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CALIBRATION BURNING OF WOOD CRIB UNDER ISO9705 HOOD

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Wood cribs free burning tests were conducted under ISO9705 hood. From the tests, the heat release rate of these cribs was grouped as 0.5, 1.0 and 1.5 MW. This result was used to correct an empirical formula for peak heat release rate calculation. The correction achieves acceptable accuracy for the typical wood. The test result also shown heat release rate curve can be normalized by the total combustion surface of the wood crib. This can also be used to predict the HRR of wood crib of certain sizes and structures.

Keywords: *effective heat of combustion, heat release rater, ISO9705 room, wood crib*

Introduction

As structural members, wood is widely used in residential and low-rise constructions. Apart from the mechanical properties, 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 [1, 2]. Many basic data on fire behavior of wood products are needed to evaluate fire safety for wood construction, and these data can be obtained from calorimetric test, such as bench scale cone test, intermediate scale ASTM E1623 test or full scale ISO9705 test. The evaluation of flame-retardant treatments that can be used to reduce the combustibility of wood is also based on these tests. Wood cribs are also used as fire source in fire safety researches [3, 4]. For full-scale fire tests in the fire performance of houses test facility, the configuration of the fuel package should be determined at first. Wood cribs are always used as a part of fuel package which would provide certain fire load to sustain the fully-developed fire for the desired period of time [5]. Wood crib fire has different characteristics from gas burner fire, spray fire or pool fire. Its behavior is closer to real fire development in compartment than other fire sources. Wood crib fire is also the most difficult fire to be suppressed by water mist. Thus, wood crib fire was chosen as fire source in compartment for water mist research. In the scaling test of water mist suppression system, wood cribs of different heat release rate (HRR) were used as fire sources. Before the real water mist suppression test, calibration burnings for wood cribs were conducted under ISO9705 hood. The HRR of different crib sizes was obtained and compared with calculation results.

Experimental

Three sizes of wood cribs were chosen for the test. Free burning experiments were conducted just under the smoke collected hood outside the ISO9705 room. The hood, exhaust duct, and all instrumentations met the specifications of ISO9705 [6].

Wood cribs were set up with wood sticks of radiata pine. The sticks had been conditioned more than one month before burning test. The conditioning room is with 23±2°C in temperature and 50±5% in humidity. Wood moisture was taken by a moisture meter (Model G-40 from Delmhorst Instrument Co.) and the density was also calculated from stick's mass and dimension. The test data for each wood crib are listed in Table 1.

Exhaust gas of wood cribs fire was gathered by the hood and continuously extracted from the exhaust duct and passed through a series of analyzers. Oxygen concentration was measured using a paramagnetic oxygen analyzer. Concentrations of CO were measured by an infrared analyzer. The exhaust gas temperature at the sample point was measured by a pair of type K thermocouples. The speed of the exhaust gas flow was measured with a bi-directional probe connected to a micromanometer. The data collected enabled the heat release from the burning crib to be determined by means of oxygen consumption calorimetric. The instrumentation in

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Table 1 Moisture, density, mass and amount of timber sticks for each tests

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Moisture/%	12.76	13.50	13.45	13.42	12.66	12.9
Density/kg m^{-3}	514.8	551.5	528.9	538.8	524.4	517.6
Initial mass, m_0/kg	30.9	32.4	31.1	63.4	61.7	91.3
Layer (short stick)	12	12	12	6	6	12
Layer (long stick)	0	0	0	6	6	12
Short stick/layer	8	8	8	16	16	8
Long stick/layer	0	0	0	8	8	8
Surface area/m^2	5.23	5.23	5.23	10.34	10.34	15.45
Calculated peak HRR/kW	305	320	307	626	610	902
Corrected peak HRR/kW	516	541	519	1059	1031	1525
Peak HRR from test/kW	516	496	486	1046	1039	1544*

*This is not the real peak HRR of the wood crib in Test 6, Test 6 was terminated when HRR reached 1.5 MW to protect the fan in exhaust duct from high temperature

the duct met the specifications in ISO9705. The sampling rate of ISO9705 is 1 sample per 2.5 s.

Six free burning tests were conducted under the hood to calibrate the fire size. The sizes of wood crib are shown in Table 1, and the cribs are labeled as Test 1 to Test 6. Cribs were put on a weighting platform with load cells underneath. Cribs were located at the center of the area which the hood covers and were placed 70 mm above the weighing platform. The wood cribs consist of different layers and size radiate pine sticks. The data of the construction of each crib are also listed in Table 1, where the short stick refers to 35×35×500 mm (width×height×length), and long stick refers to 35×35×1000 mm (width×height× length). Figure 1 shows three schematic structures of wood cribs. Under the crib aluminum foil trays filled with 0.5 L methylated spirits each to ignite the crib fire. The tray's size is 290×190×50 mm (length×width×depth). Two trays were used for Test 1 to Test 3 cribs, 4 for Test 4 and Test 5 cribs, and 6 for Test 6 cribs. The fuel inside trays was ignited by torch.

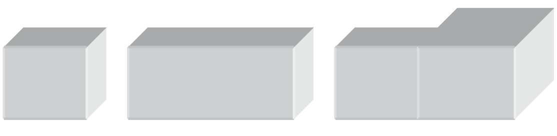

Fig. 1 Schematic diagram of wood cribs

Results and discussion

Heat release rate (HRR) is used to describe quantitatively how big the fire is [1]. The HRR is measured in kW and defined as

$$\mathrm{HRR} = \Delta h_c\, MLR \tag{1}$$

where Δh_c is the effective heat of combustion (EHC) (MJ kg^{-1}) and *MLR* is the mass loss rate (kg s^{-1}). For wood cribs, commonly the heat of combustion is taken to be 12 MJ kg^{-1}. From the cone calorimeter test EHC of wood used in constructing cribs is roughly 12 MJ kg^{-1} before charring period.

As described in reference [1], for cribs ignited uniformly overall, it is observed that the burning rate can be governed by one of three conditions: (1) the natural limit of stick surfaces burning freely; this limit applies to cribs with wide interstick spacings; (2) the maximum flow rate of air and combustion products through the air holes in the crib; this governs for tightly packed cribs and (3) the maximum oxygen that can be supplied to the room. The intersticks spacing of the wood crib used in our tests was smaller than stick thickness, thus the cribs were taken as tightly packed. When the sizes of wood cribs were determined, Eq. (2) was used to calculate the mass loss rate of each crib. As the crib we chose was tightly packed and burnt under ISO hood with enough air supply, the burning situation was more conform to condition 2. Thus crib porosity control equation (Eq. (2)) is used to calculate the governing rate.

$$\dot{m} = C\left(\frac{S}{H}\right)\left(\frac{m_0}{D}\right) \tag{2}$$

where *S* is the clear spacing, *H* is the crib height, m_0 is the crib initial mass, and *D* is the stick thickness, *C* is a constant. In reference [1] *C* is $4.4\cdot10^{-4}$. In our tests, *S* is 0.0275 m, *D* is 0.035 m, *H* is 0.42 m and m_0 is listed in Table 1. Mass loss rate of difference wood cribs is calculated by substituting these data into Eq. (2). Then, Eq. (1) is used to calculate HRR for each crib with 12 MJ kg^{-1} as EHC. The results are shown in Table 1.

But these results are quite different from the test results, as shown in Table 1. C is corrected to $7.44 \cdot 10^{-4}$ by using Test 1's result as reference. The corrected results are also shown in Table 1. These peak HRR are closer to the test results. The accuracy is acceptable in predicting HRR for wood crib of certain structures and sizes.

Figure 2 illustrates the HRR curves of these six tests. The shape of HRR curves is different from typical cone calorimeter test result of wood. A typical HRR profile obtained from cone calorimeter test for wood sample begins with a sharp peak upon ignition, and as the surface chars, the HRR drops to some minimum value. After the thermal wave travels completely through the wood thickness, the back side of a wood sample reaches pyrolysis temperature, thus giving rise to a second, broader, and even higher HRR peak. HRR of the free burning tests under the hood has only one peak. This implies thermal degradation process is different for bench scale test and full scale test. In the free burning test, wood stick chars in the flame of underneath igniting fuel at first while volatilized combustible products generated but diluted by environment air. This stage is different from the initial stage in cone test. In cone test the wood sample exposed to heat irradiation from the cone generates flammable products earlier than gets charring. The flammable products form the sharp peak upon ignition. For free burning wood cribs in ignition stage, earlier charring and relatively lower concentration of flammable volatiles prevent the formation of an initial HRR peak. Furthermore the charring exists throughout the burning procedure until all the crib chars. This function limits HRR increase. This limitation is also caused by less supply of fresh air to the char surfaces because of tightly packed crib and flaming combustion. From Fig. 2, the HRR matches probably for each crib size. It means the fire performance duplicate itself well for each crib size.

When we calculated the probable HRR for each wood crib, 12 MJ kg^{-1} was chosen as the EHC. Basically, EHC is the HRR divided by the mass loss rate as determined from the cone calorimeter test as a function of time. EHC also can be calculated from heat release and mass loss obtained from ISO9705 test, the results are shown in Fig. 3. As it shows, the EHC of the tested wood cribs is ranged from 11 to 13 MJ kg^{-1}. The EHC curves keep their shape from 200 s (at which time the ignition fuel nearly runs out) to 900 s (which refers to the maximum HRR is achieved).

Another very important factor for wood crib is the total surface area. This factor related to the stick size and the arrangement of the crib. The total surface area can be calculated by Eq. (3)

$$A_C = 2N_S N_L (wh + hl + wl) - 2(N_L - 1)(N_S w)^2 \quad (3)$$

where N_L is the layer number, N_S is the stick number per layer, l is the stick length, w is the stick width and h is the stick height. The total nominal surface areas of the cribs are also listed in Table 1.

HRR was divided by the nominal total surface area listed in Table 1 and the results are shown in Fig. 4. All the increasing part of the curve match with each other. The average slope of the increasing part is 0.125 kW m^{-2} s^{-1}. Although the burning of these wood cribs is porosity controlled, the burning rate is still governed by the total combustion surface of cribs.

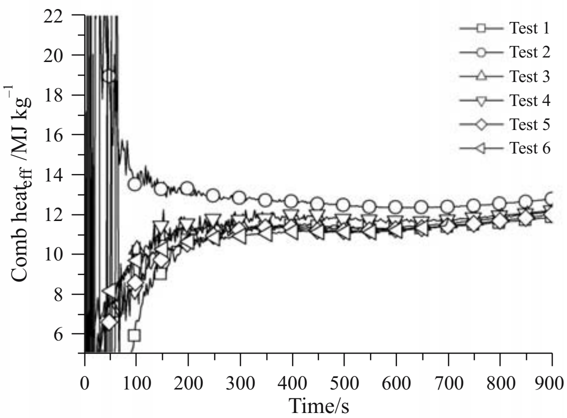

Fig. 3 Effective heat of combustion of the radiata pine

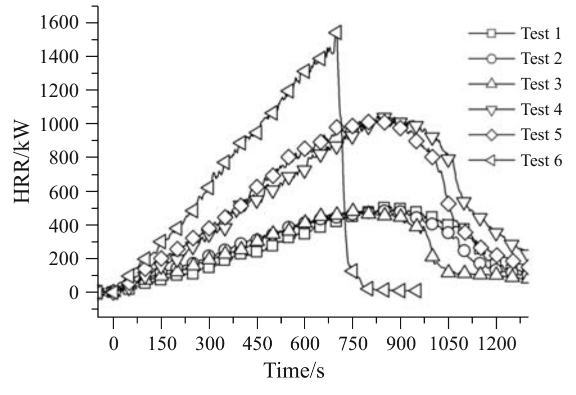

Fig. 2 Heat release rate

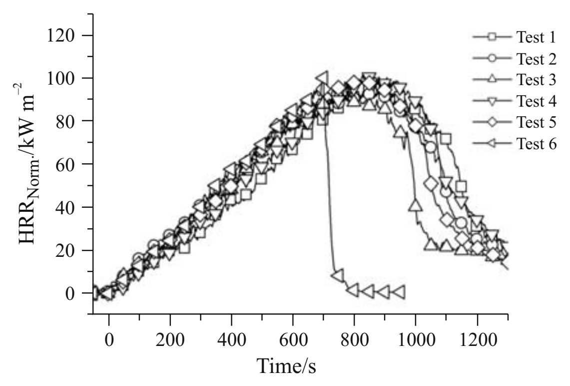

Fig. 4 Normalized heat release rate per area

Conclusions

The surrounding space around the wood crib could supply enough air to its burning. Thus the burning rate was controlled by its structure. The tests show great similarity in the shape of HRR curves and can be normalized by the total combustion surface. The average slope of normalized curve could be used to predict the HRR of wood crib with the data of total combustion surface and probable burning time. The prediction is limited to the typical wood and crib structures.

Empirical formula to predict HRR of wood cribs is chosen according to the controlling mechanism of wood crib burning. But correction should be made according to the type of wood and crib structure. The correction is also based on several tests. From the observation of the free burning tests, all the crib can hold its shape at 80% of maximum HRR and the HRR of crib can duplicate itself well for each size. These are benefit to future water mist suppression test.

The difference in the shape of HRR between bench scale cone test and large scale ISO9705 free burning test results implies that attention should be taken when cone test result is used for predict large scale burning test. But the EHC is the same from both cone test and ISO9705 test.

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