J. Korean Wood Sci. Technol. 42(5): 590~596, 2014 http://dx.doi.org/DOI : 10.5658/WOOD.2014.42.5.590

Evaluation Methods of Flame Retardants for Wooden Cultural Properties[1]

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ABSTRACT

Wooden cultural heritages of Korea have been destroyed by fire in many cases. As a result, a number of methods to protect wooden cultural properties against fire were introduced. A way of protecting wooden cultural properties installations of fire equipments such as sprinkler, fire alarm system, or fire extinguisher. Another way of protecting wooden cultural properties is to treat them with flame retardants for their safety. Development of a very effective flame retardant with a good performance without affecting danchung and wood quality is required. At the same time, methods of evaluating flame retardant treated woods should be devised to assess their efficacy. In this study, combustion characteristics using cone-calorimeter, limit oxygen index, moisture absorption, iron corrosive and weathering were analyzed to evaluate the flame resistance efficacy and performance of flame retardants treated woods. The evaluation methods of flame retardants for wooden cultural heritage were suggested.

Keywords : wooden heritages, flame retardants, performance evaluation

1. INTRODUCTION

On February 10, 2008, National Treasure No. 1, Sungremun had been burnt down in an arson attack. Since then, Yeosu Hangilam, Beomeosa Temple, Gurye Huaam Temple, Jeongup Nejang temple has been damaged by fire (Shin and Baek 2013).

In the case of dense wooden building areas, one near the building when the fire occurs in the building should be considered as the risk of metastasis (Asan city 2009). Because of in the wooden heritage which combustion is fast and flammable, the ignition process is very short and direct fire propagation occurred than normal fire resistant building (Incheon fire department, fire investigation team 2003).

The wooden cultural heritage were aged long time, drier has been advanced, combustion is likely to be that is easy to ignite. In addition, it has become a combustible material such as wood that is easy to burn, it has a feature that reaches its peak in fire (Flashover) within 10 minutes (Baek and Lee 2010).

The flame retardant sprayed to the wood surface with a 4～5 year cycle in order to protect from fire the wooden cultural property. But flame retardant treatment occurs to wood heritage maintain problems

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Table 1. Flame retardant used for test

Flame retardant	Amount of spray (mℓ/m^2)	Constituents
A	500	Phosphous compounds, water solubles
B	700	HEDP compounds, water solubles

such as decoloration of danchung, whitening, moisture absorption (Cha *et al*. 2011).

In the wooden heritage fire safety study, Shin *et al*. (2013) reported that external fire environment is most important to wooden heritage. Cha (2012) estimated the efficacy of domestic flame retardants. The most secure way to protect wooden cultural heritage is improvement of fire resistance through the fire retardants technological development (Oh *et al*. 2009).

Currently, wooden cultural heritage of the country carry out the installation of fire fighting facilities and flame-retardant treatment for fire prevention. Flame retardants for wooden cultural heritage should not affect the wood and danchung also has good performance. In addition, a unique feature of the wood should not be lose due to flame retardant treatment. Performance evaluation of flame retardants for wooden heritage has been focus for flame resistance assessment, it was not analytical for treated wood performance.

Such wetting phenomenon and whitening of flame retardant treated wooden building may be associated with hygroscopic of flame retardant. Because that flame retardants are sprayed directly on the building, the effect on the corrosion of iron should be analysed.

In this study, for the flame resistance efficacy and performance of flame treated wood, combustion characteristics of cone-calorimeter, limit oxygen index, moisture absorption, iron corrosive, weathering were analyzed.

2. MATERIALS and METHODS

2.1. Combustion Characteristics of Flame Retardant Treated Wood

Flame retardants were used two agents that are registered in the Cultural Heritage Administration. The application amount of the flame retardants used in the experiment are recommended splay volume that applied to the actual wooden assets. Flame retardants were treated A (500 mℓ/m^2) and B (700 mℓ/m^2). Flame retardant was treated to the Japanese red pine. After treatment, the specimens were placed at in the room temperature.

2.2. Evaluation of Hygroscopicity

Red pine (*Pinus densiflora*) 70 × 80 mm (W × D), thickness 5 mm specimens were used for hygroscopic test of flame retardants. The splay amount A (500 mℓ/m^2) and B (700 mℓ/m^2) were adjusted each specimens. After treatment, specimens were placed at 50% RH 20℃ for 20 days in the room for conditioning. Untreated wood and flame retardants treated wood put together in the chamber which controlled for 98% (40℃) condition. Moisture absorption was measured at regular intervals.

2.3. Analysis of Limit Oxygen Index

Japanese red pine (5 × 5 × 10 mm) specimens were dipping treatment for limit oxygen analysis. The absorption amount was A (500 mℓ/m^2) and B (700 mℓ/m^2). Limit oxygen analysis was conducted using LIMITED OXYGEN INDEX 2005.

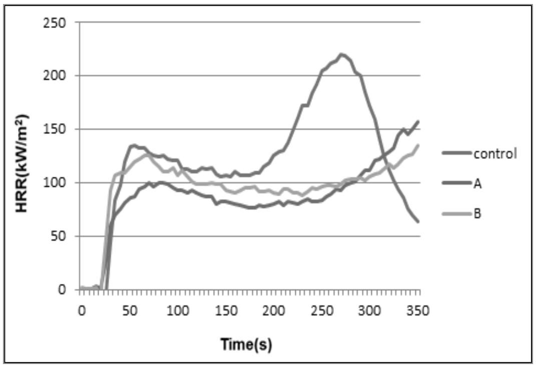

Fig. 1. Heat release rate (HRR) of flame retardant-treated woods.

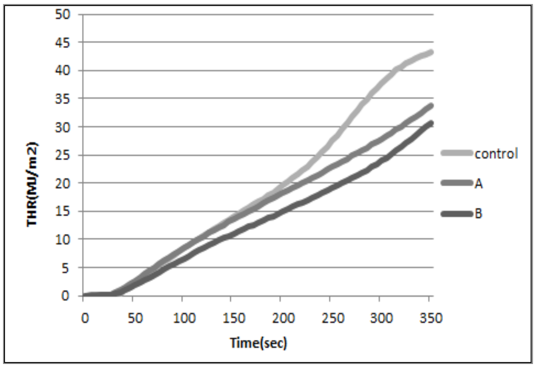

Fig. 2. Total heat release of flame retardant-treated woods.

2.4. Iron Corrosive Test

Japanese red pine (20 × 50 × 3 mm) treated dipping methods. The absorption amount of flame retardant was A (500 mℓ/m^2) and B (700 mℓ/m^2) respectively. The nails using for iron corrosion test were wiped out the oil from the nail surface. The two nails were fixed to put between the pieces of treated wood. The specimens were placed at 98% RH and 40℃ for 20 days in the chamber. The weight of nails were measured 5 days intervals. The corrosion area of nail was wiped out using boiled ammonium citrate solution. After the dried nails, weight of the nail was measured. The iron corrosion rate was calculated by weight loss.

2.5. Weathering Test

Japanese red pine was used for weathering test samples with a dimension of 100 mm × 100 mm × 12 mm (width × depth × thickness). The tester has adjusted to distance from lamp to specimen 300 mm, and light illumination was 20,500 Lux. After the test, specimens were measured color difference by Specro photo meter (M-700D).

3. RESULTS and DISCUSSION

3.1. Combustion Characteristics of Flame Retardant Treated Wood

Fig. 1 shows the heat release rate of flame retardant treated wood. Heat release rate is size of calories instantaneous generated suited to the sample surface. It is an element that can be best represents the risk of combustion. In addition, if the test material is burned, depending on combustion characteristics of the materials, which emits heat. At this time the maximum heat release rate is an important factor indicating the size of the fire (KS F 5660-1). Flame retardant treated wood shows stable heat release rate. The flame retardant treated wood did not show the peak which char formation compared untread wood. At the time of the maximum heat release rate, flame retardant treated wood has maintain a low heat release rate. Heat release rate of flame treated wood tended to increase gradually after it was maintained up to 300 seconds.

Total heat release (Fig. 2) was 30 MJ/m^2 and 33 MJ/m^2 respectively to 300 seconds after increasing steadily maintained at below 8 MJ/m^2 up to 95, 115 seconds.

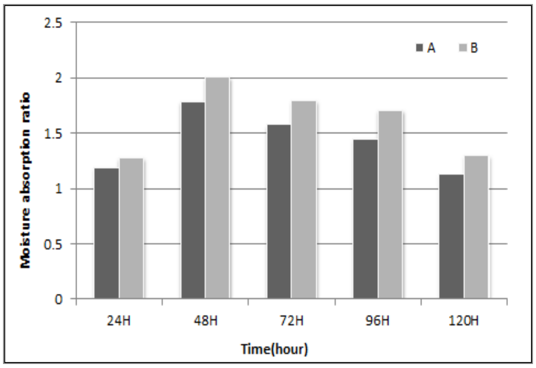

Fig. 3. Moisture absorption ratio of flame retardant-treated woods.

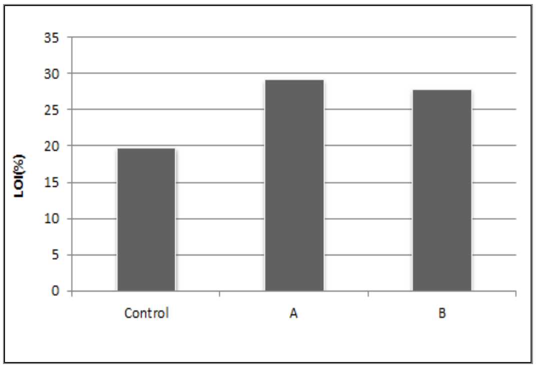

Fig. 4. Limit oxgen index of flame retardant-treated woods.

Cha and Han (2012) reported that the carbon area and carbon length of flame retardants for wooden heritage was not satisfied with the performance criteria. Danchung painted wood confirmed fire resistance, flame retardant treated wood did not show more higher efficacy than danchung. The 45° combustion test could estimate the efficacy base on evaluation of the performance evaluation, but these method is not enough analysis of the specific flame retardants efficacy.

The analysis of flame retardant treated wood by cone-calorimeter provide proper standard for the future which could relevant of stable flame efficacy, due to analyse decomposition behavior of the retardants, estimate heat rate.

3.2. Evaluation of Hygroscopicity

All flame retardant treated wood showd higher hygroscopicity than the untreated wood. The hygroscopicity was increased until 48 hr, which showed a tendency to decrease after 72 hr. Cha (2012) reported that flame retardant for woden heritage could change the danchung, effects moisture absorbency. Kim *et al*. (2007) have reported that there is an impact on the dimensional changes of the wood due to moisture absorption of the timber.

The increase in moisture in the treatment wood, because there is a possibility that the occurrence of mold, increasing humidity inside the building, chemical problem of secondary treatment chemicals, affecting the dirt of the building, flame retardant for wooden heritage must be controlled always does not happen.

3.3. Analysis of Limit Oxygen Index

Limiting oxygen index of flame-treated wood (Limited Oxygen Index: LOI) test results are shown in Fig. 4. LOI values of flame retardant treated woods were 27% and 29% respectively. The LOI is the minimum concentration required samples ignited in a stream of air which is a mixture of nitrogen and oxygen to continue burning. This value greater than 21 indicates a difficulty in air combustion. Jinxue *et al*. (2010) reported that LOI values of three different flame retardants composed phosphorus compounds showed 36, 42.5 and 57.5. They concluded that the amount of char formation might had made contribution to greater LOI values of the wood, and correlated well with the LOI values.

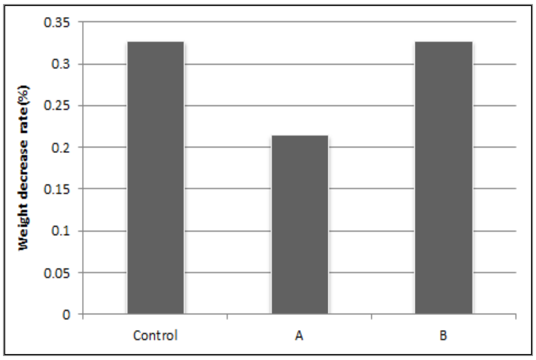

Fig. 5. Iron corrosion efficacy of flame retardant-treated woods.

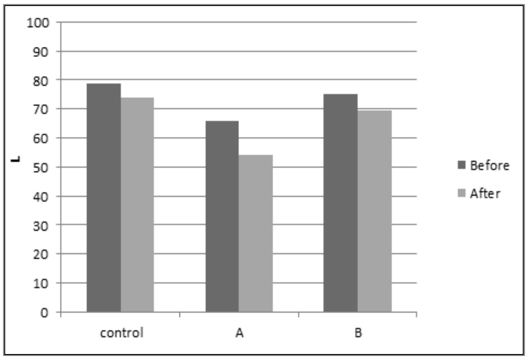

Fig. 7. L value change of the flame retardant treated-woods.

Control

A

B

Fig. 6. Nails after the iron corrosion test.

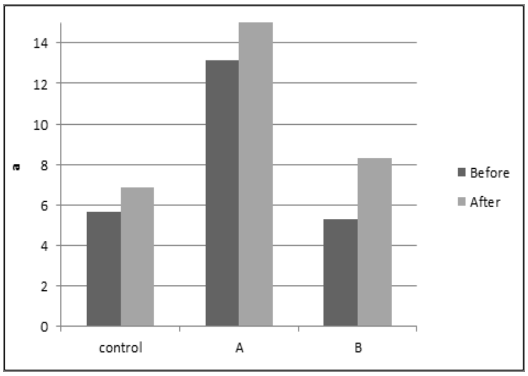

Fig. 8. *a* value change of the flame retardant treated-woods.

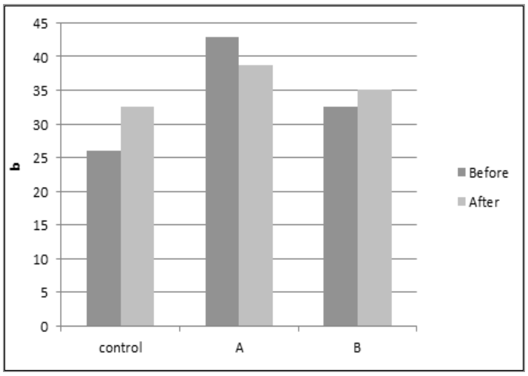

Fig. 9. *b* value change of the flame retardant treated-woods.

3.4. Iron Corrosive test

Iron corrosion test results of flame retardant treated woods are presented in Fig. 5. Weight loss due to the corrosion of iron was equal to or less than that of the untreated wood. Fig. 6 shows the state of the nails after the iron corrosion test.

Son *et al*. (2014) reported that high percentage of phosphorus flame retardants have highly corrosive to iron. Where the iron corrosion is a concern, the composition of the flame retardants should be taken into consideration. It is believed that the corrosion of iron is an important factor in the evaluation of retardant treated wood which can give a significant effect on the aesthetics and durability of a building. So, the iron corrosion should be included for the test of the flame retardant treatment.

3.5. Weathering Test

The color of the flame retardant treated wood was changed to a darken color (Figs. 7～9). It was also found that the color was changed to red and yellow line. In the untreated wood, the value of *a* and *b* is getting higher after the test, L value was lowered to the progress of the light degradation. The components of the flame retardants has caused the difference in texture and color change of the flame retardants treated wood surface. Park *et al*. (2013) confirmed the peeling of danchung and whitening of the test specimens treated with flame retardant after six-month exposure test. They suggested that these phenomenon had been occurred when the flame retardants were not penetrated into the wood.

Weathering test is also an important factor in the evaluation of the functionality of the flame retardant because it may affect the wood by ultraviolet degradation in use flame retardant treated wood.

4. CONCLUSION

1) Heat release rate of flame treated-woods tended to increase gradually after it was maintained up to 300 seconds. Total heat release was 30-33 MJ/m^2. Limit oxygen index of flame retardant treated wood were 27-29. Analytical methods of limiting oxygen index and Cone-calorimeter was determined to be an effective way as a performance evaluation method of flame retardant of cultural property.
2) In the hygroscopic test, the hygroscopicity increased about two times compared to thar of the untreated wood. It ws suggested that iron corrosive and hygroscopic test and analytical methods must be always included in the performance evaluation of flame-retardant for the management and preservation of wooden heritage.
3) The color of the flame retardant treated wood was changed to a darken color. It also analyzed that color was changed to red and yellow line. Analysis of weather resistance must be taken into the performance evaluation of flame-retardant due to consider the aesthetic part of wooden cultural heritage and endurance of the retardants.
4) The results of this study indicates that analysis methods of fire resistance and evaluation methods of functionality should be taken into the consideration of the performance evaluation of the flame retardant treated wooden cultural assets.

REFERENCES

Asan city, 2009, Oeam Folk Village Fire Prevention Research.

Baek, M.H., Lee, J.H. 2010. The Study for Fire prevention of Main Wooden Cultural Properties of Korea. Journal of Korean Institute of Fire Science & Engineering 82(3): 1～8.

Cha, J.M., Kim, I.B., Hyeon, S.H. 2011. Study on Weather Resistance of Painted Wood treated by Flame retardant Solution. Journal of Korean Institute of Fire Science & Engineering 83(4): 408-411.

Cha, S.H., Han, G.S. 2012. Performance of some commercial flame retardants. Proceeding of The Korean Wood Science and Technology. pp. 174～175.

Incheon fire department, fire investigation team, 2003. In the field of fire investigation techniques for practitioners.

Kim, J.I., Hwang, K.H., Jung, D.J., Ryu, J.Y., Kim, O.J. 2007. The moisture absorption of wood for package under the temperature and Moisture change condition. Proceeding of The Korean Wood Science and Technology. pp. 209～210.

Oh, K.Y., Kim, H.J., Lee, S.E. 2009. A Study on fire delaying effects according to flame retardation. Journal of Korean Institute of Fire Science and Engineering 23(2): 113～117.

Park, C.W., Hong, S.W., Lee, J.K., Lim, N.G. 2013. Flame retardant and weather proof characteristic of dan-chung treated wooden by flame retardant performance. Journal of Korea Institute of Building Construction 13(2): 122～130.

Shin, H.J., Beak, M.H. 2012. A study on the actural condition of external fire-fighting environment for important wooden cultural assets. Journal of Korean Society of Hazard MItigation 13(3): 115～121.

Shin, H.J., Baek, M.H. 2013. A Study on the Consciousness of Fire-fighting Officers for the Establishment of Safety Measures for wooden Cultural Assets. Journal of Korean Society of Hazard MItigation 13(3): 113～121.

Son, D.W., Kang, M.R., Lee, H.M., Hwang, W.J., Park, S.B. 2014. The evaluation of moisture absorption, iron corrosion, weathering of flame retardants treated wood. Proceeding of The Korean Wood Science and Technology. pp. 333～339.