



Research on Assessment of the Ignitability of Upholstered Furniture by Using Wooden Crib as Ignition Source

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Abstract. The ignitability of upholstered furniture was experimentally studied by using wooden crib as ignition source. Three different ignition source assemblies were assessed and compared by measuring their combustion heat release rate, total calorific value, combustion duration, and temperature. Results indicated that one ignition source assembly (randomly purchased pine + normal lint + 1.4 ml ethanol) has the similar combustion effect with other two contrast items, but better comprehensive performance. By using selected ignition source, 30 upholstered furniture were tested, 70.6% mattresses specimens and 61.5% sofa specimens failed. These results demonstrate the feasibility of this method and suggest a new approach for assessing ignitability of upholstered furniture in presence of medium-scale ignition source, improve the flame retardant performance of soft furniture, suppress the occurrence of fires, or delay the spread of fire when a fire occurs.

Keywords: soft furniture; flame retardant; small wooden stack; fire source; burning

1 Introduction

Fire is intimately linked to people's daily lives, bringing tremendous changes while also posing significant risks. Among various disasters, fire is one of the most frequent and widespread threats to public safety and social development[1-4]. In everyday life, upholstered furniture, frequently used by people, is made of covering materials such as leather and textile fabrics, as well as fillers like foam sponge, latex, and felt pads. These materials are highly flammable, easily igniting and causing fires that result in injuries and fatalities. Therefore, it is essential to implement flame retardancy requirements for upholstered furniture, especially in special venues such as nursing homes, medical institutions, and schools[5-7]. Currently, the ignition sources used in China for studying the flame retardancy of upholstered furniture are limited to smouldering cigarettes and match flame equivalent, which are only suitable for general

residential spaces. However, due to the higher probability of fire occurrences and the potential for severe fires in special venues, ignition sources with faster burning rate needs to be considered and further studied[8-9].

By comparing and analyzing the heat release rate, total calorific value, combustion duration and temperature, the combination of wooden cribs with the best comprehensive performance is selected as the test ignition source. By applying the ignition source to 30 kinds of upholstered furniture, it is found that the ignition position and whether the specimens have undergone flame retardant treatment will significantly affect the test results. This method is highly operable for measuring the flame retardant performance of upholstered furniture used in special venues, and has great application potential.

2 Experiment

2.1 Reagents, Materials, and Instruments

Cone calorimeter (7890A + 5975, FTT, UK); Calorific value test device (SB 2512DT, EKA, Germany); Anhydrous ethanol (analytical pure, Sinopharm Chemical Reagent Co., LTD.); Propan-2-ol (analytical pure, Sinopharm chemical Reagent Co., LTD.); Wood cribs (composed of pine sticks and lint, as shown in Figure 1, see Table 1 for detailed parameters).



Fig. 1. Wooden crib.

Table 1. Composition parameters of wooden crib

Parameters	Value
Stick length	(40±2) mm
Stick square section	(6.5±0.5) mm
Number of sticks	10
Total mass of sticks	(8.5±0.5) g
Number of layers each of two sticks	5
Approximate lint dimensions	40 mm ×40 mm

2.2 Preparation of Specimens and Ignition Source

2.2.1. Preparation of Specimens.

Random specimens of upholstered furniture, including sofas, upholstered chairs, and mattresses, which are labeled as having flame-retardant properties, were purchased from the market. Before the experiment, these specimens were pre-conditioned for at least 7 days in an environment with a temperature of $(23 \pm 2)^\circ \text{C}$ and a humidity of $(50 \pm 5)\%$.

2.2.1. Preparation of Ignition Source.

The sticks in each layer of the crib shall be parallel to one another and at right angles to the sticks in the adjacent layer. The sticks in each layer shall be placed as far away from each other as possible, but without undue overhang at their ends, to form a square-sectioned crib. The sticks shall be glued together and the lint secured with small amounts of the adhesive. To verify the combustion effects of different ignition sources, two types of wooden strips, two types of lint, and two types of igniting agents (organic solvents) were selected for assembled. The specific combinations are detailed in Table 2. Before the experiment, the wooden cribs were pre-conditioned for at least 24 hours in an environment with a temperature of $(23 \pm 2)^\circ \text{C}$ and a humidity of $(50 \pm 5)\%$.

Table 2. Different combinations of wooden cribs

No.	Combination
1	randomly purchased pine + normal lint + 1.4 ml ethanol
2	randomly purchased pine + normal lint + 1.4 ml propan-2-ol
3	Scottish pine + BPC grade absorbent surgical lint + 1.4 ml propan-2-ol

2.3 Combustion Test of Wooden Cribs

Within 2 min of adding 1.4 ml igniting agent to the lint, ignite the alcohol from the front and above the lint, using a match, small gas flame or hot wire ignition, and simultaneously start the clock. Cone calorimeter was used to measure parameters related to heat release, which lasted for 10 mins.

The combustion phenomena observed in the three experimental combinations were largely consistent. Figure 2(a) represents the initial ignition stage, where the flame exhibits a light blue color in its midsection, indicating the combustion of igniting agent at this point. Figure 2(b) represents the combustion has reached a relatively full stage. At this point, the igniting agent had been completely consumed, and the primary source of combustion was the wooden crib itself. Figure 2(c) shows parts of the wooden crib still glow, indicating a smoldering state.

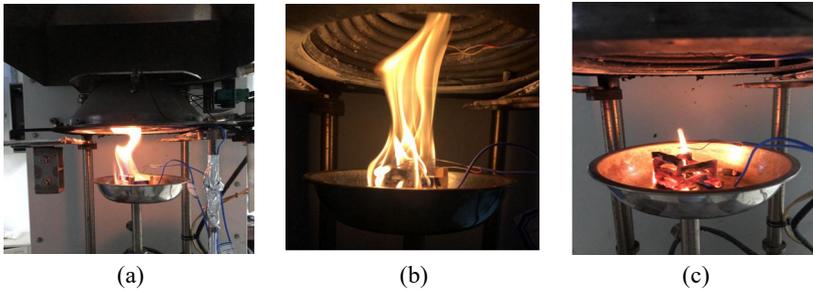


Fig. 2. The process of wooden crib combustion test

2.4 Combustion Test of Upholstered Furniture

Use a new specimen for each test. After the assembly of a crib and after pre-conditioning it, add slowly 1.4 ml of ethanol to the centre of the lint. Place the wooden crib on the test specimen where most likely to cause ignition, with the lint at the bottom of the crib, the crib touching the vertical face of the specimen cover.

Within 2 min of adding the ethanol to the lint, ignite the alcohol and simultaneously start the clock. Observe for evidence of ignition (test specimen continues to flame for more than 10 min after ignition of the crib) in the interior and/or cover. Figure 3 and Figure 4 show the combustion test process of a sofa and a mattress specimen.

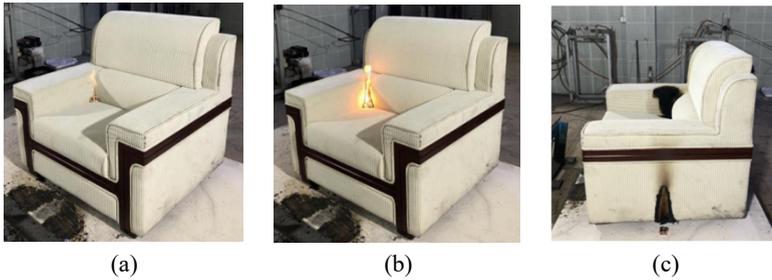


Fig. 3. Combustion test process of a sofa specimen

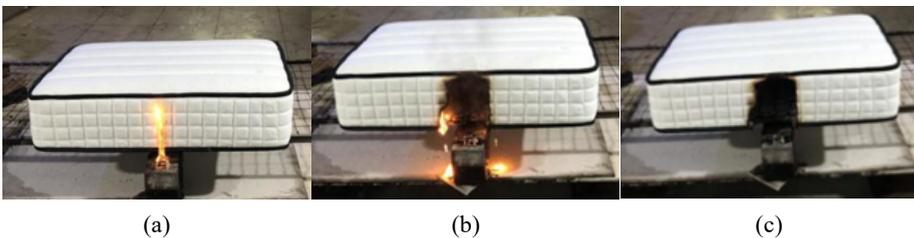


Fig. 4. Combustion test process of a mattress specimen

3 Results and Discussion

3.1 Data Analysis of Combustion Test of Wooden Cribs

Table 3 presents the relevant data collected by the cone calorimeter throughout the entire combustion process of three wooden crib combinations.

Table 3. Test data of wooden cribs combustion test by using cone calorimeter

Data type	Wooden crib combination ^a			Average value
	No. 1	No. 2	No. 3	
Flame extinction time, s	187	201	211	200
Maximum heat release rate per unit area (kW/m ²)	100.7	96.7	97.8	98.4
Total heat release per unit area (MJ/m ²)	14.9	16.3	16.9	16.0
Total smoke production per unit area in the no-flame phase (m ² ·m ⁻²)	433.6	1375.3	566.0	791.6
Total smoke production per unit area in the flame phase (m ² ·m ⁻²)	906.4	2769.7	1998.5	1891.5
Average heat release rate per unit area within the first 180s (kW/m ²)	60.9	63.4	64.5	62.9
Average rate of heat emission, ARHE (kW/m ²)	59.8	63.1	64.2	62.4

^a Corresponding to the serial number in Table 2.

As indicated in Table 3, the flame extinction times for the three wooden crib combinations were 187 s, 201 s and 211 s, suggesting that the duration of combustion among the three combinations were highly similar. The maximum relative deviation from their average value was 2.3%, indicating a high degree of proximity. As shown in Figure 5 and Figure 6, the slopes and trends of the heat release rate curves for the three combinations are generally consistent. The heat release rate curves of all three combinations rapidly increased within 25 seconds after ignition, followed by fluctuations between 60 s and 65 s. This process may represent the transition from igniting agent combustion to wooden crib combustion.

The total heat release per unit area of combination No.1 is 8.6% less than that of combination No.2. A primary reason for this discrepancy may be that the combustion heat of ethanol (1366.8 KJ/mol) is lower than that of propan-2-ol (1984.7 KJ/mol). It was found that combination No.1 produced significantly less smoke than combinations No.2 and No.3. This suggests that the ignition method used in combination No.1 resulted in more complete combustion of the wooden cribs, generating fewer smoke particles and being more environmentally friendly.

The average heat release rates were measured according to ISO 5660-1:2015[10]. According to Clause 11.3.7 of ISO 5660-1:2015, data are considered valid if the relative deviation of the average heat release rate per unit area of a single sample from the average is less than 10% within the first 180 seconds of the test. In this experiment, the maximum relative deviation was 3.2%, fully meeting the requirements of ISO 5660-1:2015. Therefore, in subsequent experiments, combination No.1 was adopted as the ignition source for conducting combustion test of upholstered furniture.

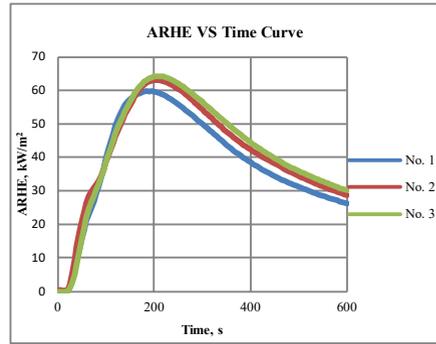
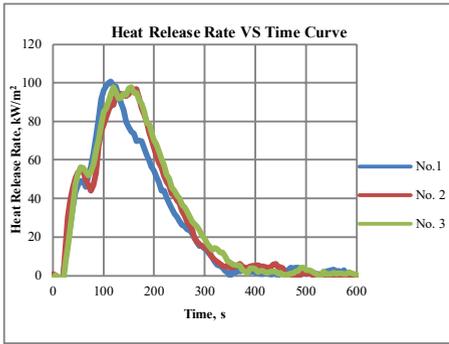


Fig. 5. Heat release rate of 3 wooden crib combinations

Fig. 6. ARHE of 3 wooden crib combinations

3.2 Data Analysis of Combustion Test of Upholstered Furniture

30 pieces upholstered furniture, which were advertised to possess flame-retardant properties, including sofas, mattresses, and upholstered chairs, were randomly purchased from the market. Their ignitability was assessed by using wooden crib combination No. 1, following the test procedure of 2.4. The detailed test results are presented in Table 4.

Table 4. Ignitability test data of 30 upholstered furniture specimens

No.	Type of specimen	Size (mm)	Ignition position	Criteria of ignition	Test result
1	Mattress	1200*700*140	Top surface	Duration of flaming ignition > 10 min	Fail
2	Mattress	1200*700*120	Top surface	Duration of flaming ignition > 10 min	Fail
3	Mattress	1000*1000*200	Top surface	Duration of flaming ignition > 10 min	Fail
4	Mattress	2000*1550*220	Top and back surface	Duration of flaming ignition > 10 min	Fail
5	Mattress	2000*1000*240	Top, side and back surface	No flaming nor smouldering	Pass
6	Mattress	1190*190*130	Top, side and back surface	No flaming nor smouldering	Pass
7	Mattress	2000*900*240	Back surface	Smouldered through the full thickness	Fail
8	Mattress	2000*900*240	Top and back surface	Forcible extinction was required	Fail
9	Mattress	920*740*220	Top, side and back surface	No flaming nor smouldering	Pass
10	Mattress	920*740*220	Top, side and back surface	No flaming nor smouldering	Pass
11	Mattress	600*600*120	Top, side and back surface	Duration of flaming ignition > 10 min	Fail
12	Mattress	600*600*120	Top, side and back surface	Duration of flaming ignition > 10 min	Fail
13	Mattress	600*600*120	Top, side and back surface	Duration of flaming ignition > 10 min	Fail
14	Mattress	600*600*120	Top, side and back surface	Duration of flaming ignition > 10 min	Fail
15	Mattress	980*1010*200	Top, side and back surface	No flaming nor smouldering	Pass
16	Mattress	2000*1550*220	Top, side and back surface	Duration of flaming ignition > 10 min	Fail
17	Mattress	720*465*275	Back surface	Smouldered through the full thickness	Fail
18	Sofa	100*930*950	Side and seat surface	Forcible extinction was required	Fail

19	Sofa	680*680*920	Seat/back junction and side	Forcible extinction was required	Fail
20	Sofa	680*680*920	Seat/back junction and side	Charring within the filling > 100 mm	Fail
21	Sofa	670*690*1145	Seat/back junction and seat	Forcible extinction was required	Fail
22	Sofa	680*810*1120	Side surface	No flaming nor smouldering	Pass
23	Sofa	980*710*940	Side surface	No flaming nor smouldering	Pass
24	Sofa	840*840*650	Seat/back junction	Duration of flaming ignition > 10 min	Fail
25	Sofa	980*710*940	Seat/back junction and side	No flaming nor smouldering	Pass
26	Sofa pad	490*490*60	Top surface	No flaming nor smouldering	Pass
27	Sofa pad	490*490*60	Top surface	Forcible extinction was required	Fail
28	Upholstered chair	485*485*450	Seat/back junction	Forcible extinction was required	Fail
29	Upholstered chair	485*485*450	Seat/back junction	Forcible extinction was required	Fail
30	Upholstered chair	660*660*1085	Seat/back junction	No flaming nor smouldering	Pass

As indicated in Table 1, among the 17 randomly purchased mattress specimens, only 5 mattresses exhibited no sustained flaming or smoldering after ignition at all ignition positions (top, side, and bottom), resulting in a pass rate of 29.4%. Since any part of a mattress can potentially come into contact with an open flame during a fire case, it is imperative that all parts of the mattress pass the wooden crib flammability test. By analyzing the combined materials and manufacturing processes of the mattresses, it was found that the top and bottom surfaces of the mattresses are typically treated with flame retardants, thus rendering them less susceptible to ignition by a wooden crib ignition source. However, the sides of the mattresses, particularly the taped-edge and sewn areas, due to inadequate or absent flame retardant treatment, are prone to being smoldered through the entire thickness of the mattress or to igniting intense flaming combustion that necessitates forcible extinction.

Among the 13 randomly purchased sofa and upholstered chair specimens, tests were conducted on the junction of the seat and backrest or on the top and side surfaces. Five specimens exhibited no sustained flaming or smoldering after ignition at all ignition positions, resulting in a pass rate of approximately 38.5%. An analysis of the combined materials and manufacturing processes of the sofas revealed that the seat and side surfaces, composed of relatively independent materials including only covering materials and a small amount of filling, were not easily ignited. At the junction of the seat and backrest, where flames could spread in multiple directions and the scale of combustible materials was large, intense flaming combustion was most likely to occur, necessitating forcible extinction. Additionally, inadequate flame retardant treatment in some specimens also facilitated intense flaming combustion under the continuous ignition of the wooden crib.

4 Conclusion

Based on the results and analysis presented above, the conclusions are obtained as below:

(1) It was shown that ignition source assembly (randomly purchased pine + normal lint + 1.4 ml ethanol) has the similar combustion properties, like flame extinction time or heat release rate, with other two contrast items. And this combination produced

significantly less smoke during the combustion process, exhibiting superior environmental performance and suitability as a ignition source for combustion tests on upholstered furniture.

(2) The majority of failures occurred at specific ignition sites, such as the side surface (taped-edge and sewn areas) of mattresses, and the junction of the seat and backrest of sofas or upholstered seating, indicating that the ignition site has a crucial impact on test results, comparable in priority to whether flame retardant treatments have been applied or not.

(3) This study employs a wooden crib as the ignition source in combustion tests, exhibiting good discrimination. This approach provides a novel perspective for evaluating the flame retardancy of upholstered furniture used in special venues and holds potential for large-scale application and promotion.

This study uses small wooden stacks to simulate the spread of fire during a fire and measure the flame retardant properties of soft furniture. It can more accurately distinguish the flame retardant level of soft furniture, promote the improvement of flame retardant performance of furniture products, and effectively suppress the spread of fire in the early stages of the fire, winning valuable time for people to extinguish the fire or escape from the fire scene.

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References

1. Wang Y and Liu JY (2016) Study on combustion performance of flame retardant mattress. *Fire science and technology*, 35(10): 1435-1437.
2. Debra H, Aika D, Barry R P, Jordan C, Pravinray G, David D and Black Marilyn (2020) Chemical exposure and flammability risks of upholstered furniture. *Fire and Materials Volume*, 45(1):167-180.
3. Chen MJ (2020) Review of heat release inhibition strategies for soft polyurethane foam. *Journal of Xihua University (Natural Science Edition)*, 39(05): 57-66.
4. Wang SP, Ding PF, Lin SR, Huang XY and Asif U (2020) Deformation of wood slice in fire: Interactions between heterogeneous chemistry and thermomechanical stress. *Proceedings of the Combustion Institute*, 38(03):5081-5090.
5. Lounis M, Leconte S, Rousselle C, Belzunces L P, Desauziers V, Lopez-Cuesta J, Julien J M, Guenot D and Bourgeois D (2019) Fireproofing of domestic upholstered furniture: Migration of flame retardants and potential risks. *Journal of Hazardous Materials*, 366:556-562.
6. Zhang XN (2022) Analysis of European and American upholstered furniture and mattress fire regulations. *Standard and quality of light industry*, (03):40-43.
7. Maake T, Asante J and Mwakikunga B (2020) Fire performance properties of commonly used South African hardwood, *Journal of Fire Sciences*,38(05): 415-432.

8. Hao HL, Chow CL and Lau D (2020) Effect of heat flux on combustion of different wood species. *Fuel*, 278.
9. BS 5852-2006, Methods of test for assessment of the ignitability of upholstered seating by smouldering and flaming ignition sources.
10. ISO 5660-1:2015, Reaction to fire tests-Heat release, smoke production and mass loss rate-Part 1: Heat release rate(Cone calorimeter method) and smoke production rate(dynamic measurement).

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