Experiments on fire resistance of common trees and shrubs in Japan

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§ 1 Studies by forerunners

OF researches on fire resistance of plantings in urban districts or in the forests the author could find not so many publications in Japan.

1) As works in laboratories, (a) fire resistance tests of leaves were carried by a forerunner K. Inoue in 1950,[6] (b) investigations of water content percentage of fresh leaves were presented by several persons, such as Dr. K. Sato in 1944,[13] M. Hosoi in 1944,[4] H. Kimura in 1948.[9]

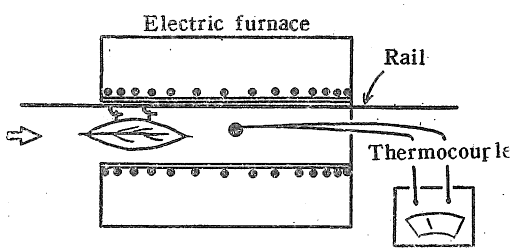
2) As field surveys of fire resistance of trees and woods in conflagrations the author could find some works, such as by Y. Tanaka in 1923 and 1935,[14][15] and M. Hamada in 1940,[3] K. Usui and K. Kawagoe in 1950,[3] etc.

3) As studies on fire behavior in forest or grass fires he found works of M. Nakamura in 1930, T. Asada and E. Honde in 1943,[3] S. Suzuki in 1949, M. Okanoue and K. Inoue in 1955[12] and K. Inoue in 1956.[7]

§ 2 Measurements of some properties of leaves affecting fire resistance of trees

To study plantings for checking the fire, we must elucidate critical conditions, in which trees or woods lost their foliage by flashing and lost their errand as a shield against fire. States and modes, how trees blaze up by flashing, will vary of course by an identified tree in accordance with the types of spreading fire and wind velocity, and also they vary in a wide range with the species of tree. By an apparatus made by the author for testing fire resistance of leaves, which consists of a cylindrical furnace and a rail sending leaves by hook into the furnace, as shown in Fig. 1, he carried comparative tests of trees on (1) the flashing types, (2) flamabilities and (3) the time required for flashing, among leaves of 74 species of common tree in Japan.

Fig. 1. An apparatus for flashing test of leaves



1) the flashing types

Leaves were carried by hooks on a rail into the furnace of which temperature was nearly fixed at 500°C by a controller. Burning of leaves were observed in 3 stages. The first stage : leaves send out vapor and/or gas. In this stage some species sound cracklings. The second stage : after that vaporing ceases smoking will start soon and lastly leaves will catch fire (carbon ignition). The third stage : in the progress of carbon ignition suddenly they burst into flame with an explosion sound, or occasionally they come to ash without any flame.

Table 1. Comparative Tests among Trees on Combustion Types, Flamability and Flashing Time

Species	Type of combustion 500°C	Number of flaming combustion per 7 trials 500°C value	mean	550°C	Average time required to blaze up (second) 500°C	550°C
Conifers						
1. Cedrus Deodra	A2	5.	5	7	16	12.5
2. Chamaecyparis obtusa	B2	4.	4	7	30	16
3. Chamaecyparis pisifera	B2	1.0.	1	7	30	17
4. Cryptomeria japonica	B1	5.3.	4	6	22	15
5. Cunninghamia lanceolata	B1	1.3.	2	6	21.5	17
6. Pinus densiflora	A2	7.7.7.	7	7	27	14.5
7. Pinus palustris	A2	6.4.4.	5	7	34	18
8. Pinus Thunbergii	A2	7.6.	7	7	28	15
9. Podocarpus macrophylla	B1	2.1.	2	6	27	13
10. Sciadopitys verticillata	B1	1.1.	1	7	25	15
11. Taxus cuspidata	B2	2.4.	3	7	40	18
12. Thujopsis dolabrata	B2	0.0.	0	6	—	15
13. Torreya nucifera	B1	3.	3	7	24	15.5
Broadleaved evergreens						
14. Aucuba japonica	B2	1.2.1.	2	6	15	12
15. Camellia japonica	A1	5.4.	4	7	18.5	13
16. Camellia Sasanqua	B1	0.0.	0	5	—	14
17. Cinnamomum Camphora	A2	2.3.	3	7	11	8
18. Cleyera ochnacea	A2	3.	3	7	20	10
19. Daphniphyllum macropodum	A1	1.1.	1	7	22.5	15.5
20. Eurya japonica	B2	2.3.	3	7	15	12
21. Euonymus japonica	B1	0.1.0.	1	7	—	11
22. Fatsia japonica	B2	0.0.1.	1	7	—	18.5
23. Gardenia jasminoides	B1	3.	3	7	14	8
24. Ilex crenata	B1	2.	2	6	18	14
25. Ilex integra	A1	5.4.	4	7	17	13

26.	Ilex latifolia	A2	3.	3	7	21	14
27.	Ilex rotunda	B1	0.0.	0	7	—	15
28.	Illicium religiosum	A1 (or) B1	0.2.	1	7	18	13
29.	Ligustrum japonicum	A1	2.	2	7	22	15
30.	Lithocarpus edulis	B2	4.	4	7	16.5	9
31.	Magnolia grandiflora	B2	5.	5	7	17	13
32.	Myrica rubra	B1	0.0.2.	1	7	11	9
33.	Nerium indicum	A2	0.2.	1	6	21	17
34.	Osmanthus fragrans	A2	5.4.5.	5	7	11	7
35.	Osmanthus ilicifolius	B1	1.0.	1	7	28	16
36.	Photinia glabra	B1	2.2.	2	7	16	11.5
37.	Pittosporum Tobira	B1	2.5.	3	6	16	13.5
38.	Quercus glauca	B2	5.	—	7	13	9
39.	Quercus phylliraeoides	B2	2.3.	3	7	15.5	9
40.	Raphiolepis umbellata	B1	2.	2	7	18	14
41.	Shiia cuspidata	A1	1.3.3.3.	3	7	10	8
42.	Shiia Sieboldi	B2	4.	4	7	10	8
43.	Ternstroemia japonica	B1	3.	3	6	22	15
44.	Viburnum odoratissimum	A2	2.0.0.2.	1	5	23	16
Deciduous							
45.	Acer palmatum	A2	5.			10	
46.	Acer pictum	A2	7.			7.5	
47.	Acer trifidium	A2	7.			9.5	
48.	Aesculus turbinata	A2 *	5.			10	
49.	Aphananthe aspera	A2	7.			7.5	
50.	Celtis sinensis	A2	7.			8	
51.	Cornus controversa	A2 *	9.			13	
52.	Deutzia crenata †	A2	7.			19	
53.	Ficus Carica	A2	5.			16	
54.	Firmiana simplex †	A2	5.			7.5	
55.	Ginkgo biloba †	B1	7.			15	
56.	Hydrangea macrophylla	A2	9.			19	
57.	Idesia polycarpa	A2	5.			13	
58.	Liquidamber formosana	A2 *	7.			10	
59.	Liriodendron tulipifera	A2	7.			11.5	
60.	Maackia amurensis	A2	5.			10	
61.	Magnolia denudata	A2	7.			12	
62.	Melia Azedarach	A2	7.			10	
63.	Platanus acerifolia	A2	7.			11.5	
64.	Prunus donarium	B2	7.			8.5	
65.	Prunus yedoensis	B2	7.			8.5	
66.	Quercus serrata	B2	7.			11	
67.	Robinia pseudo-Acacia	A2	7.			8	
68.	Salix babylonica	A2	7.			9.5	
69.	Sophora japonica	A2	5.			9.5	
70.	Toona sinensis	A2	7.			11.5	

71. Weigela coraiensis	A2	4.			15	
72. Zelkowa serrata	A2 *	7.			7	
Bamboos						
73. Phyllostachys reticulata	A2	7.			5.5	
74. Shibataea kumasasa	A2	7.			5.5	

* Accompanied with faint crepitations.
† Flame is liable to die out if the lighter goes away from the leaf.

Now in the first stage of burning the author classified the following types among species of tree.

A Burning without explosion:

A_1 No explosion; furiously jetting vapor and/or gas, such as by *Ilex integra, Ligustrum japonicum, Daphniphyllum macropodum, Camellia japonica.*

A_2 No explosion; calmly jetting vapor and/or gas (sometimes with faint crepitations), such as by *Pinus densiflora, Pinus Thunbergii, Cleyera ochnacea, Viburnum odoratissimum, Osmanthus fragrans, Hydrangea macrophylla.*

B Burning with explosion:

B_1 Sharp, strong crackling, such as by *Osmanthus ilicifolius, Podocarpus macrophylla, Torreya nucifera, Photinia glabra, Ginkgo biloba.*

B_2 Succesive weak cracklings, such as by *Quercus glauca, Chamaecyparis obtusa, Taxus cuspidata, Lithocarpus edulis, Fatsia japonica, Prunus donarium.*

B_3 Powerless explosions, such as by *Aucuba japonica.*

2) The flamability of leaves

Almost all leaves but a few were blazed up with flame by heating beyond 500°C in the above-shown furnace. But under 550°C, especially among 500°C, some species were observed to tend to burn in carbon ignition. If we could find any species which burnt down without flame in the conflagration, it would be the fittest species to be planted for fire prevention plantings. Viewed in this light he examined flamability among 44 species of trees and shrubs, i. e. whether or not leaves burnt into flame in the furnace at 500°C and 550°C, as shown in the 2nd column of Table 1.

He found the difference between blazing up in flame and burning without flame could not be definitely observed in clear separation on every species of tree in a series of repeated experiment, but the both types were found mixed in each species. The types were observed not as qualitative attribute of trees but as relatively quantitative one. He found the features of each species in percentage of a number of blazing with flame in a series of experiment.

From this table he made the following classification.

A Trees and shrubs prone to blaze up in flame:

Pinus spp., Acer spp., Bamboos, Cedrus Deodara, Quercus glauca, Magnolia *glandiflora*, *Osmanthus fragrans* etc.

B Trees and shrubs tended to do carbon ignition:

The superior species are *Camellia Sasanqua*, *Chamaecyparis pisifera*, *Daphniphyllum macropodum*, *Euonymus japonica*, *Fatsia japonica*, *Ilex rotunda*, *Illicium religiosum*, *Myrica rubra*, *Osmanthus ilicifolius*, *Sciadopitys verticillata*, *Thujopsis dolabrata*, *Viburnum odoratissimum* and the next come *Aucuba japonica*, *Cunninghamia lanceolata*, *Ficus Carica*, *Ilex crenata*, *Ligstrum japonicum*, *Photinia grabra*, *Podocarpus macrophylla*, *Rhaphiolepis umbellata*.

§ 3 Flashing blaze of leaves

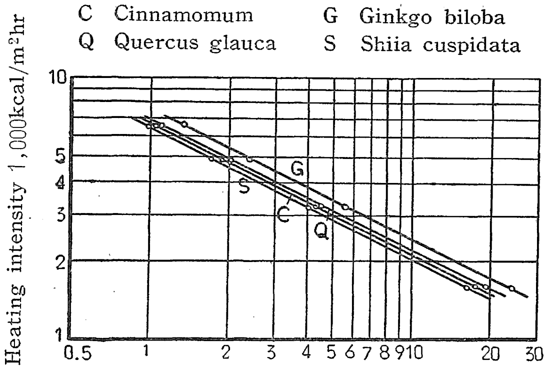
As the indicator of flamability of leaves the author uses the "flashing time". Flashing time here means the time required for blazing up by flashing, following the start of heating at the constant temperature in the furnace. To test many common species of tree on the flashing time he used two sorts of aparatus, the one small type electric furnace, the other large gas furnace for fire-proof tests of building materials.

1. Flashing time is fit for the indicator of flamability

By the heating at constant temperature, the flashing time of leaves changes in inverse proportion to the logarithm of heating intensity in W/cm^2 or in $kcal/m^2 \cdot hr$, as shown in Fig. 2. Sequence of leaves on flamability is stable among many species of tree, indifferent of heating intensity, which the author tested in the range of 1, 600 ~ 6, 600 $kcal/m^2$ hr. K. Akita is the same opinion that the flashing time is fit for the indicator of flamability of woods within the range of 500°C~800°C.[1)2)]

Fig. 2. Flashing time of leaves as a function of heating intensity

C Cinnamomum G Ginkgo biloba
Q Quercus glauca S Shiia cuspidata



2. Flashing time tests in a small scale (by a electric furnace)

Using the above-mentioned heating electric furnace, the author tested 74 species of leaves on comparative flashing time, as shown in Table 1.

3. Flashing time tests in a medium scale (by a gas furnace)

By the use of a gas furnace for fire-proof tests of building materials, constructed in the campus of the Architectural Research Institute of Japanese Government, the author could test, in 1955, flamability of branches and leaves and that of small standing trees. This gas furnace gives a radiation surface of 95 cm by 105 cm with 105 gas burners, as shown in Fig. 3. Branches and leaves were showered of heat in the fixed position in front of the furnace, maintained at constant radiation. The heat intensity was

Fig. 3. Gas furnace as a heating source

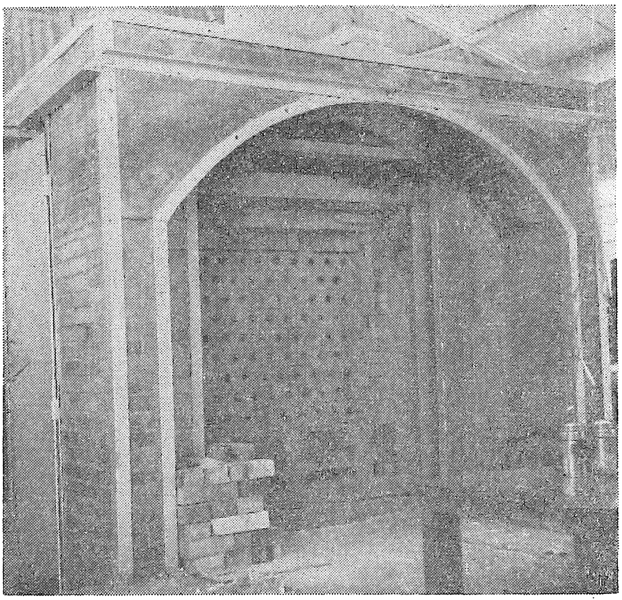


Fig. 4. Correlation between the small scale tests and the medium scale tests on flashing time

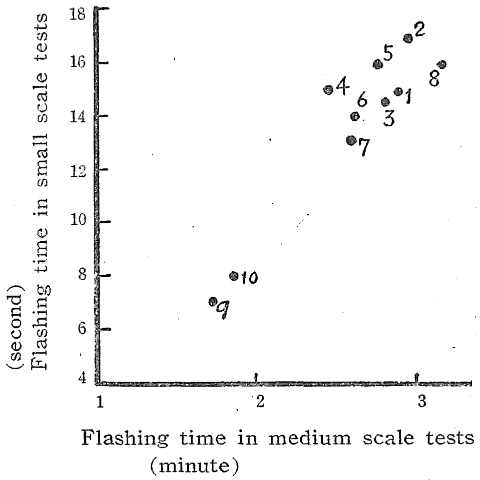


Table 2. Comparative tests of flashing time of branches and leaves by a larg gas furnace

Group	Species	Heat intensity W/cm²	Number of trial	Flashing time (minute) value	Flashing time (minute) mean	Flashing time by a electric furnace at 550°C (second)
I	Chamaecyparis pisifera	0.95	5	2′50″～3′00″	2′56″	17
	Thujopsis dolabrata	0.965	3	2′40″～3′10″	2′56″	15
II	Pinus densiflora *	0.95	5	2′30″～3′10″	2′48″	14.5
	Pinus Thunbergii *	0.95	5	2′10″～2′50″	2′26″	15
III	Camellia Sasanqua	0.925	5	2′30″～2′50″	2′38″	14
	Illicium religiosum	0.95	4	2′30″～2′55″	2′36″	13
	Viburnum odoratissimum †	0.965	4	2′35″～3′00″	2′46″	16
IV	Cinnamomum Camphora *	0.965	4	1′40″～2′00″	1′52″	8
	Osmanthus fragrans *	0.965	5	1′40″～1′50″	1′44″	7
V	Pieces of wood (Cryptomeria japonica)	0.975	3	1′50″～2′00″	1′55″	

* suddenly blazed up in vigorous flame by flashing
† flame is liable to die out if the lighter goes away

controlled at constant value near 0.95 W/cm², which he has estimated as heat radiation intensity of flashing leaves by an incendiary experimental fire of a building.[11] As the lighter for flashing was used small gas flames about 1 cm long, drawn close to it at 5 second interval.

On the flashing time were measured 43 branches with leaves of 10 species, cutted in

Table 3. Comparative tests of flashing time of standing trees by a large gas furnace

Group	Species	Heat intensity W/cm²	Number of trial	Flashing time (minute)		Flashing time by an electric furnace at 550°C (second)
				value	mean	
I	Thujopsis dolabrata	0.975	1	3′00″		15
II	Pinus densiflora *	〃	1	2′35″		14.5
	Pinus Thunbergii *	〃	1	3′00″		15
III	Camellia Sasanqua	〃	2	1′50″〜2′00″	1′55″	14
	Illicium religiosum	〃	2	2′40″〜2′50″	2′45″	13
	Osmanthus ilicifolius	〃	2	3′00″〜3′20″	3′10″	16
	Vibrunum odoratissimum †	〃	2	2′55″〜3′00″	3′00″	16
IV	Osmanthus fragrans *	〃	2	1′35″〜1′45″	1′40″	7

* Suddenly blazed up in vigorous flame by flashing
† flame is liable to die out if the lighters goes away.

70〜150 cm long, and 3 pieces of wood (*Cryptomeria japonica*, 7×60×150 mm) for the sake of contrast, as shown in Table 2, and 13 standing trees of 9 species in whole shape, as shown in Table 3.

In comparison of 2 tests, that are in a small scale and in a medium scale, the author examined the reliability of his tests on flashing time. On each species he calculated the correlation and he found a very close correlation $r=0.935$, which is significant at the risk rate of $\alpha=0.02$. As a result of this examination the flamability tests in a small

Table 4. Average flashing time of grouped trees

Group	Number of species	Flashing time at 500°C (second)		Dispersion
		value	mean	
Conifers	12	16 〜40	27	38.8
Broadleaved evergreens	27	10 〜28	17	20.3
Deciduous	28	7.5〜19	11	10.9
Bamboos	2	5.5	5.5	—

scale could introduce the estimation of flamability of leaves in actual fires and conflagrations.

At a glance of Table 2 and 3 one might make Table 4. It suggests that on the flashing time, disregarded of the flamability, the sequence of fire resistance among leaves may be as follows: conifers the first, broadleaved evergreens the second, deciduous the third and the bamboos the last.

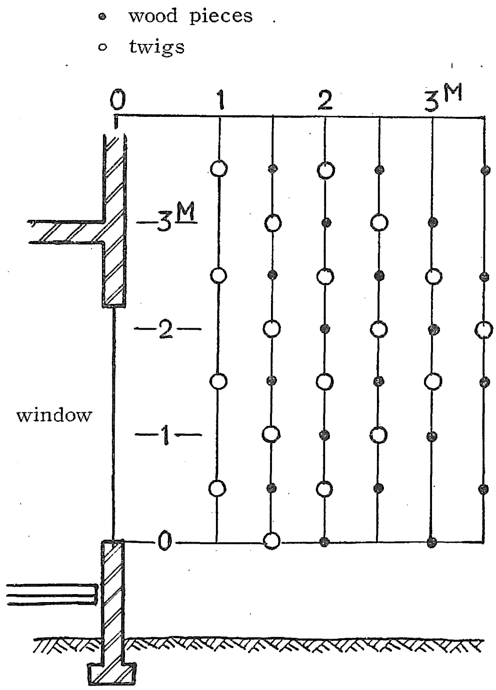


Fig. 5. Distribution of twigs and wood pieces

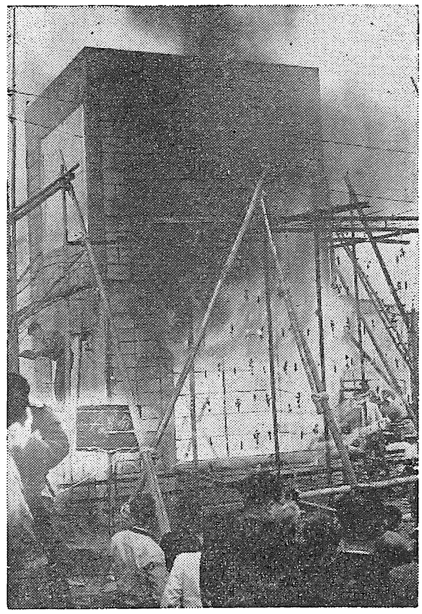


Fig. 6 A view of fire resistance test of leaves (1)

§ 4 Measurement of fire resistance of plantings by an experimental incendiary fire

Sponsored by the Architectural Research Institute of Japanese Government, with the cooperation of specialists in various fields under the direction of Dr. K. Huzita, an experimental incendiary fire was created in a steel-frame concrete building which had a floor space of 16 m^2 and windows of $6m^2$ on opposite sides.[8] The fire ran about 25 minutes long, nearly under dead wind, tracing almost the standard temperature curve for wooden houses fire in Japan (JIS A 1301),[3] that shows a summit temperature of 1100°C under the ceiling, and jetting flames 3∼3.5m off the building from the leeward window during the 13th∼15th minute, that might be attributed to the wide windows of 2.20m by 2.84m.

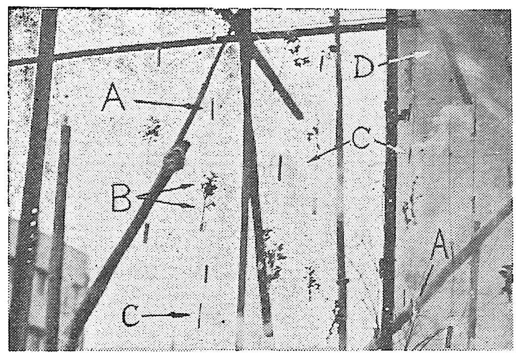


Fig. 7. A view of fire resistance test of leaves. (2)

This is printed of the original color-film slide, which show us flame and blazed pieces of wood in bright color. You might find even in this monochrome picture that fresh twigs are more fire-resistant than pieces of dry wood.

A. A wood piece now in blazing
B. Twigs are safe in the course of fire
C. Wood pieces now in smoking
D, Flames, jetted from fire source at the right

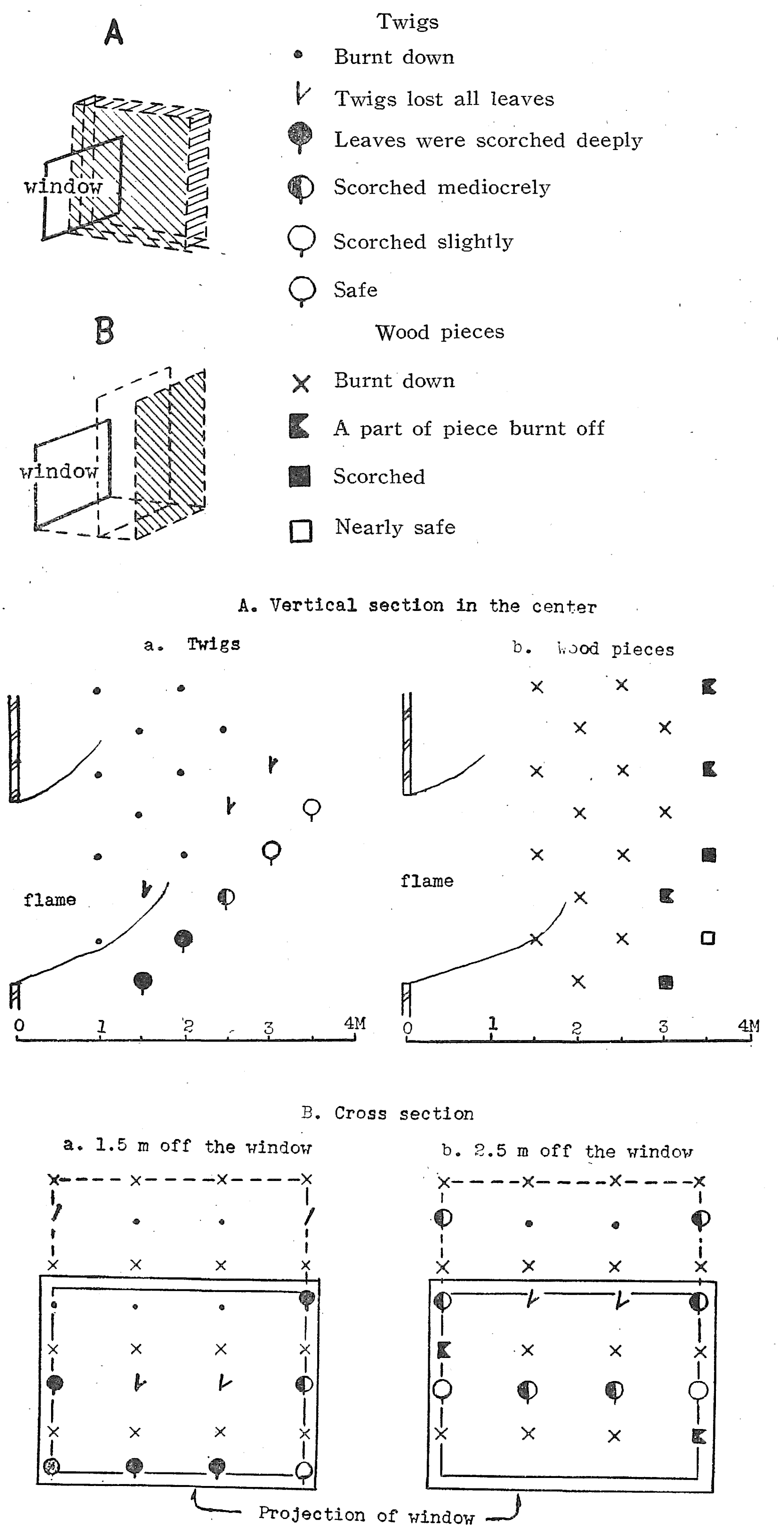


Fig. 8. Fire resistance of leaves in front of a window.

Table 5. Damages of twigs by the experimental incendiary fire

Twigs and leaves were burnt down or lost	22
Twigs remained, leaves were lost	13
Leaves were blackened	23 *
Leaves were somewhat wilted	2
Total number	60

* On five of these twigs leaves were severely carbonized.

To study the fire resistance of leaves around such a building, 60 twigs of *Euonymus japonica* and pieces of dry wood for contrast were hung in front of the leeward window, being spaced regularly in a three dimensional pattern in the space of 36 m^3, as shown in Figs. 4 and 5.

Twigs were cut in about 25 cm long and were put in small bottles filled with water. Pieces of dry wood were made of *Cryptomeria japonica*, having surface of 36 cm^2 painted with three sorts of thermo-paint (they change color at 50°C, 80°C and 300°C). Measurements of heat radiation and many photographs of flames bursting out of the window were taken, especially very useful for the examination of twigs and wood pieces were a series of photographs of the entire fire scene taken from a fixed point at one minute interval and telephotos shot by side angle.

Damages of twigs and pieces of wood were more than the expected as shown in Table 5 and Figs. 6 and 7.

In this tests the author got the following estimations.

1. The distribution of twigs, which were burnt down or lost all leaves, is seem coincede with the[5] reach range of flames. But many pieces of wood were burnt down far out of it. A picture (Fig. 7) seems support this estimation of the author.
2. Generally speaking, in common wooden houses fire in a small scale, fresh leaves seem hardly to blaze up, even if it were blackened, unless they enter into the reach range of flames for a minute or more.

Summary

1. Experiments on (1) the flashing types, (2) flamability and (3) flashing time were carried comparatively on leaves among 74 species of common tree. And an attempt of classification on (1) the flashing types and on (2) flamability, i.e. whether or not leaves are prone to blaze up in flame.
2. As the indicator of flamability of leaves the author chose "flashing time", and he carried some tests of this on 74 species of tree, using an electric furnace and a gas furnace.
3. He got a chance to test the fire resistance of plantings in an experimental incen-

diary fire sponsored by the Architectural Research Institute of Japanese Government. He spaced 60 twigs and pieces of dry wood in a three dimensional pattern in front of the window jetting flames 3 m off the building.

4. In this experiment he could get some estimations, such as fresh leaves seem hardly to blaze up unless they enter into the reach range of flame for a minute or more.

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