Study on Properties of Flame-Retardant 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 mechanical properties and flame-retardant properties of flame-retardant plywood was studied. The static bending strength data showed that the tree species had an obvious effect on the mechanical properties of the flame-retardant plywood, the flame-retardant plywood made with eucalyptus had the highest static bending strength, and the sample made with poplar had the lowest static bending strength. The results of the SBI test are consistent with the results of the LOI test, 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 FIGRA\textsubscript{0.2MJ} value and lowest THR\textsubscript{600s} 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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.[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
The flame-retardant polyvinyl alcohol adhesive was evenly coated on the surface of the wood veneers with a sizing amount of 300g/m², 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
Static bending strength: the static bending strength of the plywood sample was tested in accordance with Single burning item test for building materials and products (GB/T 17657-2013).

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).

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. Static Bending Strength
Static bending strength is one of the important mechanical properties of plywood. Fig.1 shows the static bending strength data of flame-retardant plywood made with eucalyptus, birch and poplar wood. As shown in Fig.1, static bending strength value of flame-retardant plywood made with eucalyptus veneer is 54.4 MPa, static bending strength value of flame-retardant plywood made with birch veneer is 38.3MPa, and static bending strength value of flame-retardant plywood made with poplar veneer is 31.2MPa.
Fig. 1. Static bending strength of flame-retardant plywood made with eucalyptus, birch and poplar wood

It can be seen that the static bending strength of all flame-retardant plywood samples could meet the requirements of GB/T 9846-2015 (Plywood for general use); and the tree species has an obvious effect on the static bending strength of the flame-retardant plywood samples. The flame-retardant plywood made with eucalyptus veneer has the highest static bending strength, and the fire-retardant plywood made with poplar veneer has the lowest static bending strength.

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. Fig. 2 shows the LOI data of flame-retardant plywood made with eucalyptus veneer, birch and poplar wood. As shown in Fig. 2, LOI value of flame-retardant plywood made with eucalyptus veneer is 31.8%, LOI value of flame-retardant plywood made with birch veneer is 35%, and LOI value of flame-retardant plywood made with poplar veneer is 48.2%.

Fig. 2. LOI value of flame-retardant plywood made with eucalyptus, birch and poplar wood

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. Fire growth rate index (FIGRA) and total heat release (THR) are the key parameters of the SBI test.

![SBI data of flame-retardant plywood](image)

Fig. 3. SBI data of flame-retardant plywood made with eucalyptus (a), birch (b) and poplar (c) wood

Fig. 3 shows the FIGRA curves and THR curves of the single burning item test of flame-retardant plywood made with eucalyptus (a), birch (b) and poplar (c) wood. As shown in Fig.3, the FIGRA
curves of all samples gradually increase with the increasing of the test time, and reach the maximum value rapidly around 400s, and then gradually decrease; the THR curves of all samples gradually increase with the increasing of the test time, and reach the maximum value at the end of the test. The SBI result showed that the flame-retardant plywood sample burned rapidly when it was ignited by the main burner, and then the flame retardant in the adhesive began to decompose, thereby inhibited the burning, and reduced the burning rate of the sample.

From Fig.3, the FIGRA0.2MJ values and THR600s values of the samples could be calculated. FIGRA0.2MJ value represents the fire growth rate index when the heat released of the sample reaches 0.2 MJ. THR600s value represents the total amount of heat released during the first 600 seconds after the sample is exposed to the main burner.

![FIGRA0.2MJ value of flame-retardant plywood made with eucalyptus, birch and poplar wood](image)

**Fig.4.** FIGRA0.2MJ value of flame-retardant plywood made with eucalyptus, birch and poplar wood

Fig.4 shows the FIGRA0.2MJ value of flame-retardant plywood made with eucalyptus, birch and poplar wood. As shown in Fig.4, FIGRA0.2MJ value of flame-retardant plywood made with eucalyptus veneer is 117.8 W/s, FIGRA0.2MJ value of flame-retardant plywood made with birch veneer is 79.9 W/s, and FIGRA0.2MJ value of flame-retardant plywood made with poplar veneer is 65.4 W/s. The FIGRA0.2MJ results showed that the flame-retardant plywood made with poplar veneer has the lowest FIGRA0.2MJ value, and the fire-retardant plywood made with eucalyptus veneer has the highest FIGRA0.2MJ value.

![THR600s value of flame-retardant plywood made with eucalyptus, birch and poplar wood](image)

**Fig.5.** THR600s value of flame-retardant plywood made with eucalyptus, birch and poplar wood

Fig.5 shows the THR600s value of flame-retardant plywood made with eucalyptus, birch and poplar wood. As shown in Fig.5, THR600s value of flame-retardant plywood made with eucalyptus veneer is
4.3 MJ, $THR_{600s}$ value of flame-retardant plywood made with birch veneer is 3.8 MJ, and $THR_{600s}$ value of flame-retardant plywood made with poplar veneer is 2.6 MJ. The $THR_{600s}$ results showed that the flame-retardant plywood made with poplar veneer has the lowest $THR_{600s}$ value, and the fire-retardant plywood made with eucalyptus veneer has the highest $THR_{600s}$ value.

The $SBI$ test results showed that the tree species has a significant effect on the flame-retardant properties of the flame-retardant plywood samples. Among the three samples, the flame-retardant plywood made with poplar veneer has the lowest $FIGRA_{0.2MJ}$ value and lowest $THR_{600s}$ value. It indicated that the flame-retardant plywood made with poplar veneer has a lower burning rate during the combustion process, and the heat released by its combustion is lower.

The results of the $SBI$ test are consistent with the results of the $LOI$ test; both indicated that the flame-retardant plywood made with poplar veneer has better flame-retardant performance, 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 static bending strength of the flame-retardant plywood, the flame-retardant plywood made with eucalyptus veneer has the highest static bending strength, and sample made with poplar has the lowest static bending strength.

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 $FIGRA_{0.2MJ}$ value and lowest $THR_{600s}$ value, and the flame-retardant plywood made with eucalyptus veneer has the lowest $LOI$ value, highest $FIGRA_{0.2MJ}$ value and highest $THR_{600s}$ value.

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