to the fire-receiving building (Y [m]) is 0.45 m are shown in Table 2. As shown in Table 2, in the case of no glazing in the fire-receiving building, which is assuming the case of wooden surface present on the outermost layer of the fire-receiving building, there occurred no difference in the fire spreading time between the case with the presence of a car between the buildings and the case without in both class 1 and class 2 heating test. In the case of glazing used in the fire-receiving building, which is assuming the case where the wood present indoors inside the glazing is considered to be the heat-receiving judgment point, the results of both class 1 and 2 tests show a slightly shorter fire spreading time (about 4 to 10 seconds) as a result of the presence of the car.

Table 2  Calculation of fire spreading time between the two buildings
(In case of: X = 2.7 m, Y = 0.45 m).

| Heating: Class 1 (building of fire origin is wooden construction) | Heating: Class 2 (building of fire origin is wooden building of a fire preventive construction) |
|---------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Without glazing at opening in fire-receiving building         | Without glazing at opening in fire-receiving building                                       |
| With glazing at opening in fire-receiving building            | With glazing at opening in fire-receiving building                                         |
| Without car                                                  | Without glazing at opening in fire-receiving building                                     |
| 361 sec                                                      | 400 sec                                                                                   |
| 408 sec                                                      | 473 sec                                                                                   |
| With car                                                     | With glazing at opening in fire-receiving building                                         |
| 361 sec                                                      | 396 sec                                                                                   |
| 408 sec                                                      | 463 sec                                                                                   |
5.2 Case of 4 m between the Two Buildings (: $X$ [m] in Figure 8 and Table 1)

The calculation results in the case of the distance from the car to the fire-receiving building ($Y$ [m]) being 0.5 m and 1.7 m are shown in Table 3 and 4, respectively. As shown in Table 4, when the car is about 1.7 m away from the fire-receiving building, the calculation shows a shorter fire spreading time only by about 1 sec than the case without car. When the car is close to the fire-receiving building, which is just 0.5 m away, the calculation shows that the fire spreading time is about 4 to 15 seconds shorter than the case without car particularly when the glazing is present at a heat-receiving point in a fire-receiving building, as shown in Table 3.

Table 3 Calculation of fire spreading time between the two buildings
(In case of: $X = 4.0$ m, $Y = 0.5$ m).

| Heating: Class 1 (building of fire origin is wooden construction) | Heating: Class 2 (building of fire origin is wooden building of a fire preventive construction.) |
|---|---|
| Without glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without glazing at opening in fire-receiving building | Without glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without car | 377 sec | 419 sec | 430 sec | 527 sec |
| With car | 377 sec | 415 sec | 430 sec | 512 sec |

Table 4 Calculation of fire spreading time between the two buildings
(In case of: $X = 4.0$ m, $Y = 1.7$ m).

| Heating: Class 1 (building of fire origin is wooden construction) | Heating: Class 2 (building of fire origin is wooden building of a fire preventive construction.) |
|---|---|
| Without glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without glazing at opening in fire-receiving building | Without glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without car | 377 sec | 419 sec | 430 sec | 527 sec |
| With car | 377 sec | 418 sec | 429 sec | 526 sec |
5.3 Case of 6 m between the Two Buildings (: X [m] in Figure 8 and Table 1)

The calculation results in the case of the distance from the car to the fire-receiving building (Y [m]) being 0.5 m and 4.0 m are shown in Table 5 and 6, respectively. As shown in Table 6, when the car is about 4 m away from the fire-receiving building, the calculation concludes that burning of the car has almost no impact on the fire spreading time between the buildings or on occurrence of fire spreading. When the car is close to the fire-receiving building, which is just 0.5 m away, and particularly when the building of fire origin is a wooden building of a fire preventive construction (Class 2 heating) and the glazing exists at the heat-receiving point of the fire-receiving building, the calculation result shows that no fire spreading occurred in the case without car, but also that the fire-receiving building caught fire in 1,591 seconds in the case with car, as shown in Table 5.

| Heating: Class 1 (building of fire origin is wooden construction) | Heating: Class 2 (building of fire origin is wooden building of a fire preventive construction.) |
|---|---|
| Without glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without glazing at opening in fire-receiving building | Without glazing at opening in fire-receiving building |
| With glazing at opening in fire-receiving building | With glazing at opening in fire-receiving building |
| Without car | 403 sec | 457 sec | 479 sec | No fire spread |
| With car | 403 sec | 450 sec | 478 sec | 1591 sec |
Table 6 Calculation of fire spreading time between the two buildings
(In case of: $X = 6.0 \text{ m}$, $Y = 4.0 \text{ m}$).

|                      | Heating: Class 1 (building of fire origin is wooden construction) | Heating: Class 2 (building of fire origin is wooden building of a fire preventive construction.) |
|----------------------|------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
|                      | Without glazing at opening in fire-receiving building              | With glazing at opening in fire-receiving building                                          |
|                      | Without car                                                   | With car                                                   | Without glazing at opening in fire-receiving building |
|                      | 403 sec                                                      | 457 sec                                                      | 479 sec                                                      |
|                      | 457 sec                                                      | 456 sec                                                      | 479 sec                                                      |
|                      | 479 sec                                                      |                                                               | No fire spread                                               |
|                      | No fire spread                                               |                                                               | No fire spread                                               |

6. CONCLUSION

The authors calculated the fire spreading time using the car fire experiment results and compared the cases with and without car between the two buildings in order to clarify the impact of cars fire in an urban fire spreading. In many cases, no major difference in fire spreading time was observed between the case with and the case without car. However, when the distance between the fire-giving and fire-receiving building is large and the distance from the car to the fire-receiving building is especially small, in which case the impact of the car increases, there occurred cases where the presence of a car led to a fire spreading although it was slow, while there was no fire spreading occurred without a car between the two buildings.

ACKNOWLEDGEMENTS

Colleagues from BRI and NILIM, technical staff and students from University of Tokyo, and the students from Tokyo University of Science are appreciated for their help in conducting a fire experiment for this study.

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