A STUDY ON THE FLAMMABILITY OF NON-FLAME-RETARDANT AND FLAME-RETARDANT MATERIALS BY USING CONE CALORIMETER

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ABSTRACT

Flammability of non-flame-retardant and flame-retardant materials was studied by using cone calorimeter. Also, relations between the results obtained by using cone calorimeter and those obtained by the flammability test of Japanese Fire Service Law were examined.

The results are as follows:

1) The ignition time of the molten specimens is relatively long, whereas the ignition time of the non-molten specimens is short. None of remarkable difference of the ignition time has been found between non-flame-retardant and flame-retardant materials specimens.
2) The peak heat release rates of flame-retardant materials are smaller than those of non-flame-retardant materials.
3) The carbon monoxide and smoke evolved from flame-retardant materials generate much more than those evolved from non-flame-retardant materials.
4) Even if flame-retardant materials are passed by the flammability test of Japanese Fire Service Law, they burn easily under external radiative heating condition.

INTRODUCTION

In general, the materials that easily catch fire to be aflame in building fires are natural polymeric materials such as timber, paper or synthetic fabric products such as clothing, curtains, carpets, bedclothes and synthetic polymeric materials such as synthetic resin sofas, household furniture materials. These organic materials burn very easily. From this reason, combustion of these kinds of organic materials has often been developed to catastrophic fires. For example, more than 100 of people were killed in the Osaka-Sennichi Department Building Fire [1] in May 1972 or in the Kumamoto-Taiyo Department Fire [2] in November 1973.

To prevent such disastrous fires, the Fire Service Law decrees that the curtains, blackout curtains, thick curtains, etc. must be flame-retardant in the places such as hotels, inns, arcades, high-rise buildings, dramatic theaters, movie theaters where many and unspecified persons often gather from 1969.

The required flame-retardancy of materials in fire varies depending on where the material is used or in what a manner it is used. From this reason, the test method to evaluate the flammability of the material also varies likewise depending on what place the material is used or for what purpose it is used.

In examining flammability of the flame-retardant products in Japan, the 45-degree flammability test method [3] is used. In this test, It is examined whether the flame-retardant products will burn by just a small ignition source and will spread.

On the other hand, progress of the polymer technologies in recent years makes it possible to develop new materials, and therefore flammability tests are being developed so that adequate evaluation will be made with the flammability of these materials [4]. Furthermore at the present when international harmonization and mitigation of performance evaluation are required in a variety of the fields necessity to be in harmony with the flammability test methods such as ISO (International Organization for Standardization) as an international standard in connection with the flammability test method.

However even if one is aware of the necessity of being in harmony with the international flammability test method, it is not easy to adopt a new test method offhand now in place of the various countries' flammability test methods that have conventionally been in use. This is because that since lifestyles or customs are different from each other depending on the individual countries, there is a possibility that change of the test methods will widely exercise influence on a variety of fields from a social/economic viewpoint.

As a pre-stage to be in international harmony with the flammability test methods, a correlation between the conventional 45-degree flammability test method of Japanese Fire Service Law and the ISO's flammability test method has been examined [5-7].

However, all of these test methods are the ones to examine the flammability required in the initial step of the fires. They are impossible to obtain the flammability of the materials under the situation where strong radiation generated from the flame at the growing stage of fire or at the stage of fully developed fire. The fire in the Nagoya Citizen Halls [8] was occurred when the curtain used for the dramatic stage was heated by the lights on the stage. It can appropriately be said that the disaster occurred owing to the heat brought from the strong radiation emitted onto the curtain. As shown above, it is not necessary for fires to break out exclusively when the flame-retardant products such as curtains, carpets, bedclothes, etc. come in contact with small ignition sources such as matches, lighters, etc. There is a possibility that these flame-retardant materials will be exposed to the strong radiation at such stages of fire's growth, fully developed fire. In the meanwhile, almost all of the data of the flammability for fabric products such as curtains, carpets, bedclothes, etc. have been dealt with taking up the initial stage of the fire as an objective. The data of the flammability under the situation where strong radiation and application of heat at the stages of fire's growth, fully developed fire are shown are obtained exclusively with specific materials such as cotton cloth [9], carpets [10]. Saitoh and Yanai [11] are conducted a study on classification of the flammability of the flame-retardant materials.

In this study we obtained the knowledge on fire characteristics of the flame-retardant materials by measuring heat release rate, etc. by using cone calorimeter. Moreover, we examined correlation between results obtained by using cone calorimeter and those obtained by 45 degree flammability test of Fire Service Law.

EXPERIMENT

Test Specimen

The specimens are comprised of 2 types of cotton cloth and a single type each of rayon, mixed spinning of hemp and cotton, polyester, and nylon together with a single type of polyvinyl chloride as synthetic resin film. Those fabrics contain the materials that are and are not flame-retardantly processed. In addition to the above, a single type each of the novoroid as heat-resistant fabric and carbon fabric, 2 types of carpets, and a single type each of coverlet/mattress futon that are and are not flame-retardant are contained. The specimens used are 22 types. The specimens are listed in Table 1.

Table 1 Identification of materials studied.

No.	Material	Specifications	Area density [g/m^2]
1	Cotton 100%	Velveteen	232
2	Cotton 100% (flame-retardant)	Velveteen	260
3	Cotton 100%	Plain fabrics	183
4	Cotton 100% (flame-retardant)	Plain fabrics	199
5	Rayon 100%	Flower patterns	409
6	Rayon 100% (flame-retardant)	Flower patterns	538
7	Hemp 55%, cotton 45%	Plain fabrics	260
8	Hemp 55%, cotton 45% (flame-retardant)	Plain fabrics	287
9	Polyester 100%	Lacework	115
10	Polyester 100% (flame-retardant)	Lacework	118
11	JIS L 0803 Nylon 100%	Plain fabrics	70
12	JIS L 0803 Nylon 100% (flame-retardant)	Plain fabrics	77
13	Polyvinyl chloride 100%	Film	2390
14	Polyvinyl chloride 100% (flame-retardant)	Film	2614
15	Novoroid		530
16	Carbon fiber	Twill	410
17	Carpet (face : nylon 100%)	Tufted	1565
18	Carpet (face : polypropylene 100%)	Needle punch	925
19	Mattress futon		
20	Coverlet futon		
21	Flame-retardant mattress futon		
22	Flame-retardant coverlet futon		

Test Method

A cone calorimeter (U.S. Atlas Corp. 's CONE2) was used. The specimen is horizontally set on it and heating is made in a settled amount of radiation onto the specimen surface of approximately 100mm x 100mm, and combustion is continued in such a state. With the radiation heating intensity, 3 levels of 20 kW/m^2, 30 kW/m^2, and 50 kW/m^2 were used.

With the flammability tests of Japanese Fire Service Law, tests were conducted with respect to the following. (1) The 45-degree micro-burner/ meckel burner method described in No.3, Article 3, the Fire Service Law. (2) The 5%-loose method as an additional method for the molten/shrinkable fibers such as acrylic fabrics, etc. (3) The 45-degree coil method for the molten fibers such as polyester, nylon, etc. With carpets, a test was conducted in accordance with the 45-degree air-mix burner method. Meanwhile with the futon mats, tests were conducted respectively with test methods for the completed products of the futon mats was conducted in accordance with the 45-degree methenamine method and horizontal tobacco method [12].

As pre-treatment of the specimens, the specimens cut out in a settled size are conditioned for 24 hours in an electric dryer in which temperature is maintained at 50℃± 2℃. After that, the specimens that were kept cool for more than 2 hours to adjust their state in a silica-gel-containing desiccator were used.

RESULTS AND DISCUSSION

Ignition Time

The specimens that failed to be ignited at the radiative heat flux of 20 kW/m2 were the 6 types of Nos. 9 through 12, 15, and 17. The specimens referred to above are all molten materials except the novoroid of No. 15. Meanwhile Nos. 9 and 11 are the specimens with which just onetime trial of ignition was not obserbed when the radiative heat flux reached 30 kW/m^2, and either of them is a non-flame-retardant material. When the radiation reached 50 kW/m^2, ignition was observed with all the specimens. The higher the radiative heat flux was, the shorter the ignition time was with the same specimens. There appears to be a tendency that the molten materials are harder to be ignited than others. A relation between the radiative heat flux and the ignition tine of a representative fabric specimen is shown in Fig 1.

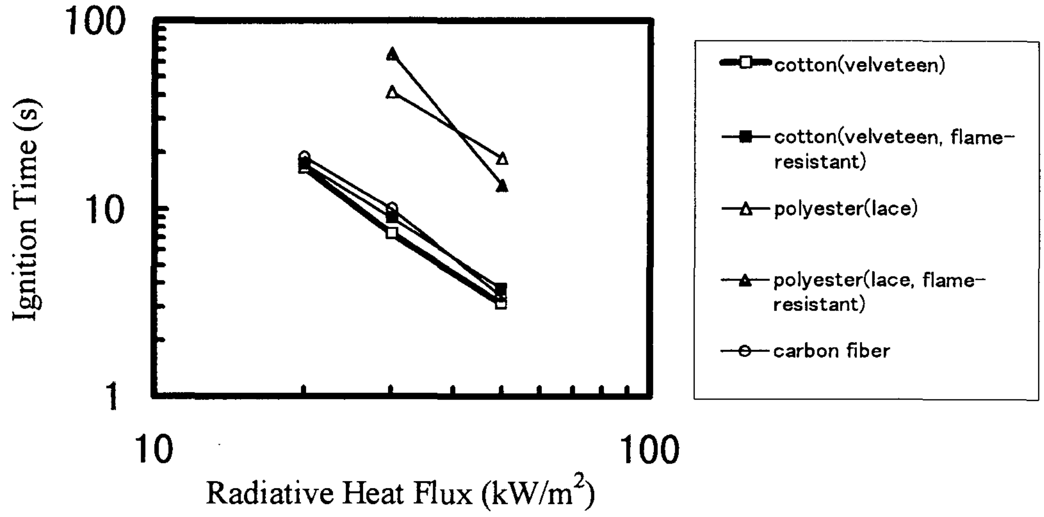

Fig.1 Relationship between the radiative heat flux and ignition time.

Comparisons are made between the non-flame-retardant and the flame-retardant materials with the sane material. The results indicates that longer ignition time than usual was seen with the 3 types of the materials, i.e. the material of rayon 100%, the mixed stuff of hemp 55% and cotton 45%, and the material of the polyvinyl chloride 100%. Among these, almost none of difference in the high radiative heat flux is found between the non-flame-retardant and the flame-retardant materials with the mixed stuff of hemp 55% and cotton 45%. Contrarily to the above, the ignition time is shorter than usual with the non-flame-retardant materials of polyester 100%, nylon 100%, and coverlet futon which is made of molten/shrinkable material. Among the other products of cotton 100% (velveteen), cotton 100%, mattress futon, nothing particular in difference can be found.

Heat Release Rate

The fabric specimens of intrinsically thin thickness are easily ignited and are violently burnt. Accordingly a curve indicating the relation between the heat release rate and the time has a sharp peak. For the carpets, futon mats, and the fabric specimens which are flame-retardant in spite of their thinness in the thickness, a curve with broad breadth was obtained.

With all the materials, either of the peak heat release rate and the total heat released was made greater when the radiative heat flux was heightened externally. When the non-flame-retardant is compared with the flame-retardant materials, it is revealed that the non-flame-retardant material took greater values in either of the peak heat release rate and the total heat released within a range of the radiative heat flux.

Time curves of the heat release rate, smoke concentration and CO concentration of the cotton (velveteen) and cotton (velveteen, flame-retardant) are shown in Fig. 2.

From the above descriptions, it is found that the heat release rate can be suppressed by converting the fabric materials from non-flame-retardant materials to flame-retardant materials.

Smoke Density and CO Concentration

A tendency was found with almost all of the materials that the higher the radiative heat flux was, the greater the smoke density and area generating smoke factor (the amount of generated smoke per unit area) became. Especially with the polyvinyl chloride, smoke concentration became remarkably high. The non-flame-retardant polyvinyl chloride of No. 13 reached no less than approximately 10 l/m in the value of the smoke density at the radiative heat flux 20 kW/m^2

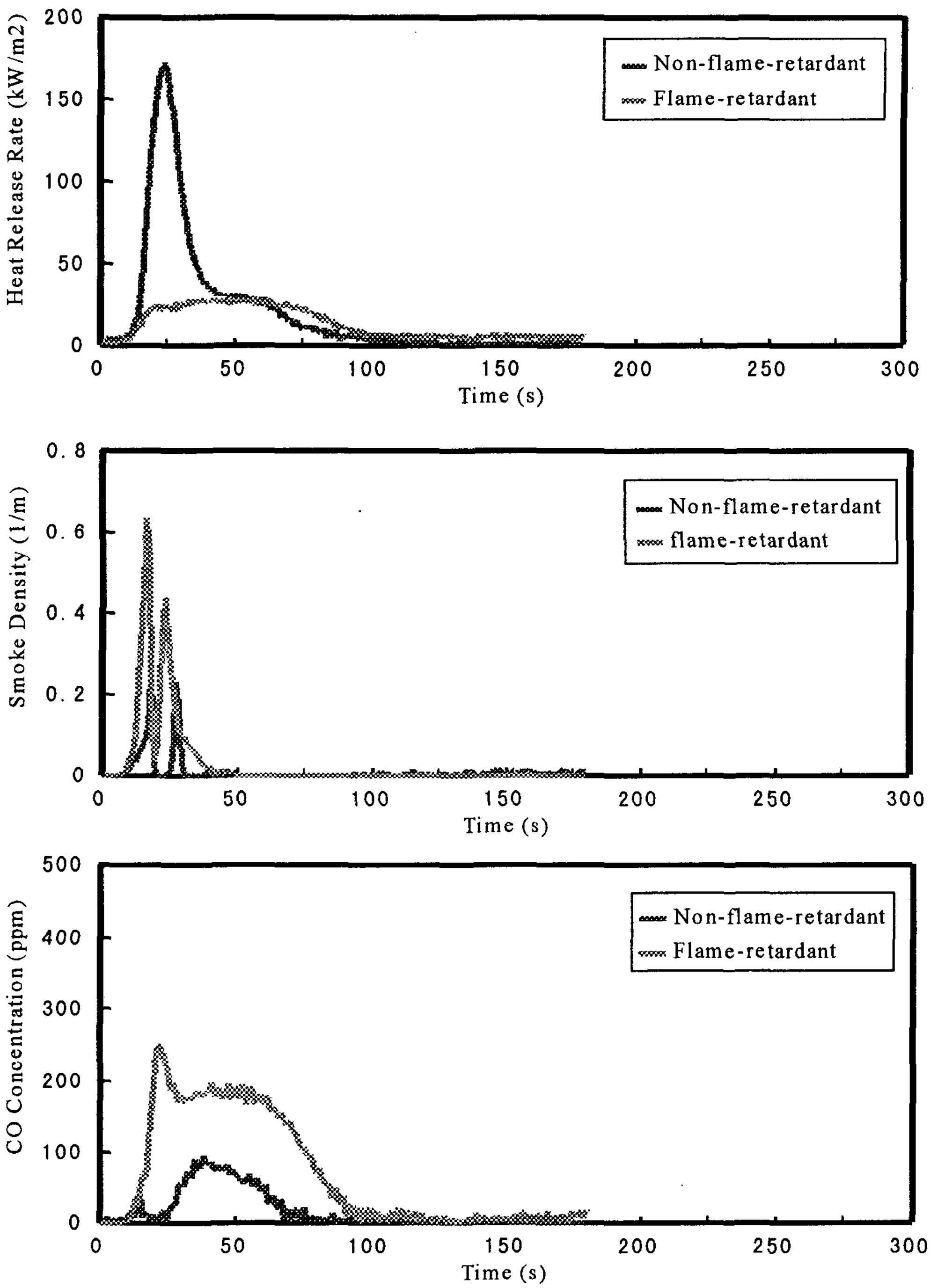

Fig.2 Time curves of heat release rate, smoke density and CO concentration for cotton (velveteen)

expressed in the extinction coefficient. When the non-flame-retardant materials are compared with the flame-retardant materials, it is revealed that more smoke was generated from the flame-retardant materials than from the non-resistant materials with respect to almost all of the specimens. This is because the flame-retardant products that are intrinsically hard to be burnt are forcibly burnt by radiating heat onto them.

The flame-retardant polyvinyl chloride exhibited the highest CO concentration, and approximately 2,000ppm was exhibited at the maximum CO concentration. In the meanwhile, less than 1,000ppm was exhibited with almost all of the other materials. Since it is widely known that the lethal concentration of CO at 30-min exposure is 4,000ppm, it can hardly be said that so much of the smoke is produced with the CO concentration in relation to either of the individual specimens. This is because that the specimens are burnt in atmosphere, and the combustion is continued at the state where a sufficient amount of air is supplied.

When the non-flame-retardant materials are compared with the flame-retardant materials, more CO is produced from the flame-retardant materials than from the non-flame-retardant materials in relation to almost all of the specimens. This is because that the affairs can be regarded as quite the same as the case of the smoke concentration.

Relationship between Result Obtained by the Cone Calorimeter Test and the Result Obtained by the Flammability Test of Japanese Fire Service Law

To examine how the result by the cone calorimeter test is concerned with the result brought from the flammability test in accordance with the Fire Service Law, the data are plotted Fig.3 in connection with the relation among the representative values of the measurement with the cone calorimeter, i.e. ignition time, maximum heat release rate, and total amount of heat generation. In the figure,□ and ■ show the data at the radiative heat flux 20 kw/m^2, Whereas △ and ■ show the data at the radiative heat flux 30 kW/m^2. Meanwhile ○ and ● show the data at the radiative heat flux 50 kW/m^2, respectively. On the other hand, the void symbols (□, △, and ○) denote specimens passed in the flammability test of the Fire Service Law. The blackened symbols (■, ▲, and ●) denote the specimens failed in flammability test of the Fire Service Law.

In regard to these figures, it can hardly be perceived how the data measured with the cone calorimeter are concerned with the result of the judgment by means of the flammability test. This is because the cone calorimeter test that is conducted here is the one conducted under the situation where the external heating of more than 20 kW/m^2 is applied by the radiative heat flux. On the other hand, this is also because that the flammability test of the Fire Service Law is conducted in view of checking to see if there is a possibility that the materials are burnt to be developed to a fire owing to small ignition sources such as tobaccos, lighters, etc. Thus it can safely be said that the purpose of the flammability test is different from each other with the cone calorimeter test and the flammability test of the Fire Service Law. In other words, the flammability test of the Fire Service Law is for the purpose of conducting a test in checking to see if the materials are burnt to be spreaded owing to an small ignition source in the start of the fire. On the contrary, the cone calorimeter test aims at checking to see if a fire occurs and how the burning behavior of the materials is under the situation where the radiation from the fire is applied to the materials.

CONCLUSIONS

The flammability test was examined with respect to 21 types of specimens such as fabrics, carpets, futon mats, etc. The results are as follows:

1) The ignition time of the molten specimens is relatively long, whereas the ignition time of the non-molten specimens is short. None of remarkable difference of the ignition time has been found between non-flame-retardant and flame-retardant materials specimens.

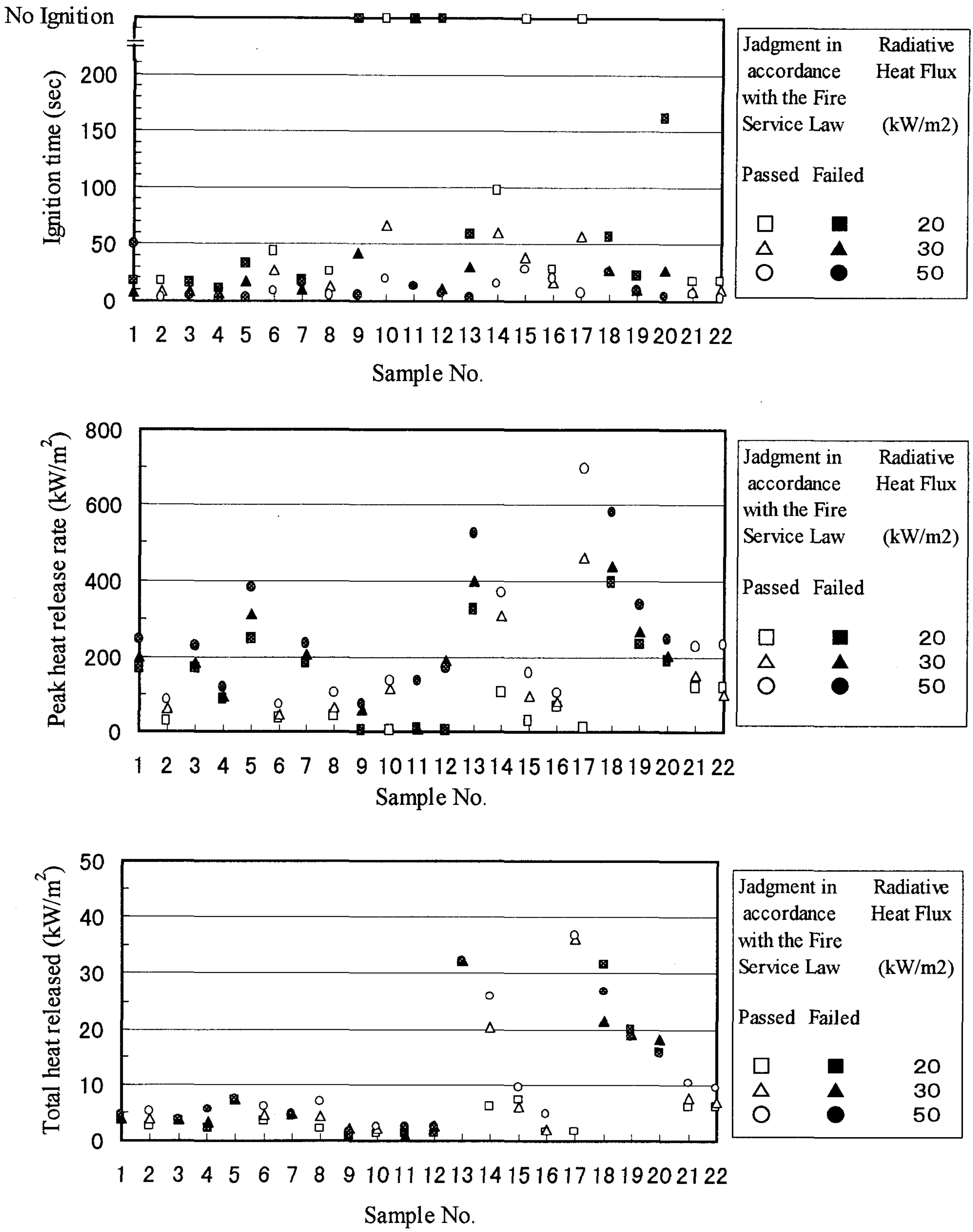

Fig.3 Relation among Ignition time, Peak heat release rate, Total heat released by cone calorimeter and the results obtained by the flammability test of the Fire Service Law.

2) The higher the radiative heat flux in external heating condition is, the higher the heat release rate is. Furthermore when the flame-retardant specimens are compared with the non-flame-retardant specimens, the non-flame-retardant specimen exhibits a considerable degree of high heat generation.
3) When the flame-retardant specimens are compared with the non-flame-retardant specimens, it is revealed that a large amount of such substances was seen with the flame-retardant materials for almost all the specimens.
4) No correlation was found between results obtained by using cone calorimeter flammability test and the result obtained by the 45-degree flammability test of Japanese Fire Service.

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