Fire Performance of Poplar and Bamboo Curtain Veneers Treated with Fire Retardants

Tao Zhang,# Fang Liang,# Hongzhong Xiang, Xiaomeng Yang, Wanhe Hu, Bingbing Mi, and Zhijia Liu*

Bamboo curtain and poplar veneers, which are used as decorative building materials, were impregnated using two types of fire retardants (A and B) at atmospheric pressure in order to investigate fire retardancy using a cone calorimeter. When the impregnation time was longer, the fire retardancy was enhanced in the decorative material samples. When poplar veneer was treated by fire retardant A with impregnation times of 8 h, 16 h, and 24 h, the peak of heat rate release (pk-HRR) decreased by 41%, 51%, and 50%; the total heat release (THR) values decreased by 61%, 69%, and 75%; the total suspended particulates (TSP) values decreased by 90%, 82%, and 72%; and mass residues increased by 39%, 41%, and 43%, respectively. Treated bamboo curtain veneer had a lower fire retardancy when compared to poplar veneer. When bamboo curtain impregnation times were 8 h, 16 h, and 24 h, their pk-HRR values decreased by 37%, 45%, and 51%; the THR values decreased by 32%, 39%, and 44%; the TSP values decreased by 69%, 57%, and 78%; and the mass residues increased by 26%, 28%, and 29%, respectively. The results from this research should help to develop bamboo curtain veneer as an indoor decorative material.

Keywords: Bamboo; Poplar; Decorative materials; Fire retardant; Cone calorimeter

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INTRODUCTION

Recently, bamboo and wood resources are being used in China as decorative materials due to their environmental performance (Song *et al.* 2013). These materials are ignited easily and burn rapidly; these attributes pose serious safety consequences (Lowden and Hull 2013). Hence, the development of better fire retardants for wood and bamboo has been a focus area for many material science researchers. Fire retardants are substances that are incorporated into or coated onto flammable materials to impede physical and chemical modes of ignition. Furthermore, fire retardants can reduce the decomposition temperature and increase the char yield (Nikolaeva and Kärki 2016). There are many types of fire retardants available in the Chinese marketplace. Synthetic fire-retardants with boron compounds are popular due to their low cost and high flame retardancy (Klyosov 2007). These fire retardants have some advantages, such as being less harmful to the environment, ease of handling, and good economic benefits, just to name a few (Baysal and Yalinkilic 2005). Boron-based fire retardants have synergistic interactions with magnesium hydroxide, phosphorus-based, and aluminum hydroxide fire retardants (He *et al*. 2014). In particular when they is used in combination with other flame retardants, excellent flame retardancy and smoke suppression can be obtained.

One of the key parameters to evaluate decoration materials is fire performance. A cone calorimeter is an effective way to analyze and quantify fire retardant properties of materials (Mitrenga *et al*. 2016). Stark *et al.* (2010) used a cone calorimeter to compare the fire resistance of wood flour-polyethylene composite, untreated polyethylene, and solid wood materials. The authors found that zinc borate improved fire retardancy of these materials. He *et al.* (2016) evaluated the effects of different pressures and durations on the flame retardancy of poplar by using a cone calorimeter. The result showed when the microwave pretreatment time and pressure gradually increased, the effectiveness of fire retardant for ammonium polyphosphate-impregnated samples gradually increased. Wang *et al*. (2016) investigated the fire retardant characteristics of wood-plastic composites using a cone calorimeter and reported that microencapsulated ammonium polyphosphate was better than ammonium phosphate as a flame retardant. Ren *et al.* (2015) investigated the synergism of multiple fire retardant agents using a cone calorimeter. The authors reported higher synergism when intumescent fire retardants and zinc borate were used together. The addition of 5 wt% of zinc borate created fire retardant wood flour-recycled polypropylene composites with excellent fire retardancy. Yang *et al.* (2016) investigated the fire retardancy of several kinds of flooring materials using a cone calorimeter. These authors reported that wool carpet coverings had better fire retardancy than rubber floor and blended carpet coverings. Mena *et al*. (2012) investigated fire reaction and fire resistance of *Guadua angustifolia* Kunth bamboo and found that it was adequate as structural and indoor finishing building material. Jin *et al.* (2011) investigated the fire retardancy of sliced bamboo veneer treated by fire-retardant FRW with different retentions and found obvious fire retardation and smoke inhibition effects of the sliced bamboo veneer treated by the fire retardant FRW. Yu *et al.* (2017) evaluated the effects of different boron fire retardants on the heat release and smoke release of bamboo filaments. The results showed that compared to the untreated samples, fire retardants that contained boric acid or borax effectively reduced the heat and smoke release from the bamboo filament.

Bamboo curtain veneer is a new indoor decorative material used in China. To the best of our knowledge, there is a lack of sufficient information concerning the flammability resistance of bamboo curtain veneer. In this study, poplar and bamboo curtain veneers were atmospherically impregnated at various times using two types of fire retardants that contained boron compounds. The fire retardancy of the decorative materials was determined with a cone calorimeter. The best fire retardants for bamboo curtain veneer was selected based on the analysis of cone calorimeter data from this study. The results from this research can be used to develop further bamboo curtain veneer as indoor decorative materials.

EXPERIMENTAL

Materials

Poplar (*Populus simonii* Carr) and bamboo curtain (*Phyllostachys heterocycla*) veneers were used in this research. Veneers from poplar, which contained no defects, were taken from Hebei Province, China. Its moisture content was 13.1%. The bamboo curtain veneer was made using 6-year old bamboo, which was harvested from Zhejiang Province, China. The moisture content was 12%. Two types of fire retardants (A and B) were purchased from the Chinese marketplace. The main chemical compositions of fire retardant-A were guanylurea phosphate, ammonium polyphosphate, and orthoboric acid.

That of fire retardant-B mainly included disodium octaborate tetrahydrate.

Impregnation Treatment of Decorative Materials

Poplar and bamboo curtain veneers were cut in accordance with the ISO 5660-1 (2002) standard with the size of 100 mm (length) × 100 mm (width) × thickness. Both veneer materials were impregnated using fire retardants; atmospheric impregnation times of 8, 16, and 24 h were examined. All samples were dried at a temperature of 105 °C until the mass stabilized.

The Determination of Fire Retardant Performance

The fire retardancy of decorative materials were determined using a cone calorimeter (Fire Testing Technology Ltd., East Grinstead, UK) in accordance with the ISO 5660-1 standard (2002). Data collected included heat release rate (HRR), total heat release (THR), total suspended particulates (TSP), mass loss rate (MLR), and time-to-ignition (TTI). All samples were tested using a 50 kW/m^2 heat flux using an edge frame. Each experimental condition was performed in triplicate. Data from the first run was used when it was shown to be in accordance with the other runs.

RESULTS AND DISCUSSION

Fire Retardant Performance of Poplar Veneer

Combustion parameters including heat release rate (HRR), time-to-ignition (TTI), total heat release (THR), total suspended particulates (TSP), and mass loss rate (MLR) made it possible to achieve a better assessment and prediction of combustion process of decoration materials. HRR and TTI were consistent with exterior heat flux, ventilation degree, and degree of material destruction. HRR is the rate of heat release per unit area of the burning sample; this parameter is one of the most important factors in safety assessment. A higher peak heat rate release (pk-HRR) indicates higher fire intensity of the material. The HRR values of poplar veneer with two kinds of fire retardants are shown in Fig. 1. The sharp increase in the HRR value was due to the rapid combustion of flammable volatiles that are released. It was found that untreated samples had a higher HRR (532 kW/m^2) when compared to samples treated by fire retardants. As the impregnation times increased, the pk-HRR values of the treated samples decreased. The pk-HRR values of the samples treated by fire retardant-A decreased by 41%, 51%, and 50% when impregnation times of 8 h, 16 h, and 24 h were used, respectively. Similarly, the pk-HRR values of the samples treated by fire retardant-B decreased by 21%, 32%, and 43% when impregnation times of 8 h, 16 h, and 24 h were used, respectively. These observations indicated that fire retardant-A had better flame retardancy than fire retardant-B based on HRR data. The different chemical compositions and bonds between fire retardant and poplar gave rise to this phenomenon.

Figure 2 shows that there were some crystal whiskers on the surface of samples when poplar was treated by fire retardant-A, compared with untreated samples. However, fire retardant-B formed a protective layer to cover the sample surface. The primary effect of this protective layer was to reduce the pk-HRR value. Figure 3 shows that no new absorbance peaks were not found in FT-IR curves of poplar veneer, indicating that there were not any kinds of chemical bonds formed between flame retardants and poplar veneer. TTI is the elapsed time required to produce ignition when exposed to thermal radiation

source. The TTI of the samples increased when impregnated with fire retardant products; higher TTI values were observed when the impregnation time increased.

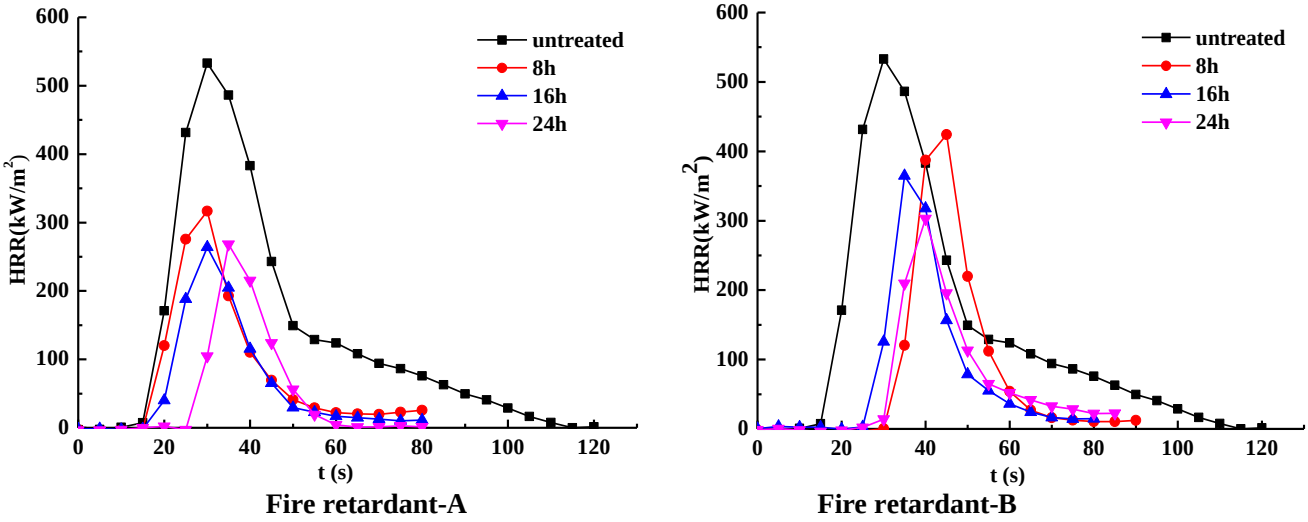

Fig. 1. HRR curves for poplar veneer

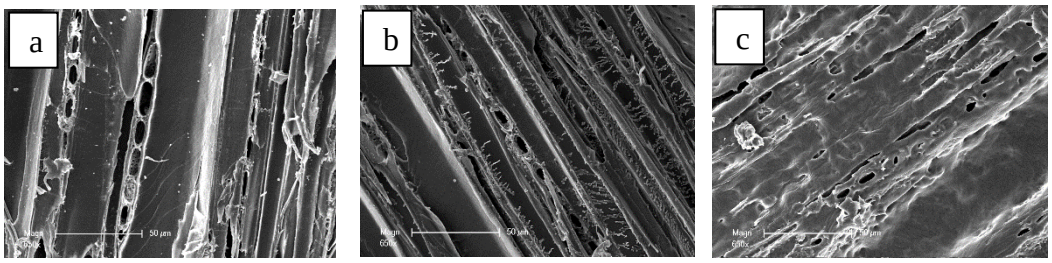

Fig. 2. SEM of poplar veneer (a-untreated, b-fire retardant-A, c-fire retardant-B)

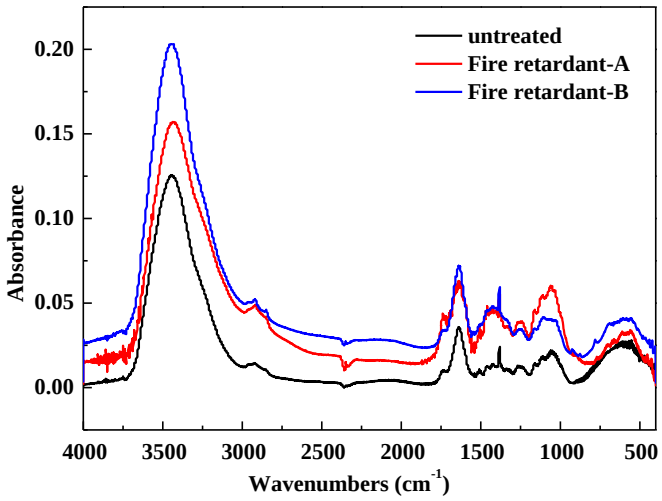

Fig. 3. FT-IR curves for poplar veneer

THR represents the heat of combustion of the material that is released, which is independent of environmental factors. Higher THR values indicate higher potential of heat

energy available for material combustion, and increased fire hazards. As anticipated, Fig. 4 illustrates that untreated samples had higher THR values when compared to treated samples. The THR value of untreated samples was 16.15 MJ/m^2. When samples were treated using fire retardant-A with impregnation times of 8 h, 16 h, and 24 h, the THR values decreased by 61%, 69%, and 75%, respectively. When the samples were treated using fire retardant-B with impregnation times of 8 h, 16 h, and 24 h, the THR values decreased by 57%, 63%, and 66%, respectively. As the fire retardant impregnation time increased, the THR values of treated samples decreased, indicating that the fire retardant inhibited the combustion process of samples. Samples treated by fire retardant-A had lower THR values, which corresponded to observed trends with HRR and TTI data sets.

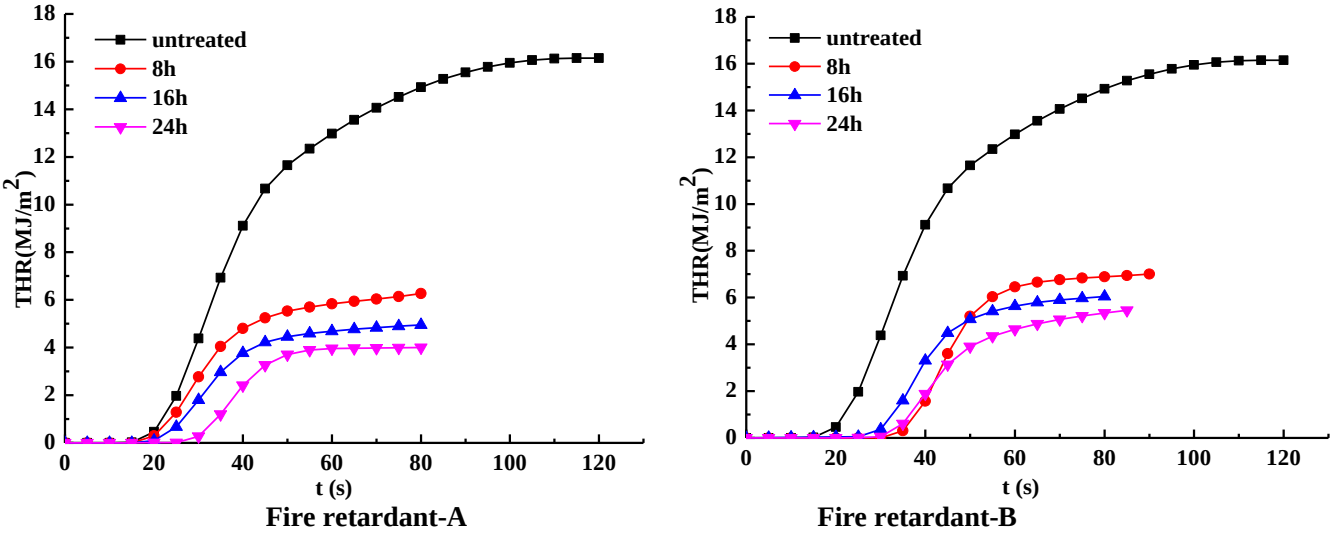

Fig. 4. THR curves for poplar veneer

TSP is an important parameter describing the fire hazard related to decorative materials. In the event of fire, a material will release TSPs (*i.e.*, smoke and soot) during combustion, which will contribute to eye and lung irritations. The TSP values of poplar veneer are graphed in Fig. 5.

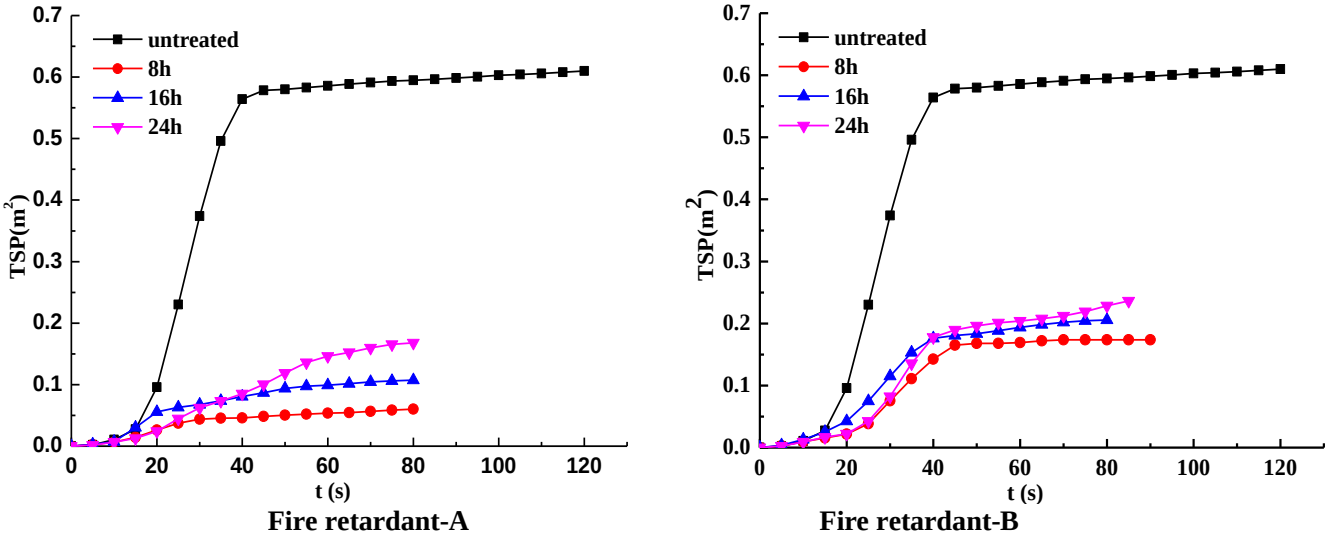

Fig. 5. TSP curves for poplar veneer

Untreated samples had a higher TSP value (0.61 m^2). This parameter was considerably lower when the samples were treated by fire retardant products. When samples were treated using fire retardant-A at impregnation times of 8 h, 16 h, and 24 h, the TSP values decreased by 90%, 82%, and 72%, respectively. When the samples were treated using fire retardant-B at impregnation times of 8 h, 16 h, and 24 h, the corresponding TSP values decreased by 72%, 69%, and 64%, respectively. The data showed that fire retardant-A was better at suppressing smoke than fire retardant-B for treated poplar veneer samples. As expected, when the impregnation time increased, the TSP values increased. The excessive content of boron fire retardants was formed vitreous coating. Thus, the sample could not completely burn and little smoke was formed. Mass loss is a measurement of the residual amount of the sample after combustion, the flame retardancy was determined by comparing the mass loss. Figure 6 shows that the untreated samples had a very high mass loss. The mass residues was 2%. With the increase in impregnated time, mass loss curve gradually decreased. The mass residues of the samples treated using fire retardant-A were 39%, 41%, and 43%, which corresponded to impregnation times of 8 h, 16 h and 24 h, respectively. For the samples treated using fire retardant-B, the mass residuals were 39%, 39%, and 47% when the impregnation times were 8 h, 16 h, and 24 h, respectively. The presence of fire retardants made the partially material isolated from oxygen so that it could not be sufficiently combusted. As the impregnation time increased, the burn rate decreased while the char production increased (Intharapat *et al.* 2016).

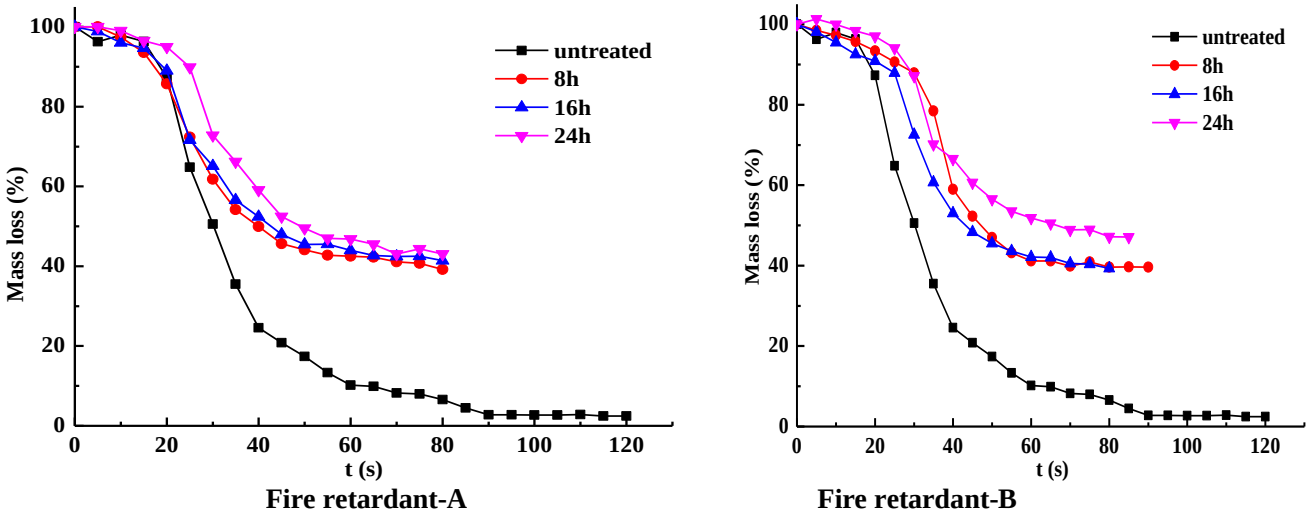

Fig. 6. Mass loss curves for poplar veneer

Fire Retardant Performance of Bamboo Curtain Veneer

The HRR curves of bamboo curtain veneers are shown in Fig. 7. The pk-HRR of untreated bamboo curtain veneers was 839 kW/m^2, which was higher than that of poplar veneer (532 kW/m^2). As anticipated, untreated bamboo curtain veneers had a higher HRR than treated samples. The pk-HRR values decreased with increasing impregnation time. The pk-HRR values of the samples treated by fire retardant-A decreased by 37%, 45%, and 51% at impregnation times of 8 h, 16 h, and 24 h, respectively. The pk-HRR values of the samples treated by fire retardant-B decreased by 23%, 25%, and 49% when the impregnation times were 8 h, 16 h, and 24 h, respectively. It was observed that bamboo curtain veneers treated by fire retardants had higher HRR values than poplar veneer. Liu *et*

al. (2014) reported that bamboo has more volatile components that made it easier to ignite and to burn than wood. Hence, bamboo curtain veneer needs to be pretreated with fire retardant(s) when they are used as indoor or outdoor decorative materials. In this research, bamboo curtain veneers treated by fire retardant-A had a better fire performance than that those treated by fire retardant-B. Similar with poplar, the crystalline state of fire retardant-A was found on the surface of bamboo curtain veneers and fire retardant-B covered sample surface, showed Fig. 8. Figure 9 shows that there was physical bonds between fire retardant and bamboo curtain veneer. The TTI values after sample treatments with the fire retardants did not increase appreciably.

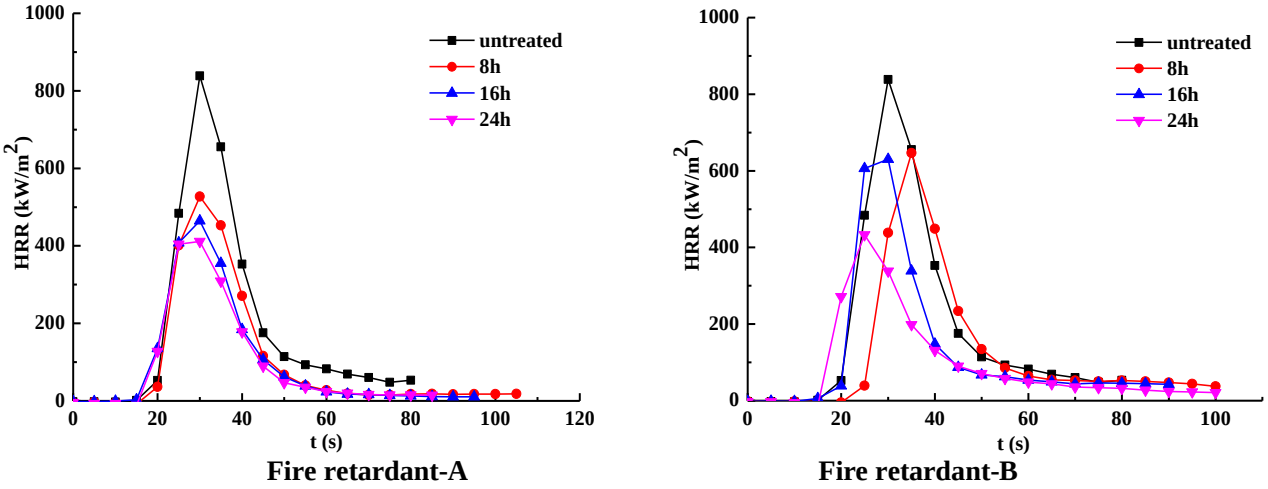

Fig. 7. HRR curves for bamboo curtain veneer

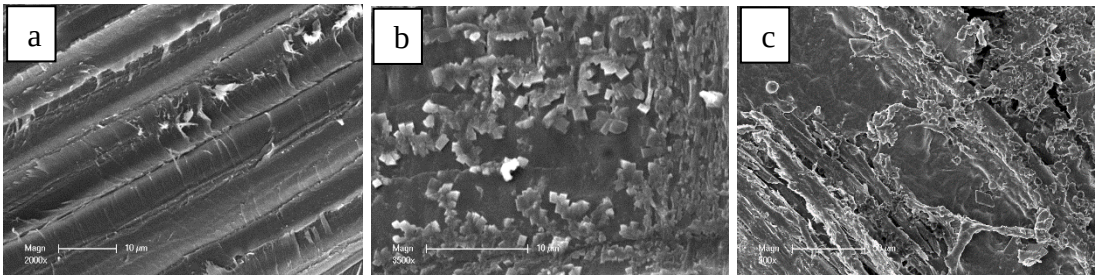

Fig. 8. SEM of bamboo curtain veneer (a-untreated, b-fire retardant-A, c-fire retardant-B)

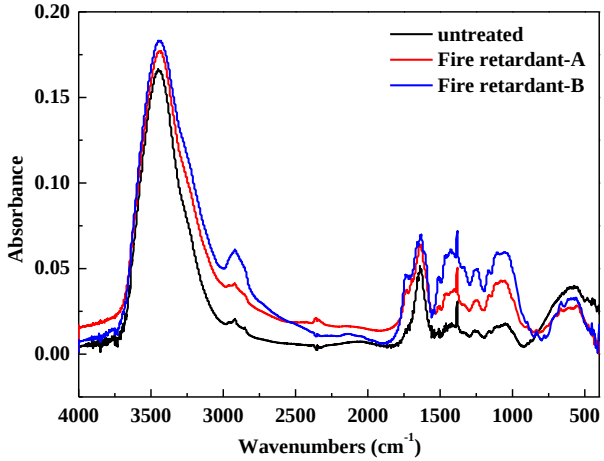

Fig. 9. FT-IR curves for bamboo curtain veneer

It was observed (Fig. 10) that untreated bamboo samples had higher THR values when compared with the impregnated samples, which was expected. The THR value of untreated bamboo curtain veneer was 15.27 MJ/m^2, which was lower than poplar veneer (16.15 MJ/m^2). When the impregnation times were 8 h, 16 h, and 24 h, the THR values of the samples treated by fire retardant-A decreased by 32%, 39%, and 44%, respectively. When the samples were impregnated with fire retardant B, THR values decreased by 20%, 25%, and 39%, which corresponded to impregnation times of 8 h, 16 h, and 24 h, respectively. Longer impregnation times resulted in lower THR values. It was interesting to observe that treated bamboo curtain veneer had a higher THR when compared to treated poplar veneer. Bamboo curtain veneer treated by fire retardant-A had a lower THR than that treated by fire retardant-B.

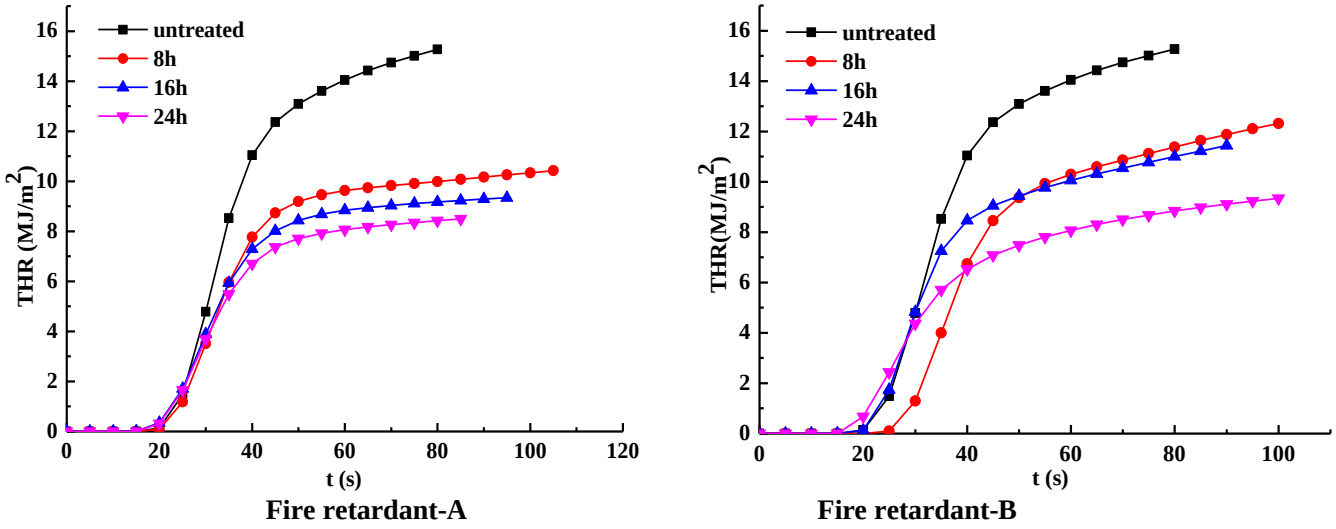

Fig. 10. THR curves for the bamboo curtain veneer

The TSP of bamboo curtain veneer treated by fire retardants (A or B) is shown in Fig. 11. The untreated samples had a higher TSP value (0.87 m^2), and this parameter decreased appreciably after fire retardant impregnation.

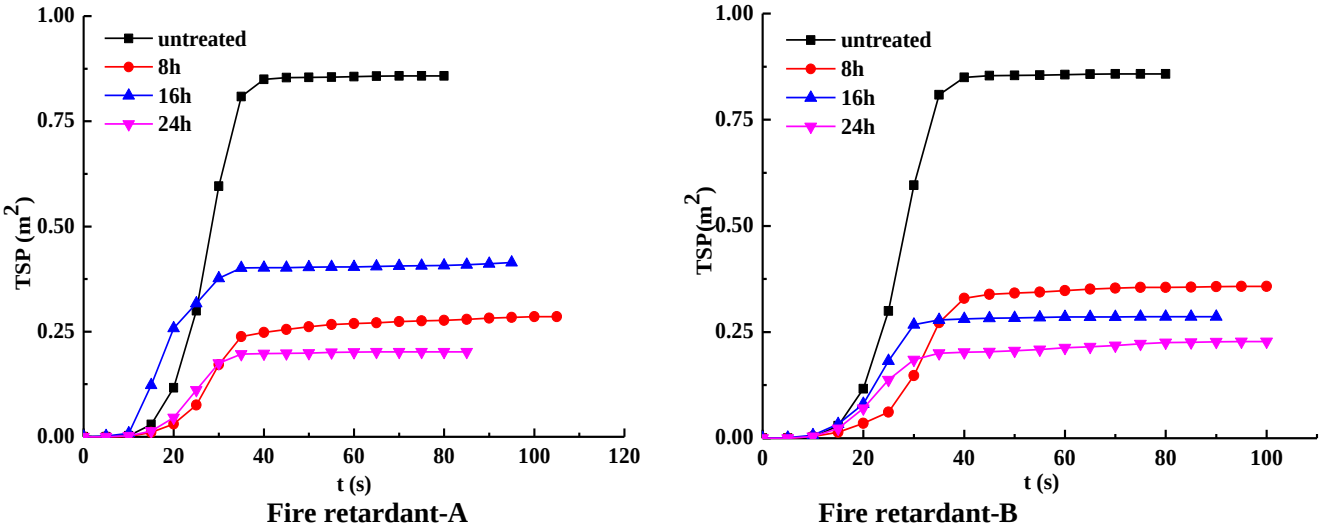

Fig. 11. TSP curves for bamboo curtain veneer

When samples were treated using fire retardant-A at impregnation times of 8 h, 16 h, and 24 h, the corresponding TSP values to decreased by 69%, 57%, and 78%, respectively. When the samples were treated using fire retardant-B at impregnation times of 8 h, 16 h, and 24 h, the TSP values decreased by 60%, 70%, and 74%, respectively. Fire retardant-A had a better smoke suppressing effect than fire retardant-B, except for impregnation time of 16 h. As the impregnation time increased, the TSP values decreased gradually. But samples treated by fire retardant-A with impregnation time of 16h had a higher TSP value than that with impregnation time of 8h. Differences were observed among bamboo curtain and poplar veneer samples. The main explanation for this observation was that bamboo curtain veneer did not form a complete carbonized layer during the combustion process.

Figure 12 shows that untreated bamboo curtain veneer had a lower mass loss than those treated by fire retardant products. Mass residues of bamboo curtain veneer was 6%, higher than poplar veneer (2%). As the impregnation time increased, the mass residues increased. Mass residues of the samples treated by fire retardant-A were 26%, 28%, and 29% when impregnated at times of 8 h, 16 h, and 24 h, respectively. The mass residues of samples treated by fire retardant-B were 23%, 26%, and 42% when the impregnation times were 8 h, 16 h, and 24 h, respectively. Longer impregnation times resulted in higher mass residues. It was observed that treated bamboo curtain veneer had lower mass residues when compared to treated poplar veneer.

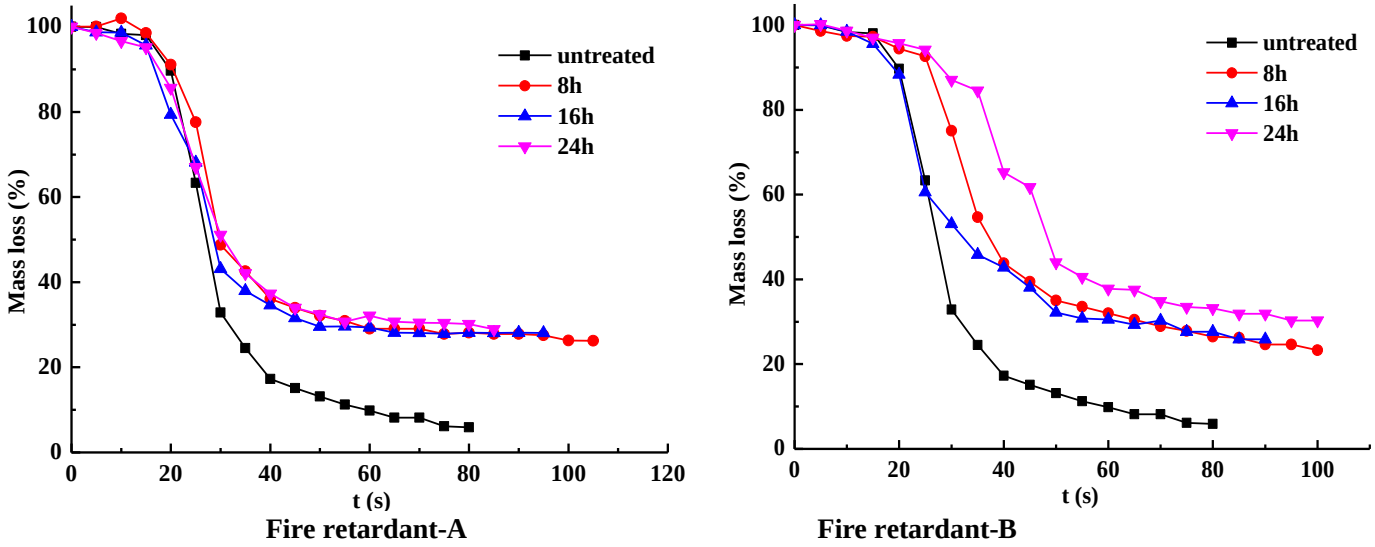

Fig. 12. Mass loss curves for bamboo curtain veneer

CONCLUSIONS

1. Bamboo and wood decorative materials treated by fire retardant-A (containing guanylurea phosphate, ammonium polyphosphate, and orthoboric acid) had better fire performance than that treated by fire retardant-B (containing disodium octaborate tetrahydrate). Longer impregnation times resulted in better fire retardancy.

2. When poplar veneer was treated by fire retardant-A at impregnation times of 8 h, 16 h and 24 h, the peak of heat rate release (pk-HRR) values decreased by 41%, 51%, and 50%. The total heat release (THR) values decreased by 61%, 69%, and 75%. The total suspended particulates (TSP) value decreased by 90%, 82%, and 72%, and mass residues increased by 39%, 41%, and 43%.
3. Compared to poplar veneer, treated bamboo curtain veneer exhibited worse fire performance. When impregnation times were 8 h, 16 h, and 24 h, the pk-HRR values decreased by 37%, 45%, and 51%. The THR values decreased by 32%, 39%, and 44%. The TSP values decreased by 69%, 57%, and 78%, whereas the mass residues increased by 26%, 28%, and 29%.

ACKNOWLEDGMENTS

This research was financially supported by the "13th Five Years Plan-Study on Manufacturing Technology of Bamboo Wastes and its Mechanism" (Grant No. 2016YFD0600906) and the "Basic Scientific Research Funds of International Centre for Bamboo and Rattan Co-Firing Technology of Torrefied Bamboo and Coal" (Grant No. 1632016011).

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Article submitted: May 19, 2017; Peer review completed: August 8, 2017; Revised version received: August 18, 2017; Accepted: August 19, 2017; Published: August 28, 2017.
DOI: 10.15376/biores.12.4.7487-7497