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EFFECT OF HYGROSCOPICITY OF FIRE RETARDANT ON HYGROSCOPICITY OF FIRE RETARDANT BAMBOO CHIPS

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ABSTRACT

This paper presents a study on the effect of hygroscopicity of fire retardant on the hygroscopicity of fire retardant materials (bamboo chips). The results showed that the hygroscopicity of fire retardant and fire retardant bamboo chips increased with increasing fire retardant concentration, and the suitable range of fire retardant concentration is 20- 30 %; the hygroscopicity of fire retardant and fire retardant bamboo chips increased with the increasing of drug loading rate of fire retardant bamboo chips, and the suitable drug loading rate is 10.2 %; the hygroscopicity of fire retardant bamboo chips increased with the increase of the hygroscopicity of fire retardant, and the hygroscopicity of fire retardant bamboo chips is smaller when treated with the fire retardant whose water absorption rate less than 18 %.

KEYWORDS: Bamboo chips, fire retardant treatment, compound fire retardant, water absorption rate, hygroscopicity.

INTRODUCTION

China is rich in bamboo resources, a wide range of bamboo products, and bamboo materials are increasingly used within construction, furniture and decoration and other fields (Li et al. 2016). But bamboo materials are burnable materials, easy to burn, and with the rapid increase of consumption of bamboo products, the possibility of fire will increase, which increase the security risks. Therefore, it is necessary to carry out fire retardant treatment of bamboo materials (Du et al. 2016). The most effective and commonly used method for fire retardant treatment of bamboo materials is to add fire retardants (Fang 2008). At present, the fire retardant materials used in bamboo materials are mostly water-based inorganic fire retardants, which are mainly due to its advantages like remarkable fire retardant effect, less pollution and cheap (Zhang et al. 2014).

Commonly used water-based fire retardants are ammonium dihydrogen phosphate, diammonium phosphate, ammonium polyphosphate, boric acid, etc. (Xue et al. 2006), while they all have a certain degree of hygroscopicity, which can make them absorb water molecules and dissolve in water before they gradually lost in high humidity conditions (Na et al. 2009). At the same time, the loss of fire retardants will inevitably lead to a corresponding reduction in fire retardant properties of bamboo materials, so the water absorption properties of water-based fire retardant and fire retardant bamboo materials cannot be avoided in the study of fire retardant treatment of bamboo materials.

At present, some scholars have used the water of fire retardant to evaluate its hygroscopicity. It has been reported that the order of the hygroscopicity of several common water-based fire retardants is: boric acid< ammonium dihydrogen phosphate< diammonium phosphate< ammonium polyphosphate<urea (Zhang et al. 2007). In addition, some other scholars have used the water absorption rate to evaluate the hygroscopicity of fire retardant materials, and investigated the effect of different fire retardant formulas and moisture content conditions on hygroscopicity of fire retardant materials (Hao and Yu 2010, Kartal et al. 2007; Pan et al. 2014, Wang et al. 2015, Zhang et al. 2015, Zhang et al. 2016).

From the above, water absorption rate can evaluate the hygroscopicity of fire retardant and fire retardant materials. But few studies have been done on the relationship between the hygroscopicity of fire retardant and fire retardant materials. Whether the greater the hygroscopicity of fire retardants, the greater the hygroscopicity of fire retardant materials? Or on the contrary? These problems have not been studied so far. In this study, several home-made complex water-based fire retardants were used to make fire retardant bamboo chips, and the water absorption rate was used to evaluate the hygroscopicity of fire retardant and fire retardant bamboo chips. In addition, the relationship between the hygroscopicity of fire retardant and fire retardant materials was investigated in this paper.

MATERIAL AND METHODS

Materials

Bleached bamboo chips with the same width and thickness were purchased from the production enterprises of bamboo flooring (Zhejiang, China), and then were processed into dimensions of 50 mm (longitudinal)× 20 mm (tangential)× 5 mm (radial) with the moisture content of about 10%. Compound fire retardant solutions were modulated to the concentration of 10%, 15%, 20% and 25% according to the ratio of m (ammonium dihydrogen phosphate): m (boric acid) = 7:3. Ammonium dihydrogen phosphate (ADP) (≧99 %) and boric acid (BA) (≧99.5 %) were purchased from Sino pharm Chemical Reagent Co., Ltd (Shanghai, China) and used without further purification.

Test method for drug loading rate

The mass of bamboo chips were measured as m1 after pretreatment within a constant temperature and humidity box to ascertain their moisture content were about 9%. Then bamboo chips were impregnated within the fire retardant solutions at atmospheric pressure for 2 h. After that, fire retardant bamboo chips were placed within constant temperature and humidity box again until the moisture content were about 9 %, and the mass of each bamboo chip was measured as m_2.

The drug loading rate is the percentage that the mass change of bamboo chips before and after the fire retardant treatment accounting for the mass of bamboo chips before treated, denoted as R, calculated according to Eq. 1:

$$R = \frac{m_2 - m_1}{m_1} \times 100\% \qquad (1)$$

Test method for water absorption rate of fire retardants

Hygroscopicity of fire retardants was determined according to the method of water-based fire retardant treating agent (GA 159-2011). Bamboo chips were placed within a constant temperature and moisture content box at 23±2°C, 50±5% RH until the mass were constant, and then placed within an oven at 50±2°C for 4 h. The mass of the bamboo chips which need fire retardant treatment is G_1, the mass of the control bamboo is G_1'. The bamboo chips with the mass of G_1 were impregnated within fire retardant solutions with their concentration of 10%, 15%, 20% and 25 within respectively, and then were placed within a constant temperature and moisture content box at 23±2°C, 50±5% RH until the mass were constant. The mass of bamboo chips were measured as G_2 after drying within an oven at 50±2°C for 4h. After that, the mass of treated and control bamboo chips were measured as G_3, G_3' after water absorption within a constant temperature and humidity box at 40±2 °C, 80±5% RH for 24 h.

Water absorption rate of fire retardant is the percentage that the mass change of fire retardant before and after water absorption treatment accounting for the mass of fire retardant before treated, denoted as ΔG, calculated according to Eq. 2:

$$\Delta G = \left[\frac{G_3 - \frac{G_3'}{G_1'} \times G_1}{G_2 - G_1} - 1\right] \times 100\% \qquad (2)$$

Test method for water absorption rate of fire retardant bamboo chips

Hygroscopicity of fire retardant bamboo chips was determined according to ASTM D3201 / D3201M-2013). The mass of fire retardant bamboo chips were measured as m_2 after air drying at room temperature for 7 d. Then the treated bamboo chips were placed in a constant temperature and moisture content box at 27 ±2 °C, 92±2% RH for 168 h. After that, the mass of treated bamboo chips were measured as m'_2.

Water absorption rate of fire retardant bamboo chips is the percentage that the mass change of fire retardant bamboo chips before and after water absorption treatment accounting for the mass of fire retardant bamboo chips before treated, denoted as W, calculated according to Eq. 3:

$$W = \frac{m_2' - m_2}{m_2} \times 100\% \qquad (3)$$

RESULTS AND DISCUSSION

Effect of fire retardant concentration on water absorption rate of fire retardant and fire retardant bamboo chips

The influences of different concentration of compound fire retardant solutions on water absorption rate of fire retardant and fire retardant bamboo chips were shown on Figs. 1 and 2.

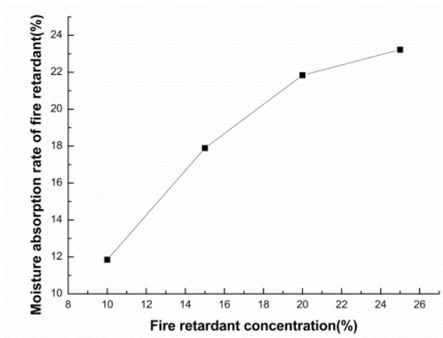

Fig. 1: Effect of fire retardant concentration on water absorption rate of fire retardant.

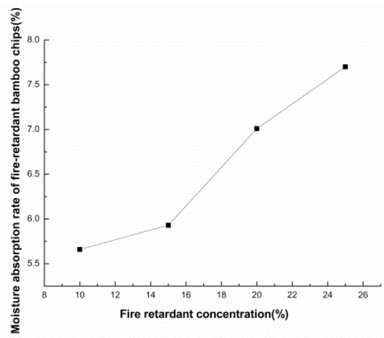

Fig. 2: Effect of fire retardant concentration on water absorption rate of fire retardant bamboo chips.

Fig. 1 shows that different concentration of fire retardant had a significant effect on the water absorption rate of compound fire retardant. With the increasing of agent concentration, the water absorption rate of compound fire retardant was also increasing. When the agent concentration was less than 20%, the water absorption rate of compound fire retardant increased quickly, and when the agent concentration exceeded 20%, the growth rate of compound fire retardant decreased obviously. The possible reason may be that when the agent concentration was less than 20%, fire retardants penetrate into the cell cavity of bamboo rapidly because of the action of temperature gradient and moisture gradient (Liu et al. 2012), so that the fire retardant retention of bamboo chips increased rapidly, which may directly result in a quickly increase of water absorption rate of compound fire retardant. While the agent concentration exceeded 20 %, fire retardants filled in the bamboo cell cavity were almost saturated, which may lead to slowly increase of drug loading rate(Nussbaum 1988; Izran et al.2011) and water absorption rate of compound fire retardant. In addition, the water absorption rate of compound fire retardant with different concentration after they treated bamboo chips was less than 35 % which had met the technical indicators of China's public safety industry standard GA 159-2011.

Fig. 2 shows that the water absorption rate of fire retardant bamboo chips increased with the increasing of agent concentration, which was consistent with that in Japanese pine (Dong et al. 2014) and medium density fiberboard (MDF) panel (Ustaomer and Usta 2012). When the agent concentration was less than 15 %, the growth rate of water absorption rate of fire retardant bamboo chips was small, while the agent concentration more than 15%, the water absorption rate of fire-retardant bamboo chips increased quickly. The possible reason may be that when the agent concentration was less than 15%, fire retardants that filled into the cavity of bamboo cell were less and the hygroscopicity of fire retardant bamboo chips was mainly due to the hygroscopicity of bamboo chips. While the agent concentration was more than 15%, the drug loading rate of fire retardant bamboo chips increased rapil (Wang et al. 2015), which may directly lead to an quickly increase of water absorption rate of fire retardant bamboo chips. Considering that the water absorption rate of fire retardant increased slowly and tended to be stable when the agent concentration exceeded 20%, and other research shows that the concentration of fire retardant solution should not exceed 30%. Therefore, the suitable range of the concentration of fire retardant is 20- 30%.

Effect of drug loading rate on water absorption rate of fire retardant and fire retardant bamboo chips

The relationship between the drug loading rate and the water absorption rate of fire retardant was shown on Figs. 3 and 4.

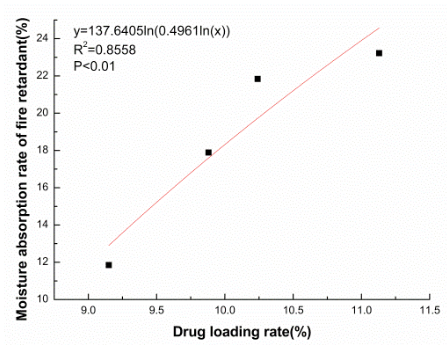

Fig. 3: Correlation analysis of drug loading rate and water absorption rate of fire retardant.

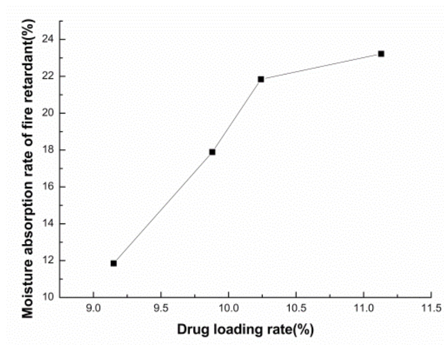

Fig.4: Effect of drug loading rate on water absorption rate of fire retardant.

It can be seen from Fig. 3 that there was a significant positive correlation between the water absorption rate of compound fire retardant and the drug loading rate, and the logarithmic fitting relationship was good (R2=0.8558, P<0.01). Fig. 4 shows that the water absorption rate of compound fire retardant increased with the increasing of drug loading rate, and when the drug loading rate was less than 10.2%, the water absorption rate of compound fire retardant increased at a high speed, while the drug loading rate was over 10.2%, the growth rate of water absorption rate of compound fire retardant reduced significantly. The water absorption rates of the compound fire retardant were 11.9%, 21.8 % and 23.2 %, respectively when the drug loading rates were 9.2%, 10.2% and 11.1%. Compared with the water absorption rate of compound fire retardant when the drug loading rate was 9.2%, the water absorption rate was increased by 83.2% when the drug loading rate was 10.2%. while the water absorption rate was only increased by 6.4% when the drug loading rate was 11.1% comparing the water absorption rate of compound fire retardant when the drug loading rate was 10.2%. As the higher the drug loading rate of fire retardant in bamboo chips, the better the fire retardant properties of fire retardant bamboo chips (Li 2014, Nussbaum 1988, Son et al. 2012). Therefore, taking into account the fire retardant properties and the water absorption rate of fire retardant, the suitable drug loading rate is 10%.

The relationship between the drug loading rate and the water absorption rate of fire retardant bamboo chips was shown on Figs. 5 and 6.

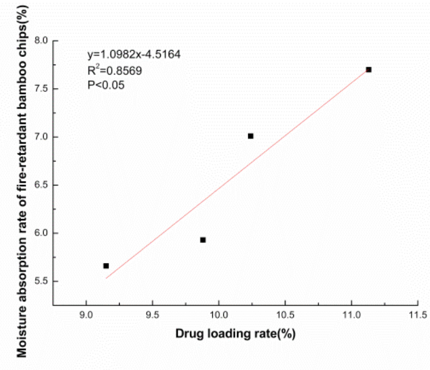

Fig. 5: Correlation analysis of drug loading rate and water absorption rate of fire retardant bamboo chips.

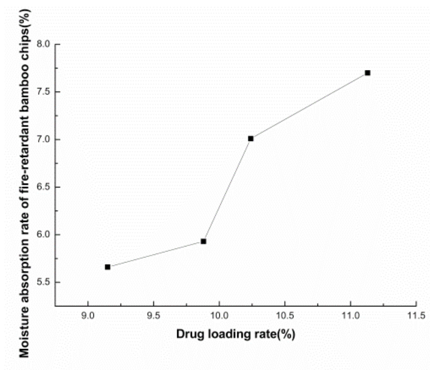

Fig. 6: Effect of drug loading rate on water absorption rate of fire retardant bamboo chips.

It can be seen on Fig. 5 that there was a significant positive correlation between the water absorption rate of fire retardant bamboo chips and the drug loading rate of, and the linear fitting relationship was good (R2=0.8569, P<0.05). Fig. 6 shows that the water absorption rate of fire retardant bamboo chips increased with the increasing of the drug loading rate (Wang et al. 2015). When the drug loading rate was less than 9.9%, the water absorption rate of fire retardant bamboo chips increased slowly, and when the drug loading rate between 9.9%- 10.2%, the water absorption rate increased quickly, while the drug loading rate was higher than 10. %, the growth rate of water absorption rate of fire retardant bamboo chips slowed down. Furthermore, the water absorption rates of fire retardant bamboo chips were 5.7%, 5.9%, 7.0% and 7.7% when the drug loading rates were 9.2%, 9.9%, 10.2 % and 11.1%. Compared with the water absorption rate of fire retardant bamboo chips when the drug loading rates were 9.2%, 9.9 % and 10.2%, the water absorption rates were increased by 4.8 %, 18.2 % and 9.8% when the drug loading rates were 9.9%, 10.2% and 11.1%. In summary, the smaller the drug loading rate, the smaller the water absorption rate of fire retardant bamboo chips, but the decrease of drug loading rate would reduce the fire retardant properties of bamboo chips (He et al. 2015, Uner et al. 2016, Terzi et al. 2011). Therefore, taking into account the fire retardant properties and the hygroscopicity of fire retardant bamboo chips, the suitable drug loading rate is 10.2 %.

Effect of water absorption rate of fire retardant on water absorption rate of fire retardant bamboo chips

The relationship between the water absorption rate of compound fire retardant and fire retardant bamboo chips was shown on Figs. 7 and 8.

Fig. 7 shows that there was a significant positive correlation between the water absorption rate of compound fire retardant and fire retardant bamboo chips, and the exponential fitting relationship was excellent (R2 = 0.9942, P <0.01). It can be seen on Fig. 8 that the water absorption rate of compound fire retardant had a significant effect on the water absorption rate of fire retardant bamboo chips, and the water absorption rate of fire retardant bamboo chips increased with the increasing of water absorption rate of fire retardant. When the water absorption rate of fire retardant less than 18%, the water absorption rate of fire retardant bamboo chips increased at a low speed, and when the water absorption rate of fire retardant more than 18%, the water absorption rate of fire retardant bamboo chips increased rapidly.

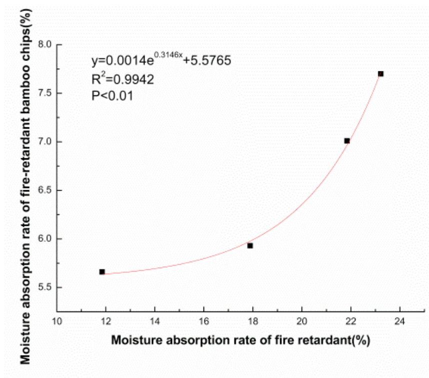

Fig. 7: Correlation analysis of water absorption rate on fire retardant and fire retardant bamboo chips.

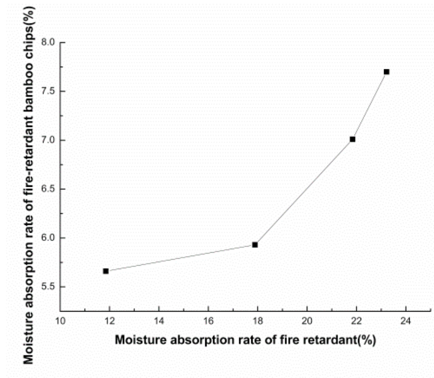

Fig. 8: Effect of water absorption rate of fire retardant on the water absorption rate fire of retardant bamboo.

Therefore, in order to reduce the water absorption rate of fire retardant materials, cut down the loss of fire retardant due to its water absorption and prevent the reduction of fire retardant properties, we should use the fire retardant whose water absorption rate less than 18 % to make fire retardant materials.

CONCLUSIONS

(1) The hygroscopicity (water absorption rate) of compound fire retardant and fire retardant bamboo chips increased with the increasing of fire retardant concentration, the suitable range of fire retardant concentration is 20- 30 %.

(2) The hygroscopicity (water absorption rate) of compound fire retardant and fire retardant bamboo chips increased with the increasing of drug loading rate of fire retardant bamboo chips, the suitable drug loading rate of fire retardant bamboo chips is 10.2 %.

(3) The hygroscopicity (water absorption rate) of fire retardant bamboo chips increased with the increasing of hygroscopicity (water absorption rate) of fire retardant, and the hygroscopicity of fire retardant bamboo chips is smaller when treated with the fire retardant whose water absorption rate less than 18 %.

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