Study on flame retardant properties of Plywood Made with Eucalyptus, Birch and Poplar Wood

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Abstract: In this work, the laboratory-made flame-retardant polyvinyl alcohol adhesive was used to prepare flame-retardant plywood made with eucalyptus, birch and poplar respectively, and the effect of tree species on the Thermogravimetric behavior and flame-retardant properties of flame-retardant plywood was studied. Thermogravimetric behavior of the flame-retardant plywood prepared by eucalyptus, birch and poplar showed that poplar plywood had highest thermostability. The results of the SBI test are consistent with the results of the LOI test and Thermogravimetric analysis, both indicated that the tree species had a significant effect on the flame-retardant properties of the flame-retardant plywood, the flame-retardant plywood made with poplar veneer has the highest LOI value, lowest HRR value and lowest THR value.

1. Introduction

Plywood is one of the most important products in man-made boards. Due to its significant advantages, such as excellent mechanical properties, ease of manufacture and abundant raw materials, plywood is widely used in the construction industry, interior decoration and furniture manufacturing. Plywood is mainly composed of wood veneer and organic adhesive. Both wood veneer and organic adhesive are extremely flammable; therefore, plywood is a flammable material. With the improvement of social fire safety awareness, the flame-retardant treatment of plywood has attracted more and more attention.[1, 2]

There are many ways to flame-retardant plywood. The most commonly used method is to immerse wood veneers with a flame-retardant solution.[3-5] This method is to improve the flame-retardant properties of plywood by improving the flame-retardant properties of the wood itself. Chen et al.[6] studied the effect of composite flame retardant on the properties of poplar plywood, results indicated that poplar veneers treated by immersing method could have positive effect on flame-retardant properties of plywood. Hu et al.[7] reported the comparison analysis on properties of fire-retardant plywood made with eucalyptus and poplar wood. The wood veneers were impregnated with a phosphorus-nitrogen-boron fire retardant solution, and the fire-retardant properties of the plywood were promoted by the impregnating treatment of wood veneers. Gong et al.[8] reported the effects of flame retardants on combustion performance of plywood. Three kinds of flame retardants were used to immerse the wood veneers, and the LOI results indicated that the flame-retardant performance of plywood increased with the immersion time of wood veneers.
Although the immersing treatment of wood veneer can improve the flame-retardant performance of the plywood, however, the application of this method in flame retardant plywood still has certain limitations. The flame-retardant immersing treatment is very complicated, including long-time immersion and drying. The flame-retardant immersing treatment will also reduce the mechanical properties of the plywood, and the mechanical strength of plywood gradually decreases with the increasing of immersion time.\(^\text{6-10}\)

In this work, the laboratory-made flame-retardant polyvinyl alcohol adhesive was used for the flame-retardant treatment of plywood. Three wood veneers, such as eucalyptus, birch and poplar, were used to prepare flame-retardant plywood respectively, and the effect of tree species on the mechanical properties and flame-retardant properties of flame-retardant plywood was studied.

2. Experimental

2.1. Materials
Eucalyptus veneer with a thickness of 1.7mm; birch veneer with a thickness of 1.5mm; poplar veneer with a thickness of 1.3mm; flame retardant polyvinyl alcohol adhesive, laboratory-made.

2.2. Sample Preparation
Flame retardant polyvinyl alcohol adhesive was prepared by mixing polyvinyl alcohol, OP-10, magnesium oxide, silica, ammonium borate and so on. The flame-retardant polyvinyl alcohol adhesive was evenly coated on the surface of the wood veneers with a sizing amount of 300g/m\(^2\), and then, the wood veneers were pressed at room temperature for 24h with a pressure of 10MPa. After naturally dried for 14 days, the plywood was dried to a moisture content of 12%. The thickness of three flame-retardant plywood samples, made with eucalyptus, birch and poplar veneers respectively, were all controlled to 12.5mm.

2.3. Testing method
Limit oxygen index (LOI): the LOI value of the plywood sample was tested in accordance with plastics - determination of burning behaviour by oxygen index - part 2: ambient-temperature test (GB/T 2406.2-2009).

The log or glulam material was crushed and weighed 6-8mg to test the thermal stability of the material in the air atmosphere, the thermal stability of the material was tested by TGA Q-5000 thermal gravimetric analyzer.

Single burning item test (SBI): the SBI property of the plywood sample was tested in accordance with single burning item test for building materials and products (GB/T 20284-2006).

3. Results and discussion

3.1. Thermogravimetric test
Thermogravimetric behavior test is one of the important methods to characterize the thermal stability of materials at high temperature. The thermogravimetric behavior curve and thermogravimetric rate curve of log under air atmosphere are shown in Fig.1. The thermogravimetric behavior of poplar, eucalyptus and birch all show obvious two-step decomposition, and the interval from 280°C to 350°C is the wood carbonization stage. According to the curve in Figure 1, the coking amount of poplar and eucalyptus at 350°C is significantly higher than that of birch. When the temperature continues to rise to more than 400°C, the carbon layer begins to decompose rapidly, and the residual ash content is about 1%. The decomposition temperature of carbon layer of poplar and birch was significantly higher than that of eucalyptus, indicating that the structural carbon stability of eucalyptus was low.

According to the DTG curve, the peak temperature of thermal weight loss rate of poplar and birch was significantly higher than that of eucalyptus. The difference is that poplar also has a significant
mass loss between 450 and 500℃, indicating that the carbon layer formed by poplar has a strong high temperature resistance.

![Fig.1. Thermogravimetric curves of eucalyptus, birch and poplar wood](image1)

![Fig.2. Thermogravimetric curves of flame-retardant plywood made with eucalyptus, birch and poplar wood](image2)

The thermal weight loss behavior curves of the flame-retardant plywood prepared by eucalyptus, birch and poplar are shown in Fig.2. The thermal weight loss curves of eucalyptus, birch and poplar plywood shift to high temperature successively, which proves that the thermal stability of the three materials increases gradually, and the high temperature residual amount of the materials also increases gradually under the same sizing amount. According to the DTG curves of the three kinds of plywood, the peak of thermal weight loss rate of poplar plywood is the smallest and the peak of thermal weight loss rate is obviously shifted to high temperature.

3.2. Limit Oxygen Index

The LOI value is one of the most common and important methods to evaluate the flame-retardant properties of materials. It characterizes the difficulty of self-extinguishing when the material burns. Tab.1 shows the LOI data of wood Log and flame-retardant plywood made with eucalyptus veneer, birch and poplar wood. As shown in Tab.1, LOI value of flame-retardant plywood made with
eucalyptus veneer is 32.5%, LOI value of flame-retardant plywood made with birch veneer is 36.3%, and LOI value of flame-retardant plywood made with poplar veneer is 46.8%.

| Test item       | LOI  | Test item       | LOI  |
|-----------------|------|-----------------|------|
| Eucalyptus      | 23.8 | Eucalyptus plywood | 32.5 |
| Birch           | 24.5 | Birch plywood   | 36.3 |
| Poplar          | 25.6 | Poplar plywood  | 46.8 |

The LOI results showed that the tree species has a significant effect on the flame-retardant properties of the flame-retardant plywood samples. The flame-retardant plywood made with poplar veneer has the highest LOI value, and the fire-retardant plywood made with eucalyptus veneer has the lowest LOI value.

3.3. Single Burning Item Test
The single burning item test (SBI) is an important test method for the classification of the combustion performance of building materials and products. Since the actual fire scene is simulated, the result of the single burning item test has a good correlation with the real fire. The heat release rate (HRR) and total heat release (THR) are the key parameters of SBI test.
Experimental thermal radiation in the 300 s after starting point firearms and record the fire parameters such as heat release rate, total heat release rate and ignition time. Fig.3(a) shows heat release rate curves of flame retardant plywood, the figure shows three kinds of plywood in eucalyptus wood is the most easy to ignite, poplar and birch plywood heat release curve significantly delayed, ignition time is greater than the eucalyptus wood. The maximum heat release rate of eucalyptus plywood is about 20.3kW, birch plywood is 11.8kW, poplar plywood is 9.2kW, poplar plywood has the lowest heat release rate.

Fig.3(b) shows the total heat release curve of flame retardant plywood in the monomer combustion test. In the whole test process, the total heat release of eucalyptus, birch and poplar were 14.1MJ, 7.9MJ and 5.2MJ, respectively.

The results of the SBI test are consistent with the results of the LOI test, both indicated that the tree species has a significant effect on the flame-retardant properties of the flame-retardant plywood, while the flame-retardant plywood made with eucalyptus veneer has lower flame-retardant performance.

4. Conclusion
In summary, the main conclusions of this article are as follows:

(1) The tree species has an obvious effect on the Thermogravimetric behavior of the flame-retardant plywood, the flame-retardant plywood made with eucalyptus veneer has the lowest thermostability, and sample made with poplar has the highest thermostability.

(2) The results of the SBI test are consistent with the results of the LOI test, both indicated that the tree species has a significant effect on the flame-retardant properties of the flame-retardant plywood, the flame-retardant plywood made with poplar veneer has the highest LOI value, lowest HRR and

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(b) Fig.3. SBI data of flame-retardant plywood (a HRR, b THR)
lowest THR value, and the flame-retardant plywood made with eucalyptus veneer has the highest LOI value, highest HRR value and highest THR value.

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References
[1] Zhang WB, Lu XB, Liu XY, et al. Status and countermeasures on fire retardant plywood [J]. Journal of Zhejiang A&F University, 2000, 17(2): 208-214.
[2] Cui HW, Du GB. Advance on wood fire-retardance. World Forestry Research, 2008, 21(3): 43-48.
[3] Zhao D, Zhou YM, Sun XB, et al. Effects of different fire retardant treatment on properties of poplar plywood [J]. Chinese Agricultural Science Bulletin, 2014, 30(28): 67-71.
[4] Terzi E, Kartal SN, White RH, et al. Fire performance and decay resistance of solid wood and plywood treated with quaternary ammonia compounds and common fire retardants [J]. European Journal of Wood and Wood Products, 2011, 69(1): 41-51.
[5] Charles BV. Phenolic adhesive bonds to aspen veneers treated with amino-resin fire retardant [J]. Forest Products Journal, 1994, 44(1):33-40.
[6] Chen J, Yu LP, Tian MF, et al. Effect of composite flame retardant on the properties of poplar plywood [J]. China Forest Products Industry, 2020, 57(01): 22-24, 36.
[7] Hu L, Chen ZL, Fu F. Comparison analysis on properties of fire-retardant plywood made with eucalyptus and poplar wood [J]. China Wood Industry, 2015, 29(3): 43-46.
[8] Gong YC, Yin ZW, Li XP, et al. Effects of flame retardants on bonding strength and combustion performance of plywood [J]. China Forestry Science and Technology, 2014, 28(2): 99-101.
[9] Ma LR, Zhang SF, Gao Q, et al. Fire retardancy of plywood treated with a nitrogen-phosphorus-boron fire retardant [J]. China Wood Industry, 2014, 28(3): 30-33.
[10] Wei PL, Qin ZY, Fu YL, et al. Bonding strength and wettability of eucalyptus flame-retardant plywood [J]. Journal of Northwest Forestry University, 2017, 23(4): 244-247.