The 5th Conference on Performance-based Fire and Fire Protection Engineering

Study of the Combustion Performance of Three Kinds of Organic Heat Insulation Materials

YI Ai-hua\textsuperscript{a,b,*}, LIU Jian-yong\textsuperscript{a}, ZHAO Xia\textsuperscript{a}, YANG Zhan\textsuperscript{a}

\textsuperscript{a}Guangzhou Key Lab.of Testing Technology and Assessment for Building Materials and Element, GuangdongGuangzhou, 510663,china
\textsuperscript{b}Guangzhou Building Material Institute Limited Company, GuangdongGuangzhou, 510663,china

Abstract

In this research, the combustion performances and the smoke toxic of three kinds of thermal insulation materials: Expanded Polystyrene (XPS) insulation boards, polyurethane and rube-plastic sponge were studied by single burning item test(SBI), limiting oxygen index (LOI), oxygen bomb combustion heat and smoke toxicity test. Results showed that fireproof safety performance of the polyurethane is worst.

© 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.

Keywords: Single burning item test (SBI), Smoke toxicity, combustion performances ;

Introduction

Fire, especially indoor fire is one of the most significant dangers which endanger the lives and property of the people. The organic heat insulation material which is widely used in building products usually make the fire develop and spread quickly. The organic heat insulation materials not only provide the fire load but also increase the toxicity smoke which will add the dangers of the fire. So the correct assessment is very important. XPS insulation boards, polyurethane and rube-plastic sponge are popular thermal insulation materials, and have attracted great attention of scientists. In this paper, the combustion performance and smoke toxicity of the XPS insulation boards, polyurethane and rube-plastic sponge were studied by single burning Item test(SBI), Limiting oxygen index(LOI), Oxygen bomb combustion heat and smoke toxicity hazard test.

Experimental

1. Analysis Methods

1.1. Single burning item test (SBI)

Calorimeter (Fire Testing Technology Limited, England) was used to perform SBI testing. SBI testing simulates the single specimen burning in the corner of the room. The instrument shown in Fig.1. The test refered to EN

* Corresponding author. Tel.:+86-20-82201230; fax:+86-20-82201573.
E-mail address: yiaihua92751@163.com

1877–7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.04.704
13823:2002《Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item》。The specimen is fixed in the corner of the wall. The dimension of burning room is $3\text{m}\times3\text{m}\times2.4\text{m}$ and the specimen dimensions is $1.0\text{m}\times1.5\text{m}\times0.04\text{m}$ and $0.5\text{m}\times1.5\text{m}\times0.04\text{m}$.

Fig.1 SBI instrument

1.1.2 Limiting oxygen index (LOI)

LOI test measures the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen that will just support flaming combustion. The HC-2 oxygen index meter (Nanjing Jiangning Analysis Instrument Company, China) was used for testing. LOI was measured according to ISO 4589-2:1996.

1.1.3 Oxygen Bomb Combustion Heat

Oxygen bomb instrument (Changsha Bente Instrument Factory, China) was used to perform the oxygen bomb combustion heat testing according to ISO 1716:2002. In this test, a specified mass of the test specimen is burned under standardized conditions. The heat of combustion under these conditions is calculated on the basis of the observed temperature rise, taking account of heat loss and the latent heat of vaporization of water.

1.1.4 Smoke Toxicity

Smoke Toxicity testing Instrument (Shenzhen Vizna Precision Instrument Co.,Ltd., China) was used to perform the smoke toxicity testing according to GB/T 20285. In this method, the small white mice are made to exposure to toxic smoke for 30min, and then observed for 3 days. The results express by the mass of the smoke material in unit area(MSMU), the higher the value, the less the smoke toxicity of material.

2 Results and discussion

2.1 LOI and oxygen bomb combustion heat testing

The LOI is widely used to evaluate flame retardancy of polymers. The flammability behavior of the various composite materials in terms of LOI and oxygen bomb combustion heat testing are summarized in Table 1. The oxygen index of rube-plastic sponge, XPS insulation boards and polyurethane is 33.8%, 26.4% and 22.6% respectively. The rube-plastic sponge has the highest LOI indicating the flame retardant of rube-plastic sponge is best. The XPS insulation boards has the highest value of combustion heat of 3.91MJ/kg, the rube-plastic sponge has the lowest value of combustion heat of 1.66 MJ/kg indicating the fire fatalness of XPS insulation boards is the biggest and the rube-plastic sponge is the safest.

Table 1. Result of combustion performance

|                      | XPS insulation boards | rube-plastic sponge | polyurethane |
|----------------------|-----------------------|---------------------|--------------|
| LOI                  | 33.8%                 | 26.4%               | 22.6%        |
| Oxygen bomb combustion heat | 3.91 MJ/kg           | 1.66 MJ/kg         |              |
| Oxygen Index (%) | 26.4 | 33.8 | 22.6 |
|------------------|------|------|------|
| Combustion Heat (MJ/kg) | 3.91 | 1.66 | 2.62 |
| Peak value of CO content in smoke (%) | 0.023 | 0.063 | 0.081 |
| Peak value of CO₂ content in smoke (%) | 0.32 | 0.24 | 0.76 |
| Peak value of smoke release rate (m²/s) | 0.27 | 2.71 | 0.79 |
| Peak value of combustion heat release (kW) | 20.3 | 14.2 | 54.3 |
| Total heat release (KJ) | 7.92 | 1.68 | 9.27 |
| Smoke toxicity (mg/L) | 23.5 | 14.5 | 3.5 |

### 2.2 Smoke toxicity

Maintain the carrier gas velocity, diluent gas velocity and pyrolysis temperature and other parameter invariant, change the mass of the generating smoke material in unit area (MSMU) to decide the max MSMU of irritation eligible and narcotic eligible. The less the mass number, the more the toxicity of the material is. The smoke toxicity results of the three organic heat insulation materials shown in table 2, table 3 and table 4. The irritation eligible and narcotic eligible of max mass of MSMU of XPS insulation boards is 23.5mg/L, which is the highest of the three materials, while that of the rube-plastic sponge and polyurethane is 14.5mg/L and 3.5mg/L respectively. Conclude from the data in table 2, table 3 and table 4, the smoke toxicity of the polyurethane is heaviest, outclass that of the XPS insulation boards and rube-plastic sponge. So in the using of the building products, the flammability behavior and smoke toxicity of the materials should be considered in the same time.

#### Table 2 The toxicity testing results of XPS insulation boards

| MSMU (mg/L) | 20.5 | 21.5 | 22.5 | 23.5 | 24.5 | 25.5 |
|-------------|------|------|------|------|------|------|
| XPS insulation boards | irritation eligible | irritation eligible | irritation eligible | irritation eligible | irritation ineligible | / |
|             | narcotic eligible | narcotic eligible | narcotic eligible | narcotic eligible | narcotic eligible |  |

#### Table 3 The toxicity testing results of rube-plastic sponge

| MSMU (mg/L) | 11.5 | 12.5 | 13.5 | 14.5 | 15.5 | 16.5 |
|-------------|------|------|------|------|------|------|
| rube-plastic sponge | irritation eligible | irritation eligible | irritation eligible | irritation eligible | irritation ineligible | / |
|             | narcotic eligible | narcotic eligible | narcotic eligible | narcotic eligible | narcotic eligible |  |

#### Table 4 The toxicity testing results of polyurethane

| MSMU (mg/L) | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 |
|-------------|-----|-----|-----|-----|-----|
| polyurethane | irritation eligible | irritation eligible | irritation eligible | irritation ineligible | / |
|             | narcotic eligible | narcotic eligible | narcotic eligible | narcotic eligible |  |

**Note:** Irritation: the mice is alive in 30-min exposure to smoke; Narcotic: the mice middleweight recover after testing for 3days. MSMU: the mass of generating smoke material in unit area.

### 2.2 Heat Release

Total heat release (THR) and heat release rate (HRR) are also important factors for assessing performance of materials fireproof safety performance which determine the flashover probability and the flame spread velocity in the fire. In this paper, wall corner fire was simulated by the SBI test. HRR curve of the three specimens shown in Fig.2. As shown in Figure 2, HRR curve for rube-plastic sponge show a lowest peak value, which implies that rube-plastic sponge has the best flame retardant.
The time when of the peak value of HRR appeared is also very important to evaluate the fireproof safety performance of the material. The peak value appeared early will make against person escape. From the Fig.2, the time when the peak value of the HRR appeared of polyurethane is about 150s and XPS insulation boards is about 550s.

The values of the THR of the three specimens are shown in Table 1. As observed in the Table 1, the rube-plastic sponge has the lowest value of THR of 1.68KJ, much higher than that of polyurethane and XPS insulation boards which is 9.27KJ and 7.92KJ respectively. The higher value of THR and HRR, the higher probability of flashover of the material has. From the above analysis, the probability of flashover of polyurethane is highest in the fire, and the rube-plastic sponge is lowest. This is different from the result of LOI and smoke toxicity testing, so we should take different factors into consideration in the practice.

![Fig.2 Heat release rate (HRR) curves](image1)

![Fig.3 Smoke and gas release rate curves](image2)

2.4 Smoke release, carbon monoxide (CO) and carbon dioxide (CO2) content analysis

The smoke is solid granules, fluid drops and gas-phase substance produced by combustion or decomposing of the materials. According to the statistic, 70%~75% people die from inhaling the toxicity smoke in the fire. So smoke release rate (SRR) is other important parameter for assessing performance of materials fireproof safety performance. The SRR curves shown in Fig.3.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.

In Fig.3, the peak values of SRR of rube-plastic sponge is the biggest and the XPS insulation boards is the lowest. The result is different from the smoke toxicity result which showed that polyurethane is the most toxic, and XPS insulation board is the least toxic. This is because the smoke toxicity not only relate with the value of SRR but also mostly effect by the toxicity gas content. The atmosphere will harm the health of person when the CO content of the atmosphere is beyond $5 \times 10^{-5}$. The increasing of CO$_2$ content in the atmosphere will increase the breath of people and much more toxicity gas will be inhaled. So the CO and CO$_2$ content is an important parameter to assessment materials fireproof safety performance.
Combustion is a complex process, toxic gas in smoke contain HCN, NO, HCl and SO₂ except for CO and CO₂, different gas can also react with each other which increase the toxicity of smoke.

3. Conclusion

(1) The LOI of rube-plastic sponge is the hightest and that of polyurethane is the lowest. The flame retardant of rube-plastic sponge is the best and the polyurethane is the worst.

(2) The max MSMU of polyurethane is only 3.5 mg/L indicated that the smoke toxicity of the polyurethane is heaviest, outclass that of the XPS insulation boards and rube-plastic sponge. The CO and CO₂ content in combustion smoke and gas of polyurethane is also much higher than that of XPS insulation boards and rube-plastic sponge. So the smoke toxicity of polyurethane is the biggest, the fire danger is the highest.

(3) The value of HRR and THR of XPS insulation boards are bigger than the rube-plastic sponge, so the potential flashover fatalness of XPS insulation boards is higher. But the fatalness of combustion smoke of XPS
insulation boards is less than rube-plastic sponge. So in the using of the building products, different parameter of the materials should be considered in the same time.

References

[1] Min Zhao. Damage and Control of Conflagration Smoke Produced by Polymer Material. China Plastics Industry, 2004, 32: 53-55
[2] Yanjun Li. Smoke hazard and its controlling measures in building fire. Journal of Safety Science and Technology, 2008, 4: 65-67
[3] Jin He, Junjun Liu, Feng Li, Bi Lan. Toxicity assessments of the thermal decomposition products of two nitrous polymers Acta Scientiae Circumstantiae, 2006, 27: 1049-1055
[4] Cheng Lu, Lei Peng, Jianjun Zhou. Smolder Ignition of Polyurethane Foam. Journal of Combustion Science and Technology, 2005, 11: 487-492
[5] Guangqi Ji, Chunling Zhu, Changyou Song. Conical Calorimeter Fire-2proof Test for Outer-wall External Thermal Insulation System Building Science, 2008, 24: 4-8
[6] Alarie Y. Toxicity of fire smoke. Crit Rev Toxicol, 2002, 32: 259-289
[7] Zhaoyang Tong, Yifeng Yin, Qibin Huang, Fusheng Lin. Review of quantitative assessment methods on fire smoke toxicity. Journal of Safety Science and Technology, 2005, 5: 101-105