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STUDY OF BURNING BEHAVIOR OF SMALL SCALE WOOD CRIB WITH CONE CALORIMETER

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Burning behavior of small-scale wood crib was studied by a serial of cone calorimeter tests. The heat release rate curves of these small wood cribs were different due to porosity factor and this shows that the control condition switches from one to another. The burning of some crib with small porosity factors was self-extinguished in fixed flow rate of air supply in cone calorimeter. These results were compared with Gross's studies. The switch point of porosity-controlled and surface area controlled burning regime is different from Gross's result.

Keywords: *burning behavior, porosity factor, wood crib*

Introduction

Wood cribs have been commonly used in fire safety studies as fire source independently or used to ignite other combustible materials. Wood crib fire has good repeatability of heat release rate. It can duplicate itself better in different burning scenarios. Its behavior is closer to real fire development in compartment than other fire sources. Numerous experiments were reported by using of wood cribs in compartment fire studies [1] and fire-suppression system tests [2, 3]. Fire safety performance, which has high level of international concern for fire safety reflected in limitations and design requirements in building codes, is also important for wood productions [4].

In the SFPE Handbook of Fire Protection Engineering [5], wood cribs is defined as the wood structure with regular, three dimensional array of wood sticks. Each stick is of a square cross section and of a length much greater than its thickness. The sticks are placed in alternating rows, with an air space separating horizontally adjacent sticks.

The burning behavior of wood cribs is controlled by the dimension of stick, structure of cribs, effective combustion surface area, igniting position, type of wood and air supply from surrounding area. Three conditions that govern burning behavior were derived by previous studies [5]. Fuel area control, porosity control and room ventilation control govern the burning rate with different mass. A single burning process is controlled by one of these three conditions or combination of these conditions, one condition can switch to the other. Gross [6] studied the burning of wood cribs in free space and identified two distinct burning regimes: surface area controlled burning (for loosely packed cribs) and porosity controlled burning (for tightly packed cribs). In study of porosity controlled burning, Gross [6] defined porosity factor ϕ to describe porosity condition of wood cribs. For a wood crib, the dimension of stick is $l \times b \times b$ (which is length×width×height, and the cross section of the stick is square), N is the layer of crib, and n is the number of stick per layer, the porosity factor ϕ is

$$\phi = N^{1/2} b^{1.1} (A_v/A_s) \qquad (1)$$

where A_s is the exposed surface area of the wood crib

$$A_s = nN(4lb + 2b^2) - (N-1)n^2 b^2 \qquad (2)$$

and A_v is the total cross-sectional area of the vertical crib shafts

$$A_v = (l - nb)^2 \qquad (3)$$

Further studies on porosity factor ϕ and burning behavior of wood cribs were conducted by several other researchers [7, 8]. This paper presents experiments on small-scale wood cribs conducted in CSIRO (Commonwealth Science and Industrial Organization, Australia).

Experimental

The wood sticks were made from radiata pine.The pre-made small-scale wood cribs were conditioned to

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equilibrium at a relative humidity of 50±5% RAH and 23±2°C prior to testing in a conditioning case for two weeks. The parameters of these cribs are listed in Table 1. All the sticks have the same length *l*=0.05 m, and all layers of wood crib have eight sticks, that is *n*=8.

The tests were conducted in CSIRO's Fire Science and Technology Laboratory. Tests were carried out on cone calorimeter in accordance with AS/NZS 3837:1998 [9]. For cone calorimeter tests, the wood crib was put on specimens sample holder. The holder was supported horizontally on a load cell. Cone heater was not used in the test. Instead, a gas torch was used to ignite the wood crib underneath at the center. After confirming the crib was ignited, the window of cone calorimeter was closed. The nominal exhaust system flow rate for all tests was 0.024 m^3 s^{-1}. Sampling rate of data taken was 1 sample/2 s. Necessary calibration procedures were carried out to ensure accuracy of measurement and repeatability. Heat release calibration was carried out daily using methanol. Load cell was checked for its response time and accuracy by applying a mass on it. All gas analysers were calibrated daily.

Results and discussion

The burning style of these small cribs could be classified in three groups according to the shape of heat release rate (HRR) curves. The first group has only one peak, and in this group the crib burnt fast and completely. Test A1 to A5, Test B1 to B3, Test C1, Test D1 and D2, which have relatively big porosity factors, belong to this group. The burning of these cribs in this group could get enough air supply not only around the crib but also at the center of the cribs. As the normal cone calorimeter test, at the beginning of burning shows an initial peak in HRR curve. But there is only one peak throughout the burning. This is attributed to the quick flame spread in the crib. The effect of surface char formation was less than the pyrolysis effect of wood sticks. The charring effect was not strong enough to make the HRR decrease to form a middle flat range as that in those results of flat wood sample tests. Thus, the HRR curve was not influenced by the char formation during the burning. The HRR curve decreased due to volatiles were consumed. The burning procedure of this group was relatively short and achieved peak HRR quickly. Figure 1 illustrates

Table 1 Parameters of wood cribs

Test label	Stick b/m	Layer N	Porosity factor/ $cm^{1.1}$	Initial mass/ g	Steady mass loss rate/% s^{-1}	Burning surface/$\cdot 10^{-3}$ m^2
A1	0.002	3	0.0367	3.3	2.125	9.28
A2	0.002	6	0.0263	6.2	2.33	17.02
A3	0.002	9	0.0216	8.6	2.325	25.28
A4	0.002	12	0.0188	11.4	1.49	33.54
A5	0.002	15	0.0168	15.1	1.588	41.85
B1	0.003	3	0.0228	6.2	1.397	12.53
B2	0.003	6	0.0164	11.8	1.356	23.90
B3	0.003	9	0.0135	17.9	0.776	35.28
B4	0.003	12	0.0118	24.2	0.661	46.66
B5	0.003	15	0.0105	32.6	0.4	58.04
C1	0.0035	3	0.0167	7.9	1.051	14.25
C2	0.0035	6	0.0121	15.1	0.662	26.94
C3	0.0035	9	0.01	23.3	0.513	39.62
C4	0.0035	12	0.0087	29.9	0.2	52.30
C5	0.0035	15	0.0078	39.5	0.399	64.98
D1	0.004	3	0.0114	10.7	0.654	15.87
D2	0.004	6	0.0083	20.0	0.3	29.70
D3	0.004	9	0.0069	29.7	–	43.52
D4	0.004	12	0.006	38.8	–	57.34
D5	0.004	15	0.0054	49.9	–	71.16

the burning styles refer to different tests and porosity factors. One typical HRR curve of each group is shown in Fig. 2.

The second group has two peaks, and the shape of these HRR curves is similar to the cone test result of flat wood sample. Test B4 and B5, Test C2 to C5 belong to this group. In this group, the burning of crib was controlled by how much air could reach the burning area in the central part of crib. The airflow rate was reduced due to more compacted structure of crib. Burning procedure was slowed down by reduced air supply. While on the other side, the surface char formation had more negative effect on the combustion of wood cribs. The joint effect resulted in a middle part of HRR curve. A second peak corresponds to the post-surface char formation stage while an increased rate of volatiles formation was achieved.

The third group is those with different number of peaks but did not burn completely and self-extinguished in the middle of combustion. Test D3 to D5 belong to this group. Less than 10% of the initial mass of these cribs was consumed. When the crib was ignited underneath at the center, the fire spread outside. But the fire propagation was limited by insufficiency air supply due to the very compacted structure or very small porosity factors. Combined with surface char formation, the fire propagation was attenuated and the fire was extinguished finally.

The scaled steady mass loss rate $Rb^{1.6}$ of these tests are shown in Fig. 3 *vs*. porosity factors. R is the steady mass loss rate which is defined as the mass loss rate reaches 90% of the maximum value [8]. A fitting line of these results is drawn along with Gross's results. In Fig. 3, the scaled burning rate scatters over relatively large area for those cribs with porosity factor larger than 0.015 $cm^{1.1}$. This implies that crib fires with porosity factor more than 0.015 $cm^{1.1}$ are not controlled by porosity, but controlled by the surface area of wood cribs. This is different from Gross's results [6], in which control mode for burning procedure changes at porosity factor is nearly 0.1 $cm^{1.1}$. This result is also different from Hu's result [7] which has slight difference from Gross's results [6].

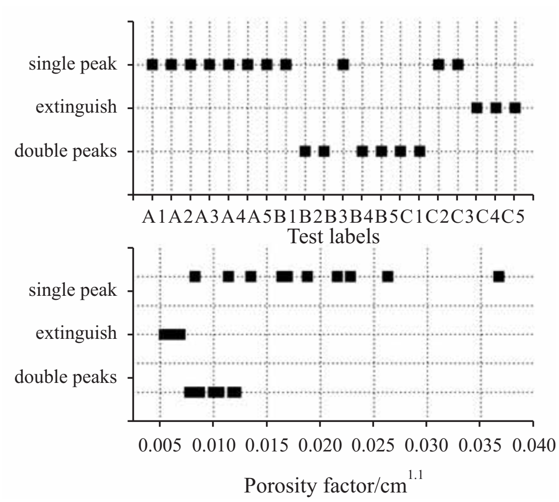

Fig. 1 Burning styles of different tests and porosity factor

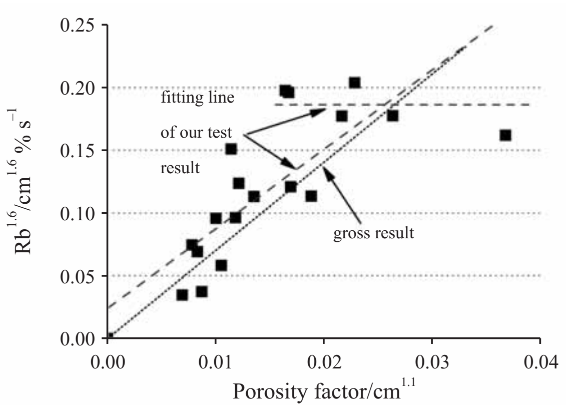

Fig. 3 Scaled rate of burning and porosity factor compared with Gross's studies

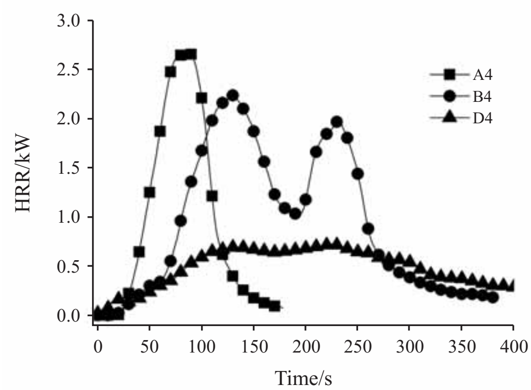

Fig. 2 Heat release rate HRR curves of one peak A4, double-peak B4 and extinguished burn D4

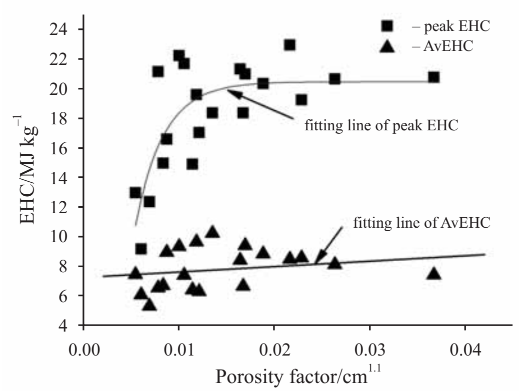

Fig. 4 Peak EHC and average EHC changes with porosity factor

The effective heat of combustion (EHC) was also obtained from heat release and mass loss of wood crib in each test. The peak EHC changes with porosity factor in exponential growth style as shown in Fig. 4, while the average EHC is nearly 8 MJ kg^{-1} that is close to the flat sample cone test result. For the cribs with porosity factor more than 0.015 $cm^{1.1}$, the peak EHC changes around 20 MJ kg^{-1}.

Conclusions

From the above results, we can see that the scale-effect can change the switch point of control condition. The combustion procedure is different for the large-scale and small-scale wood cribs. For the large-scale crib with relatively thick sticks, the surface char formation effect is greater during its burning procedure than the effect in small crib burning. For large-scale and small-scale cribs with same porosity factor, the small one is easier to achieve complete combustion due to thinner sticks. Thus, for different scales of wood cribs the switch point between porosity-controlled and surface area-controlled burning regime is different. It is necessary to take the scale-effect into consideration in burning tests of wood cribs.

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References

1 P. A. Croce and Y. Xin, Fire Safety J., 40 (2005) 245.
2 D. J. E. Harvie, V. Novozhilov, J. H. Kent and D. F. Fletcher, J. Appl. Fire Sci., 8 (1998) 283.
3 G. Granta, J. Brentonb and D. Drysdalec, Progr. Energy Combust. Sci., 26 (2000) 79.
4 M. Gao, C. Y. Sun and C. X. Wang, J. Therm. Anal. Cal., 85 (2006) 765.
5 The SFPE Handbook of Fire Protection Engineering, 3rd Ed., ISBN: 087765-451-4, pp. 3-13-15.
6 D. Gross, J. Res. National Bureau of Standards, C. Engineering Instrumentation, 66C (1962) 99.
7 L. H. Hu, R. Huo, Y. Z. Li and H. B. Wang, J. Fire Sci., 22 (2004) 473.
8 L. H. Hu, Y. Z. Li, H. B. Wang and R. Huo, J. Fire Sci., 24 (2006) 153.
9 AS/NZS 3837 Method of Test for Heat and Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, Standards Australia, Sydney 1998.

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