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Research Article

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Research on the enhanced composite mode of low temperature solidified glued laminated timber

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ABSTRACT

Selecting appropriate reinforcing materials and composite models are the keys to apply the plantation wood widely in the field of building engineering. The process of low temperature solidification was applied and the basic mechanical properties were viewed as the evaluation index to explore the enhanced manner and composite mode of glued laminated timber made up of the plantation eucalyptus veneers with the reinforced materials of glass fiber cloth, aluminium foil and copper foil. The results show that the influence of reinforcing material type on Modulus of Rupture (MOR) and standard Modulus of Elasticity (MOE) is significant and the influence of reinforcing material layer number and assemble pattern on standard MOR and MOE is more significant than which on MOR and standard MOE, and the glass fiber cloth combined with the aluminum foil as the reinforcing materials and the aluminum foil placed on the outermost surface of glued laminated timber is the best assemble pattern to make the glued laminated timber, and the limit load and safety factor of the glued laminated timber can be increased by the thickness of veneers and the parallel assemble structure of veneers is superior to its cross assemble structure. Finally, the fitting curve equations were obtained in our experimental condition to clarify the relationship of the thickness of glued laminated timber , the limit load and the standard MOR, and the goodness of fit was 0.891 and 0.852, respectively. It will promote the plantation wood rationally to be applied in the field of building engineering.

Key words: Glued laminated timber, eucalyptus wood veneer, glass fiber cloth, aluminum foil, copper foil, enhanced composite, data fitting

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INTRODUCTION

Architecture is an important part of energy and material consumption [1]. With the shortage of resource and the worsening of environment, both sustainable development of building materials and improvement of resource efficiency have been concerned with more and more people. The production of building materials in the process of raw material mining, extraction, processing and preparation consumes large amounts of resources and energy and discharges pollutant to pollute the environment; especially the production of materials consumes coal, oil and other carbon-based energy and releases large quantities of CO_2 which is the warm greenhouse gas contributing to the global climate change [2]. To be a kind of traditional building materials, wood belongs to the renewable resources which can be recycled. Nowadays, how the wood is widely used in the field of building engineering to improve its added-value has become a hot research at home and abroad [3]. China's plantation area has reached 800 million mu, but the plantation wood was in low efficiency using state due to the loose texture, the low mechanical strength, the backward processing technology and few content of science and technology. Previous theory studies suggested that wood contained a large amount of starch, sugar, protein and other salt materials and the structures were different leading to more aforementioned serious defects [4-5]. However, the researches mostly focused on the wood anatomical structure, mould and insect preventing, etc. [6-8]. The plantation eucalyptus wood has a huge potential on mass production with high added-value solid wood products and wood composite materials due to the low price,

the good stem form and the mechanical strength [9]. However, the problems that the plantation eucalyptus wood is easy to crack, split and shrivel and difficult to glue and painting still restrict the processing and utilization of plantation eucalyptus [10]. Fiberglass is an excellent inorganic nonmetallic material with good insulation and corrosion resistance, strong heat-resistant and high mechanical strength, which is always used in composites. Copper foil has the features of obtaining a wildly temperature range, enhancing abrasion performance and attaching to different substrate such as metal, insulating materials and so forth owing to low surface oxygen characteristic. Compared with copper foil, aluminum foil is a sort of soft metallic film with graceful silver lustre, which is not only dampproof, airtight, shading, corrosion resisting, fragrance-holding, non-toxic and tasteless, but also easily processed out kinds of beautiful designs and patterned to be a kind of favorite and perfect packaging material. Furthermore, selecting appropriate reinforced materials and composite models are the keys to apply the plantation wood widely in the field of building engineering. Therefore, using the full factor test method and low temperature solidification process and viewing basic mechanical properties as the evaluation index, we explored the enhanced way and composite mechanism of glued laminated timber which was made up of the plantation eucalyptus wood veneers with the reinforcing materials of glass fiber cloth, aluminum foil and copper foil under the premise of energy conservation and emission reduction. This research can promote the plantation wood rationally to be applied in the field of building engineering to maintain the sustained development of building materials and contribute to the "resource-saving and environment-friendly" social construction.

EXPERİMENTAL SECTİON

Experimental materials: *Eucalyptus wood veneer*: The size is 1.27 m×0.64 m×1.3 mm, the density is about 0.61 g/cm3 and the moisture content is 5%-8%. *Aluminum foil*: The thickness is 0.05 mm, the type is aluminum alloy 1060, the density is 2.71 g/cm3, the tensile strength≥75 MPa and the offset yield strength≥35 MPa. *Copper foil*: The thickness is 0.05mm, the type is ordinary copper T2, the density is 2.85 g/cm3, the tensile strength≥295 MPa and the hardness≥80 HV5. *Two-component epoxy adhesive*: The A component is milk white or grey white sticky liquid, The B component is yellow-brown or red-brown sticky liquid, applicable period is 1 hour (25℃), the curing speed is 2.5-3.5 hour (25℃) and the tensile shear strength≥8 MPa (25℃×48h). *Glass fiber cloth*: plain weave, the warp and weft density is 128×68.

Tab. 1: Design proposals of specimens

Test group	Assemble pattern	Veneer texture angle	Proportion of reinforcing layer	Reinforcing material
1	7 layers wood veneers	90°	0	——
2	5 layers wood veneers and copper foil was placed among every two veneers	90°	44.4%	Copper foil
3	5 layers wood veneers and aluminum was placed among every two veneers	90°	44.4%	Aluminum foil
4	5 layers wood veneers and glass fiber cloth was placed among every two veneers	90°	44.4%	Glass fiber cloth
5	5 layers wood veneers and the veneer was placed among every two copper foil	90°	58.3%	Copper foil
6	5 layers wood veneers and the veneer was placed among every two aluminum foil	90°	58.3%	Aluminum foil
7	5 layers wood veneers and the veneer was placed among every two glass fiber cloth	90°	58.3%	Glass fiber cloth
8	9 layers wood veneers and 3 layers copper foil were placed on the surface	90°	54.5%	Copper foil
9	9 layers wood veneers and 3 layers aluminum foil were placed on the surface	90°	54.5%	Aluminum foil
10	9 layers wood veneers and 3 layers glass fiber cloth were placed on the surface	90°	54.5%	Glass fiber cloth
11	9 layers wood veneers and 3 layers copper foil were placed on the surface	0	54.5%	Copper foil
12	9 layers wood veneers and 3 layers aluminum foil were placed on the surface	0	54.5%	Aluminum foil
13	9 layers wood veneers and 3 layers aluminum foil were placed on the surface	0	54.5%	Glass fiber cloth

Design proposals of specimens: Design proposals of specimens were shown in Table 1 and the normal section sketch map of each proposal was shown in Figure 1 respectively. 3 parallel specimens in each test group and 13 test groups in total. The influence of reinforcing material type on glued laminated timber mechanical properties was obtained through the comparison of group 1/8/9/10, group 1/2/3/4, and group 1/5/6/7. Meanwhile, the influence of reinforcing material layer number on glued laminated timber mechanical properties was obtained through the comparison of group 1/2/5/8/11, group 1/3/6/12, and group 1/4/7/10/13.

Experimental methods: According to the assemble pattern in table 1 to assemble the specimens with a double spread of 350 g/cm2, then the specimens were put into the cold press with the air temperature about 20 ℃, and then to be pressurized to 4 MPa quickly and to be maintained for 1 hour, then the power source was turned off and the press-holding time was 23 hour. The sectional area of obtained specimens was 350×350 mm. The standard specimens were made and tested according to "Standard for Methods testing of Timber Structures" (GB/T 50329-2002) and "Plywood" (GB9846-2004). The specimens for Testing MOR and MOE: Length×Width=300 mm×50 mm, they were loaded to failure at the rate of 10 Pa/s and the loading methods were consulted "Test methods of evaluating the properties of wood-based panels and surface decorated wood-based panels" (GB/T 17657-1999).

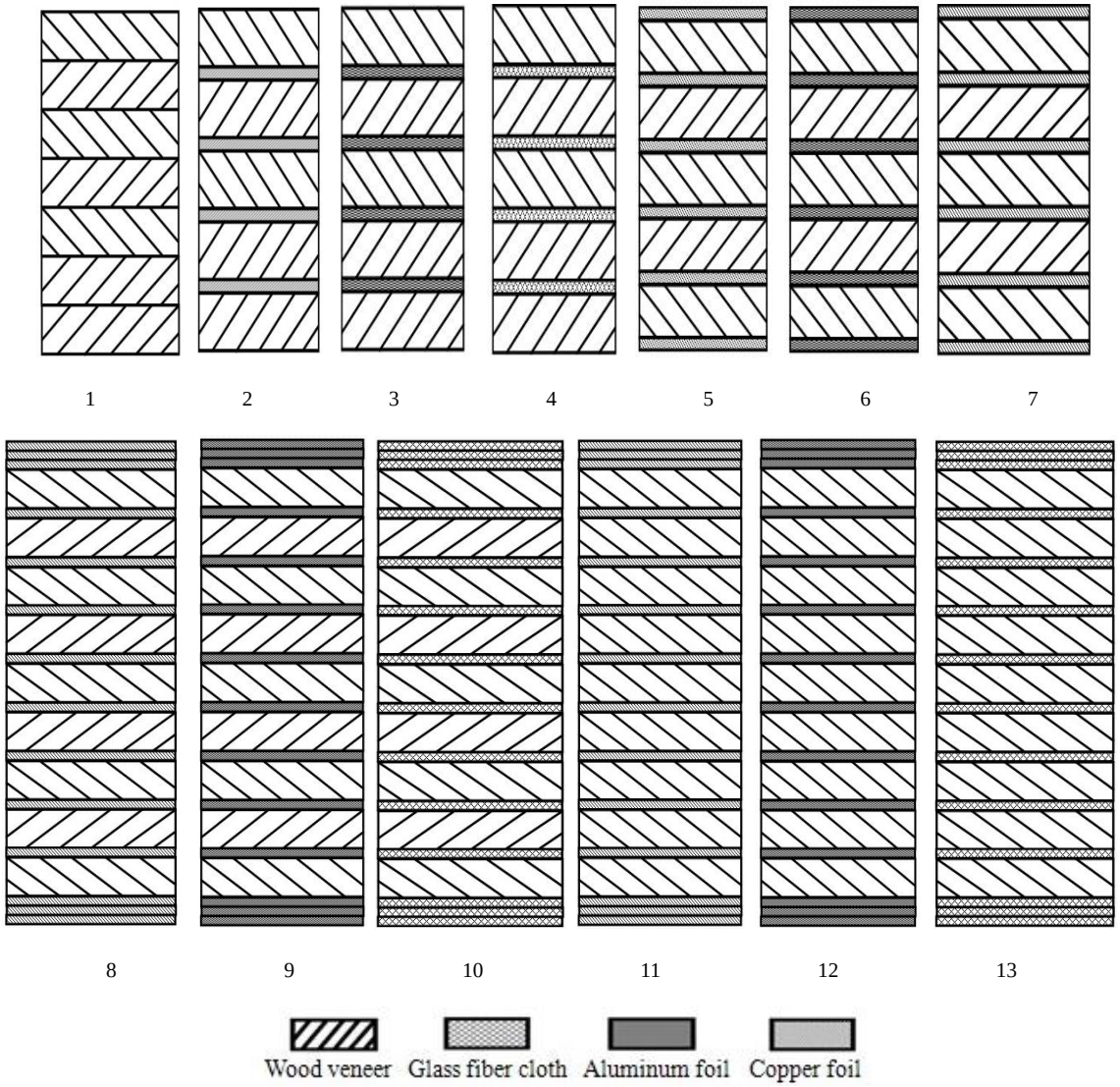

Fig. 1: The normal section sketch map of each proposal

RESULTS AND DISCUSSION

The average of 3 parallel specimens in each group was taken, and the total test results of 13 groups of specimens were shown in Table 2. Variance analysis of the influence of each factor to mechanical properties of the glue lumber was shown Table 3, Table 4, Table 5 and Table 6.

Tab. 2: Results of testing

Test Group	Thickness (mm)	Limit load (N)	MOR (MPa)	Standard MOR (MPa)	MOE (MPa)	Standard MOE (MPa)
1	9.88	796	30.87	25.62	4228	5091
2	7.11	70	6.23	9.98	1387	1095
3	7.25	165	14.13	21.77	3023	2436
4	6.95	530	49.38	82.80	11500	8881
5	5.85	140	18.41	43.57	6052	3934
6	5.59	295	42.48	110.12	15295	9500
7	6.60	295	30.48	56.67	7871	5772
8	11.64	365	12.12	7.25	1007	1302
9	10.97	505	18.88	12.71	1765	2152
10	10.91	870	32.89	22.38	3109	3768
11	12.54	860	27.15	15.42	2142	2842
12	11.94	1615	46.22	23.81	3306	4607
13	11.62	1575	52.49	31.49	4373	5647

Tab. 3: Variance analysis of the influence of each factor on MOR

Source of variance	Sum of square of deviation	Degree of freedom	Mean-square deviation	Test statistic F
The type of reinforcing material	690.01	3	230.00	0.47
Layer numbers of reinforcing material	46.00	3	15.33	0.03
Layer numbers of Veneer	13.69	2	6.85	0.01
Error	1957.27	4	489.32	--
Sum	2706.97	12	--	--

Tab. 4: Variance analysis of the influence of each factor on standard MOR

Source of variance	Sum of square of deviation	Degree of freedom	Mean-square deviation	Test statistic F
The type of reinforcing material	1297.61	3	432.54	0.22
Layer numbers of reinforcing material	1577.45	3	525.82	0.27
Layer numbers of Veneer	725.56	2	362.78	0.19
Error	7700.70	4	1925.17	--
Sum	11301.31	12	--	--

Tab. 5: Variance analysis of the influence of each factor on MOE

Source of variance	Sum of square of deviation	Degree of freedom	Mean-square deviation	Test statistic F
The type of reinforcing material	23138506	3	7712835	0.20
Layer numbers of reinforcing material	28811200	3	9603733	0.25
Layer numbers of Veneer	12637509	2	6318754	0.17
Error	151973262	4	37993316	--
Sum	216560477	12	--	--

Tab. 6: Variance analysis of the influence of each factor on standard MOE

Source of variance	Sum of square of deviation	Degree of freedom	Mean-square deviation	Test statistic F
The type of reinforcing material	15844131	3	5281377	0.36
Layer numbers of reinforcing material	5620412	3	1873471	0.13
Layer numbers of Veneer	2276411	2	1138206	0.08
Error	58779201	4	14694800	--
Sum	82520155	12	--	--

The influence of reinforcing material type: From table 3 to table 6 showed that the influence of reinforcing material type on MOR and standard MOE was significant. According to the data from the group of 1/8/9/10, the results showed that three layers glass fiber cloth on the surface could effectively increase the limit load and MOR of the glue lumber, while the same layers of cooper foil and aluminum foil on the surface could not. It was found that copper foil was glued to epoxy resin insecurely due to good hardness and special surface molecular structure, and cementing surface cracked in early stage, which affected the increase of ultimate load. However, both aluminum foil and glass fiber cloth were glued well to epoxy resin to reach the high strength of bonding interface, especially glass fiber cloth was full of epoxy resin to improve gluing property which made the wood cracked earlier than the bonding interface in the loading procedure. Therefore, the most obvious enhancement effect was from glass fiber cloth, followed by aluminum foil and copper foil was the worst.

Exploring the enhancement effect of single material of copper foil, aluminum foil and glass fiber cloth on the glue lumber according to the data from the group 2/3/4 and the results showed that when the layer number of wood veneer was more than the reinforcing material-that was reinforcing materials paced among the veneers, the most

obvious enhancement effect came from glass fiber cloth, followed by aluminum foil and copper foil was the worst with the evaluation index of limit load and MOR.

Exploring the enhancement effect of single material of copper foil, aluminum foil and glass fiber cloth on the glue lumber according to the data on the group 5/6/7 and the results showed that when the layer number of wood veneer was less than the reinforcing material-that was veneers placed among reinforcing materials, the obvious enhancement effect was from glass fiber cloth and aluminum foil, and copper foil was the worst with the evaluation index of limit load. While the most obvious enhancement influence was from aluminum foil, followed by glass fiber cloth and copper foil was the worst with the evaluation index of MOR.

From the above, It was found that the type of reinforcing materials affected the mechanical properties of the glue lumber, so did the assemble pattern of reinforcing materials.

The influence of reinforcing material layer number: From table 3 to table 6 showed that the influence of reinforcing material layer number and assemble pattern on standard MOR and MOE was more significant than that on MOR and standard MOE. The influence of reinforcing material layer number and assemble pattern on mechanical properties of the glue lumber was converted to which on standard MOR and standard MOE for the sake of being compared directly. When the reinforcing material was copper foil, according to the data from the group 1/2/5/8/11, the results showed the assemble pattern of veneers placed among copper foil resulting in the maximum value of standard MOR and standard MOE. When the reinforcing material was aluminum foil, according to the data from the group 1/3/6/9/12, the results showed the assemble pattern of veneers placed among aluminum foil resulting in the maximum value of standard MOR and standard MOE. When the reinforcing material was glass fiber cloth, according to the data from the group 1/4/7/10/13, the results showed the assemble pattern of veneers placed among glass fiber cloth resulting in the maximum value of standard MOR and standard MOE. However, according to the increasing of reinforcing material layer number causing the variation tendency of standard MOR and standard MOE, it was found that the most obvious enhancement effect was from glass fiber cloth, followed by aluminum foil and copper foil was the worst, and the best assemble pattern was the veneers paced among reinforcing materials. Although the flexural behavior of copper foil was the best, the enhancement effect of copper foil was not good due to the low bonding strength. Glass fiber cloth had the grid space, which was placed on the surface of glue lumber not only needed a mass of epoxy resin adhesive to fill the blank space, but also the structure was disadvantageous to the protection of veneers. Therefore, in spite of the reinforcing effect of aluminum foil weaker than glass fiber cloth, the combination reinforcement of aluminum foil and glass fiber cloth with aluminum foil on the surface was optimal to produce the glue lumber.

The influence of veneer: According to table 2, the average of standard MOR, standard MOE and limit load of 5 layers veneers (group 2/3/4/5/6/7), 7 layers veneers (group 1), 9 layers veneers (group 8/9/10/11/12/13) were calculated respectively. The results showed that with the increasing of veneer lay number, standard MOR and standard MOE of the glue lumber showed a decreasing tendency and its limit load showed an increasing tendency. Both standard MOR and standard MOE were the intrinsic properties of materials, it was found that when the glue lumber with the same thickness were produced, the more layers of veneers (the thinner of veneers), the more flaws in producing and gluing which triggered strength decreasing easier. Thus, thicker veneer was more likely to be selected. While the thickness of glue lumber was not limited, the veneer with the same thickness layer number got more, the thickness of the glue lumber got larger, and consequently the ultimate load grew higher. So it was demonstrated that the security coefficient and limit load could be improved by increasing the thickness of the glue lumber.

According the data from group 8/11, group 9/12 and group10/13, the results showed that under the premise of the same assemble pattern of reinforcing materials, parallel veneer assembling structure was better than cross veneer assembling structure.

The influence of the thickness of glue lumber: Aforementioned results and analysis showed that the assemble pattern and layer number of reinforcing materials had deep influence on mechanical properties of the glue lumber, so did the assemble structure and layer number of veneers. So such questions as reinforcing materials, assemble structure of veneers and the thickness of glue lumber should be considered to produce the glue lumber. In this experimental condition, a mathematical prediction model could be established to clarify the relationship between the limit load & the standard MOR and the thickness of glue lumber based on the obtained 39 parameters as follows:

$$\mathrm{Y} = c_1\mathrm{x}^3 + c_2\mathrm{x}^2 + c_3\mathrm{x} + c_4 \quad (1)$$

In Equation 1, x represented the thickness of glued Timber, Y represented the limit load or the standard MOR. c_i

represented the regression parameter.

In order to solve the model, the SPSS18.0 statistical software could be used to obtain the fitting curve equation between the limit load (F) and the thickness of glue lumber (t) as follows, and the goodness of fit was 0.891.

$$F = 1.2t^3 - 62.4t + 72.6 \quad (2)$$

Figure 2 showed the comparison of calculated and measured results of the limit load and the thickness of glue lumber, which proved the rationality of the fitting curve equation (Equation 2).

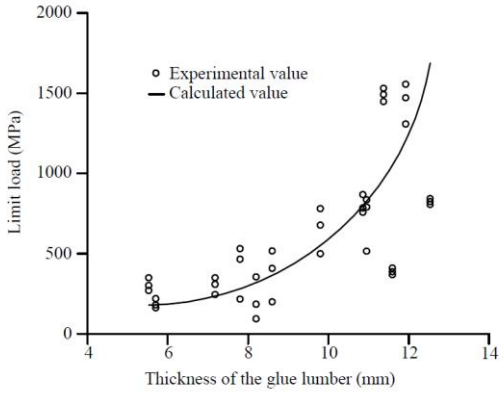

Fig. 2: The comparison of calculated and measured results of the limit load and the thickness of glue lumber

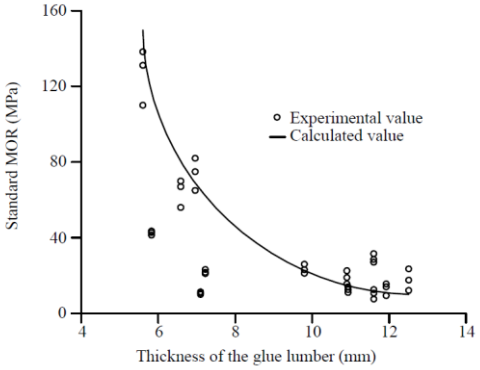

Fig. 3: The comparison of calculated and measured results of the standard MOR and the thickness of glue lumber

At the same time, the fitting curve equation between the standard MOR (M) and the thickness of glue lumber (t) could be obtained as follows, and the goodness of fit was 0.852.

$$M = 2.5t^2 - 65.4t + 436.8 \quad (3)$$

Figure 3 showed the comparison of calculated and measured results of the standard MOR and the thickness of glue lumber, which proved the rationality of the fitting curve equation (Eq. 3).

CONCLUSION

(1) The influence of reinforcing material type on MOR and standard MOE is significant, and the assemble pattern of reinforcing materials affected the mechanical properties of the glue lumber.

(2) The influence of reinforcing material layer number and assemble pattern on standard MOR and MOE was more significant than that on MOR and standard MOE. And the combination reinforcement of aluminum foil and glass fiber cloth with aluminum foil on the surface was optimal to produce the glue lumber.

(3) The security coefficient and the limit load could be improved by increasing the thickness of the glue lumber. And under the premise of the same assemble pattern of reinforcing materials, the parallel veneer assemble structure is

better than the cross veneer assemble structure.

(4) In this experimental condition, the fitting curve equations are obtained to clarify the relationship of the thickness of glued laminated timber (t), the limit load (F) and the standard MOR (M), which is $F = 1.2t^3 - 62.4t + 72.6$ and $M = 2.5t^2 - 65.4t + 436.8$, and the goodness of fit is 0.891 and 0.852, respectively.

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