IMPROVEMENT OF BONDING PERFORMANCE OF LIGHTWEIGHT PANEL COMPOSED OF POLYSTYRENE FOAM CORE AND POPLAR VENEER WITH PINE TANNIN AND LIGNIN

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The study describes the improvement of the bonding performance of lightweight panels, faced with poplar veneer and with a polystyrene foam core, treated with a solution of pine tannin and lignin. Contact angle values, measured with water droplet as liquid, indicate that the wettability of the polystyrene foam soaked in pine tannin and lignin has been remarkably reduced, from 87.5° to 28.5°. The bonding performance demonstrates that a higher concentration of pine tannin and a lower concentration of lignin present a high failure ratio of the polystyrene foam. The concentration of 10% pine tannin and 5% lignin presented a failure ratio higher than 90%. The results provide a simple and effective method to improve the adhesion between polystyrene foam and poplar veneer in the manufacture of lightweight panels.

Keywords: polystyrene foam, poplar, tannin, lignin, contact angle, bonding performance

INTRODUCTION

The development of lightweight panels has been determined by the fast-growing market of knockdown furniture, the shortage of raw material and the need to reduce costs in the wood-based panel industry,[1] customers' packaging and transportation demands. Sandwich panels are made from veneer, thin PB or MDF for the faces, and expandable materials, such as polystyrene foam and honeycomb paper, for the core.[2,3] Apart from excellent stiffness and strength to weight ratios, cellular cores are attractive due to their good thermal and acoustic insulation, and energy absorbing capabilities. Polystyrene foams are widely used as packaging and construction materials, in household appliances and for many other applications,[4] which has led to great amounts of wastes and, consequently, to environmental pollution, as polystyrene foam cannot be decomposed in nature.[5] It appears to be viable as core material in fabricating lightweight panels and presents the advantage of cost saving. However, poplar veneer is a polar substance that is not compatible with nonpolar polystyrene foam. As a consequence, the adhesion at the veneer-polystyrene interface is typically weak, which results in poor bonding properties.

Tannin and lignin are natural phenol-containing materials, which are similar to polystyrene foam. They are expected to undergo the same type of reactions that occur between formaldehyde and phenol.[6-9] When polystyrene foam is treated with tannin and lignin, the adhesion of poplar veneer and polystyrene foam to the urea-formaldehyde adhesive is expected to improve significantly. Urea-formaldehyde adhesive has been selected for this study, because it is widely used in the adhesion of wood composites due to a number of advantages, including low cost, ease of use under a wide variety of curing conditions, low curing temperatures, water solubility, resistance to microorganisms, hardness, excellent thermal properties and lack of color of the cured resin.

In this paper, lightweight panels composed of poplar veneer and waste polystyrene foam (depicted in Figure 1), treated with a mixture of tannin and lignin were investigated. The pretreatment method used in this experiment differs from the application of expensive silicon-alkyl coupling agent and titanium-ester acid coupling agent. Also, as both tannin and lignin are obtained from nature, they are cheap and environment-friendly.

EXPERIMENTAL

Materials

Poplar veneer with the thickness of 1.2 mm was obtained from the north area of Jiangsu province, China. Polystyrene foam panels with the thickness of 18 mm were achieved from package waste. Urea-formaldehyde adhesive (UF) with F/U molar ratio of 1.25 was synthesized in our laboratory. A pine tannin and lignin solution was prepared at room temperature.

Treatment of polystyrene foam panel and preparation of lightweight panel

A piece of polystyrene foam panel was soaked in the pine tannin and lignin solution at room temperature for about 1 h, then it was oven dried. The lightweight panel was assembled from a polystyrene foam panel and two layers of poplar veneer at the top and bottom, bonded with urea-formaldehyde adhesive. The hot pressing was conducted under the following conditions: pressure – 0.22 Mpa, time – 10 min, and temperature – 85±3 °C.

Wettability and failure ratio of plastic measurements

The contact angles of the polystyrene foam panel before and after soaking in the pine tannin and lignin solution were recorded with a JC2000A contact angle measuring apparatus. Before testing the bonding performance, lightweight panels of 50×50 mm (length×width) were soaked in 63±2 °C water for 3 hours. Then they were torn along the gluing line and the failure ratio of the plastic (polystyrene) was written down. The experiment was repeated 10 times under the same conditions.

RESULTS AND DISCUSSION

Wettability

Wettability is one of the most important properties in the manufacture of wood-based panels. As shown in Figure 2, θ_1 and θ_2 are the contact angles of water on unmodified polystyrene foam and on the modified sample, respectively. The contact angle values obtained with the help of a JC2000A contact angle measuring apparatus are the following: $\theta_1 = 87.5°$ and $\theta_2 = 28.5°$. Obviously, the wettability of the polystyrene foam treated with the mixture of pine tannin and lignin is improved, compared to that of unmodified polystyrene foam. A close contact between the polystyrene foam and poplar veneer may account for the high plastic failure ratio in lightweight panels.

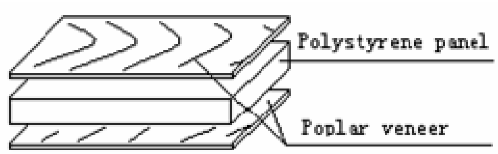

Figure 1: Structure of a lightweight panel

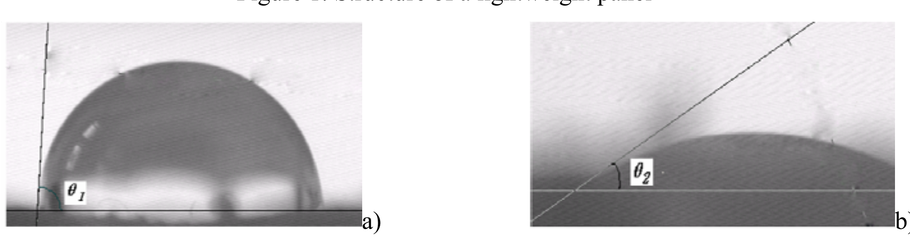

Figure 2: Contact angle of a water droplet on unmodified polystyrene foam (a) and on polystyrene foam modified with pine tannin and lignin (b)

Table 1
Plastic failure ratio (%) of composites treated with different concentrations of pine tannin and lignin

	A0	*A1*	*A2*	*A3*
B0	8	89	91	70
B1	88	35	58	97
B2	75	15	76	55
B3	43	14	89	37

A0, A1, A2 and A3 – concentration of pine tannin, which is 0, 1wt%, 5 wt% and 10 wt%, respectively
B0, B1, B2 and B3 – concentration of lignin, which is 0, 5 wt%, 10 wt% and 15 wt%, respectively

Table 2
Analysis of factors (α = 0.05)

Variables	Square summation	Freedom degree	MS	F Value	Critical value	Significant result
Factor A	1.64	3	0.547	17.40	2.66	Affected
Factor B	3.53	3	1.176	37.44	2.66	Significantly affected
Factor AB	9.88	9	1.09	34.96	1.94	Significantly affected
Random error	5.03	160	0.03			
Summation	20.07	175				

Plastic failure ratio

The plastic failure ratios of composites treated with different concentrations of the pine tannin and lignin mixture are listed in Table 1. Compared to the control sample, the lightweight panels manufactured with polystyrene foam soaked in the mixture of pine tannin and lignin demonstrated an evident improvement in plastic failure ratio. Also, the lightweight panel with a higher pine tannin concentration and a lower lignin concentration presented a higher plastic failure ratio. The effect of the tannin and lignin treatment on the plastic failure ratio was determined and the results are shown in Table 2.

A3B1 (10% pine tannin and 5% lignin in the mixture) level was considered as an optimal scheme. To validate the result, 10 more pieces of panel with polystyrene foam treated with A3B1 were tested. All of these samples showed a plastic failure ratio above 90%.

CONCLUSION

The bonding performance of a lightweight panel composed of polystyrene foam panel and poplar veneer can be improved by treating the polystyrene foam with pine tannin and lignin. The contact angle of water on modified polystyrene foam is better than that of the control. The optimal concentration of tannin and lignin was found to be of 10% and 5%, respectively. The lightweight panel bonded with UF resin exhibited a good bonding performance and a plastic failure ratio above 90%.

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