WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.4.661670
e-ISSN 2729-8906
67(4): 2022 661-670 pp.

THE STUDY ON GLUE-APPLYING METHODS AND HOT-PRESSING TECHNOLOGY OF PARALLEL STRAND LUMBER

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(RECEIVED DECEMBER 2021)

ABSTRACT

Parallel strand lumber (PSL) was manufactured from the veneer strand cut from the poplar broken veneers of the plywood enterprises, by analyzing the influence of the size of veneer strands, the glue concentration and glue-applying time on the glue-absorbing amount of veneer strands, the influence of three different glue-applying was, hot-pressing time and temperature on the physical and mechanical properties of PSL was reviewed and the hot-pressing technology was optimized. The experiment results showed that the size of the veneer strands have not notable influence on the gluing-absorbing amount, and mainly affect the homogeneity and appearance quality of the product. The glue concentration is one main factor to affect the glue-absorbing amount of veneer strands and PF resin of 30% concentration was chosen. The glue-applying way is the main factor to affect the mechanical property of PSL. The hot-pressing time and temperature have significant influence on physical and mechanical properties of PSL. Comprehensively considering, the physical and mechanical properties and homogeneity of products are better using the veneer strands with 100 mm length, the glue-spraying way and hot-pressing technology with the time 35 min and the temperature of 150°C.

KEYWORDS: PSL, veneer, poplar, gluing-applying method, hot-pressing technology, physical and mechanical properties.

INTRODUCTION

Parallel strand lumber (PSL), trade name parallam, is a type of wood-based panel (Wang and Pei 1999) which made by hot-pressing parallel to the grain after narrow veneer strands were glued. It is an important achievement that high strength and large size alternative structures building materials were produced by using small diameter wood and low grade veneer (Liu and Lee 2003, Lee et al. 2007, Sukontasukkul et al. 2000, Wang and Shi 2007, Jing and Cai 1997).

PSL was widely used in the wood industry. The advantages of high timber utilization rate, uniform material (Wang et al. 2012), beautiful texture (Clouston 2007, Amini et al. 2015), high mechanical properties (Fridiyanti and Massiya 2018, Chen et al. 2014, Liu et al. 2021) and good machining performance (Wang et al. 2016) were favored among researchers. It can be used as decorative and structural materials (Chen et al. 1993, 2006).

Poplar plantation forest was rich and widely-cultivated in China, it has became the main raw material for plywood production (Lv et al. 2010, Xu et al. 1993, Chen et al. 1994). The scale of most plywood production enterprises in China are small, and the production technology and equipment are backward. The broken veneers accounted for 10-15% in the veneer rotary-cutting process (Castro et al. 2014) and a large number of veneer strands were produced in dry shear processing (Wang et al. 2019, 2021). Most of the broken veneers were used as fuel or waste gas treatment currently.

In this paper, PSL from plywood enterprises were cut into veneer strands (Lu et al. 2010) to make PSL, so the wood utilization rate and the products added value (Wei et al. 2015) were increased. In the study, the influence of veneer strands size and shape, the glue concentration (Wang et al. 2016b) and the glue time on gluing-absorbing amount were analyzed, the effect of three gluing-applying ways (Jiang et al. 2017, Chen 1995), hot-pressing temperature and time on the physical and mechanical properties of PSL were investigated and the hot-pressing technology (Esteves and Pereira 2008, Goli et al. 2014, Romagnoli et al. 2015, Chen et al. 1994) was optimized to provide theoretical guidance for the production of PSL.

MATERIAL AND METHODS

Plant material

The poplar fragmentary veneer strands were 2 mm thick from Xuzhou Sheng He Wood Co., Ltd, Jiangsu Province, China. Then they were cut into 15 mm wide veneer strands along the grain and the length of them were 50 mm, 75 mm, 100 mm three specifications respectively. The dry moisture content of the veneer strands was 12%. The solid content of the phenolic resin was 44.1% and viscosity was 48.72 cps, pH is 6.2, free phenol content was $\leq$ 0.2%.

Methods

First, according to the method of orthogonal experiment, the veneer strands with width of 15 mm and length of 50 mm, 75 mm and 100 mm were impregnated in phenolic resin, the concentration of it was 20%, 25%, 30% and the impregnated time was 3 min, 6 min, 9 min, As the concentration was 20%, the adhesive amount was 10.18,13.54,18.37 g respectively. The adhesive amount increased to 14.63,18.38,22.53 g with the concentration increase to 25%. While the concentration reached the maximum of 30%, the corresponding amount reached 16.65,18.67, and 22.95 g. The effect of veneer strands shape and size, glue concentration and dipping time on glue absorption of veneer strands were investigated, the results will be used for the next experiment. Then, the veneer strands were dipped, mixed or sprayed, respectively. Similarly, the orthogonal test method was divided into three groups, as the concentration was 20%, 25%, 30% respectively, the orthogonal test method was used for hot

pressing of the veneer strands. The hot-pressing time was 25 min, 35 min and 45 min and the hot-pressing temperature was 140°C, 150°C, 160°C, respectively. Afterwards, the specimens were intercepted and the physical and mechanical properties were tested according to the national standard GB/T 17657 - 1999 (Test methods of evaluating the properties of wood-based panels and surface decorated wood-based panels) after hot pressing.

RESULTS AND DISCUSSION

Result analysis

In order to facilitate the control of glue absorption in production, the effects of the size and shape of the veneer stands, the concentration of the glue solution, and the immersion time on the glue absorption of the veneer strands were mainly investigated. Compared with other experiments, the advantage of this experiment was the glue-applying way was divided into three methods, so more persuasive (Yu et al. 2007). The result was more accurate due to the longer impregnated time, the glue concentration was appropriate to facilitate experimental data (Zhang and Liu 2005). The orthogonal method (a mathematical statistical method in experimental design) was adopted. The values of each factor and the experimental arrangement were shown in Tab. 1 and Fig. 1.

Tab. 1: Experiment arrangement and results.

Test number	Glue concentration (%)	Impregnated time (min)	Unit shape (veneer strands length) (mm)	Impregnation amount
1	20	3	50	10.18
2		6	75	13.54
3		9	100	18.37
4	25	3	75	14.63
5		6	100	18.38
6		9	50	22.53
7	30	3	100	16.65
8		6	50	18.67
9		9	75	22.95

As shown in Tab. 1, the size (length) of the veneer strands have not notable influence on the gluing-absorbing amount, and mainly affect the homogeneity and appearance quality of the product. The method of measuring glue absorption was: First, the quality of veneer strands was measured at normal temperature and pressure, Then the veneer strands was impregnated in glue for a while, the glue will be absorbed by veneer strands gradually. Finally the quality was measured again. The mass after absorbing glue minus the mass before absorbing glue is the impregnation amount. The processing quantity enhanced and the labor productivity was decreased with the length of the veneer strands decreased. The largest glue absorption was seen as the veneer strand length was 100 mm. Considering the processing quantity and the labor productivity, the length of 100 was the best from the experimental process and results.

The glue absorption of the veneer strands was affected by the solution concentration. The glue absorption of veneer strands enhanced with the glue concentration increased, so the glue liquid penetrates into the veneer stands was more and the resin content per unit volume was high. At the same time, the veneer strands were firmly bonded because of the sufficient resin on each cementing layer. Because the phenolic resin was self-made, phenolic resin with the 30% concentration was chosen to ensure its viscosity. Compared with other experiments (Hu and Chen 2006), the glue concentration used in this experiment is not single, so it can be more comprehensive to analyze the influence of concentration on impregnation amount. small diameter wood and low grade veneer was used in the article, Compared to hybrid poplar specimen (Chen et al. 1994), more materials can be saved and multiple physical properties were measured in this experiment, the data on physical and mechanical properties of PSL were more comprehensive and more persuasive.

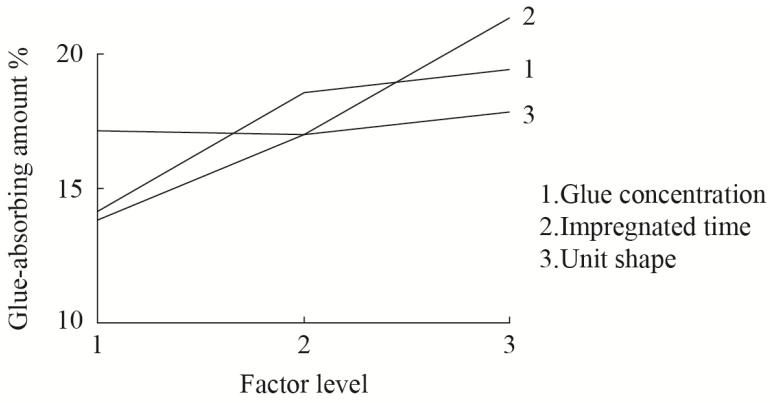

Fig. 1: Relationship between glue-absorbing amount and factor level

Glue-dipping time was one main factor affect the glue-absorbing amount of veneer strands. The glue-absorbing amount of the veneer strands increased with the glue-dipping time extended. Although most phenolic adhesives were absorbed at 3 min, as the phenolic resin was self-made, the dipping time 9 min was chosen to ensure the solid content of resin in the veneer strands.

PSL hot-pressing test results and analysis

Different glue-applying ways, hot-pressing time and temperature on the physical and mechanical properties of PSL were investigated in the hot-pressing experiment of veneer strands. The density, moisture content (MC), static bending strength (MOR), elastic modulus (MOE), internal bonding strength (IB) and water absorption thickness expansion rate of PSL were also tested. The hot-pressing pressure was not studied because of veneer strands thickness has been set to 15 mm. According to references, the hot-pressing pressure was 7 MPa. The values and experimental arrangements of each factor were shown in Tabs. 2-3 and Figs. 2-7.

Tab. 2: Experiment arrangement and results of MOR, MOE and IB.

Test number	Gluing-applying way	Hot-pressing time (min)	Hot-pressing temperature (°C)	Static bending strength MOR (MPa)			Elastic modulus MOE (MPa)			Internal bond strength IB (MPa)
				1	2	3	1	2	3	
1	glue-dipping way	25	140	73.45	70.90	75.99	8411.68	9164.02	9705.44	1.35
2		35	150	68.49	71.03	76.71	11820.64	10339.71	11031.05	1.83
3		45	160	59.90	52.25	46.09	11219.69	11402.25	10328.21	1.75
4	glue-mixing way	25	150	59.21	74.77	69.50	10696.01	11171.81	11757.27	2.23
5		35	160	57.61	67.49	66.79	11498.93	11132.13	11629.97	1.58
6		45	140	45.97	58.94	62.53	9966.24	10319.41	10456.03	2.33
7	glue-spraying way	25	160	44.36	51.25	59.96	11926.66	11164.54	10890.29	1.62
8		35	140	60.05	57.44	55.87	9878.24	11300.40	10928.00	1.94
9		45	150	63.45	68.46	83.37	10066.85	11690.61	12069.17	1.93

As we can see from Figs. 2-4, the glue-applying way was the main factor to affect the mechanical property of PSL. The highest static bending strength of PSL will be seen with glue-dipping way adopted. Relatively small static bending strength of PSL will be observed while glue-mixing and glue-spraying way adopted; High moisture content will be seen while used glue-dipping way. The veneer strands structure will be destroyed when using glue-mixing way. Glue can be absorbed evenly by the veneer strands with the glue-spraying way adopted, so the largest elastic modulus of PSL as glue-spraying way used and the largest internal bonding strength of PSL while glue-mixing way adopted.

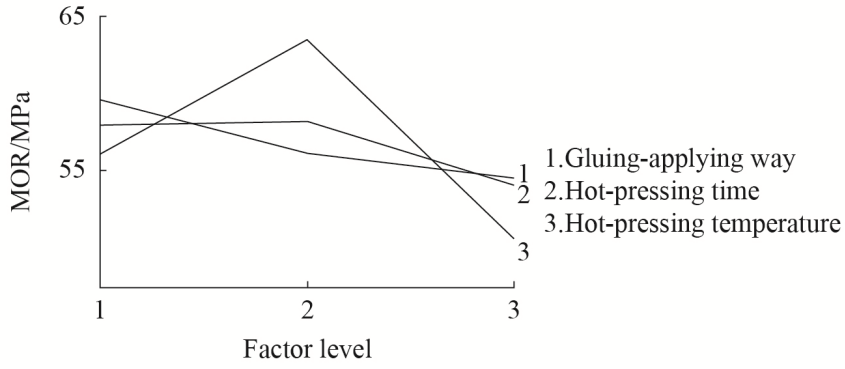

Fig. 2: Relationship between MOR and factor level.

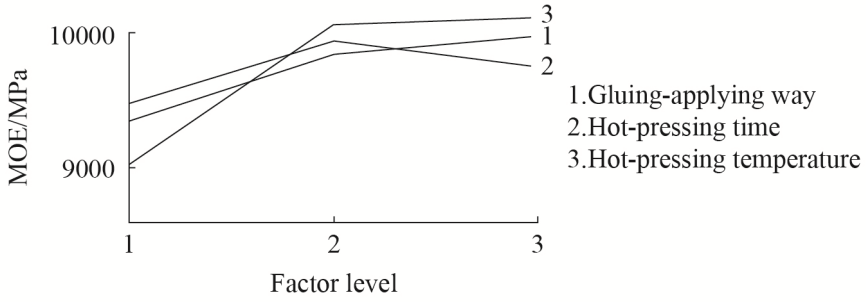

Fig.3: Relationship between MOE and factor level.

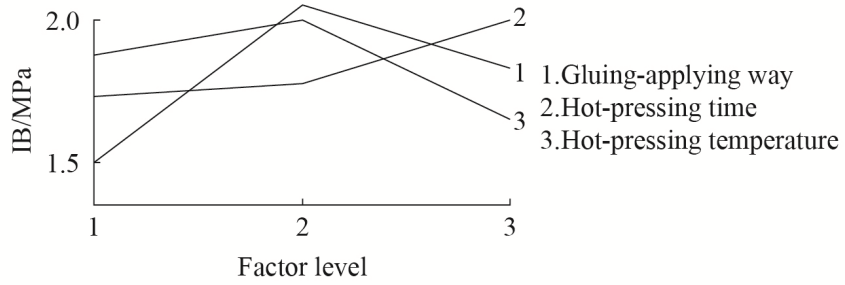

Fig. 4: Relationship between IB and factor level.

The hot-pressing time has significant influence on physical and mechanical properties of PSL. It can make the adhesive fully solidified. The static bending strength, elastic modulus and IB increased with the hot-pressing time was chosen from 25 min to 35 min, However, the tendency in static bending strength and elastic modulus from 35 min to 45 min was opposite. Therefore, the largest static bending strength, elastic modulus and internal bonding strength of PSL will be observed as the hot-pressing time was 35 min.

The hot-pressing temperature also has significant influence on physical and mechanical properties of PSL. The static bending strength increased gradually with the temperature increased. However, when the temperature was too high, the hot-pressing temperature will make the adhesive layer brittle, and the performance of the veneer strands were also relatively reduced. The largest static bending strength will be seen when the temperature was 150°C in the experiment. The elastic modulus and internal bonding strength also increased with the hot-pressing temperature enhanced. Before 150°C, the elastic modulus increased rapidly, However, between 150°C and 160°C, the elastic modulus of PSL increased relatively slowly due to the increase of temperature and the curing of adhesive.

Considering the static bending strength, elastic modulus and internal bonding strength of PSL, relative better mechanical strength of PSL will be obtained with the hot pressing-time was 35 min and the hot-pressing temperature was 150°C by glue-spraying way adopted.

Tab. 3: Experiment arrangement and results of density, MC and thickness swelling rate.

Test number	Gluing-applying way	Hot-pressing time(min)	Hot-pressing temperature (°C)	Density ($g \cdot cm^{-3}$)	Water content (%)	Thickness swelling rate (%)
1	glue-dipping way	25	140	0.67	5.8	9.1
2		35	150	0.72	3.3	7.9
3		45	160	0.68	3.78	8.0
4	glue-mixing way	25	150	0.61	4.56	4.1
5		35	160	0.76	3.4	4.7
6		45	140	0.76	5.6	5.0
7	glue-spraying way	25	160	0.68	3.2	8.7
8		35	140	0.65	3.5	5.2
9		45	150	0.67	3.6	5.8

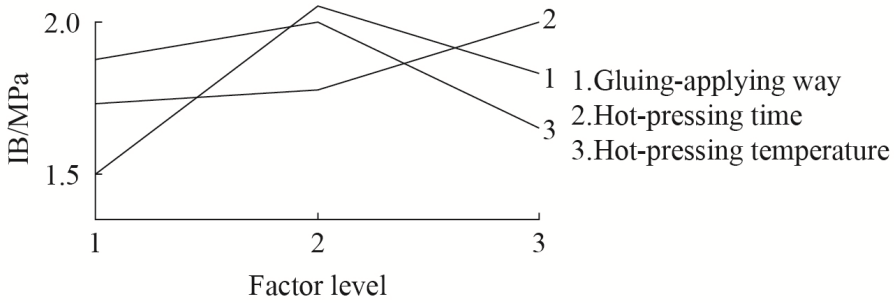

Fig. 5: Relationship between density and factor level.

The physical and mechanical properties and application range of PSL was affected by the density, the cost of PSL was also affected directly. The initial design density was 0.7 $g \cdot cm^{-3}$. There is no big difference between veneer strands, each veneer strand density was between 0.65-0.76 $g \cdot cm^{-3}$, basically meet the requirements. It can be concluded that the static bending strength of PSL was affected by density as compared Fig. 5 with Fig. 2, Fig. 3 and Fig. 4. Relatively low static bending strength will be observed as density was about 0.70 $g \cdot cm^{-3}$, However, the largest static bending strength can be observed when the density was about 0.67 $g \cdot cm^{-3}$. The elastic modulus increased with the density improved, but the elastic modulus will decreased as the value excess 0.67 $g \cdot cm^{-3}$.

The initial design moisture content of PSL was 6%. Relatively high moisture content of veneer strands will be obtained with the glue-dipping way adopted. It needs to be dried before pressing the veneer strands to reduce the moisture content of the veneer strands because the glue was extruded easily during the pressing process, so the moisture content of the pressed PSL was low. The change of PSL moisture content was most affected by hot-pressure temperature. The PSL water was evaporated and moisture content was significantly decreased with the temperature increased. The static bending strength, elastic modulus and internal bonding strength of PSL increased with the veneer strands moisture content decreased as compared Fig. 6 with Fig. 2, Fig. 3 and Fig. 4.

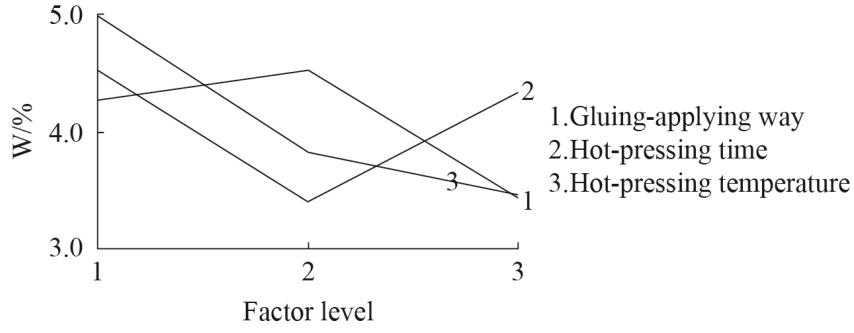

Fig. 6: Relationship between MC and factor level.

From Fig. 7, the thickness swelling rate decreased with hot-pressing temperature increased and the hot-pressing time extended, However, the tendency in the thickness swelling rate of PSL was opposite. The thickness swelling rate enhanced with the veneer strands density increased.

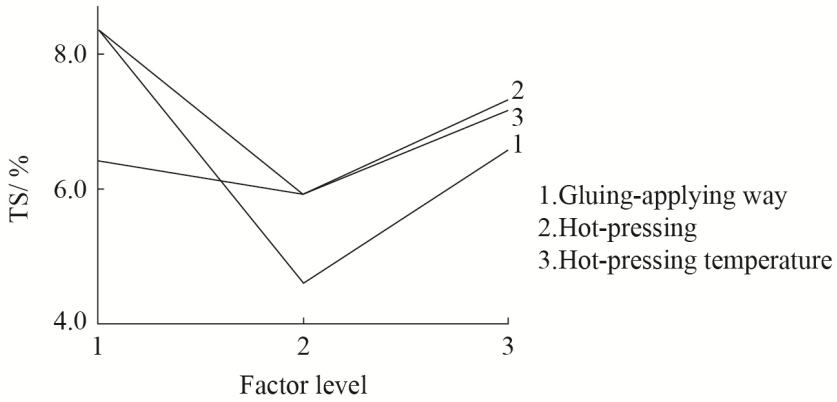

Fig. 7: Relationship between TS and factor level.

CONCLUSIONS

(1) The size of the veneer strands have not notable influence on the gluing-absorbing amount, and mainly affect the homogeneity and appearance quality of the product. The veneer strands with 100 mm length was used. *(2)* The glue-applying way was the main factor to affect the mechanical property of PSL. The highest static bending strength of PSL will be seen with glue-dipping way adopted. *(3)* The hot-pressing time has significant influence on physical and mechanical properties of PSL. The largest static bending strength, elastic modulus and internal bonding strength of PSL will be observed for the hot-pressing time 35 min. *(4)* The hot-pressing temperature also has significant influence on physical and mechanical properties of PSL. *(5)* The static bending strength, elastic modulus and internal bonding strength of PSL increased with the veneer strands moisture content decreased. *(6)* Considering the static bending strength, elastic modulus and internal bonding strength of PSL, relative better mechanical strength of PSL will be obtained with the hot pressing-time 35 min and the hot-pressing temperature 150°C by glue-spraying way adopted.

ACKNOWLEDGEMENTS

This study is funded by National Natural Science Foundation (31070502) and Public Farewell Project of National Forestry Bureau (201004006-6). The authors would also like to thank the support of the Priority Academic Program Development of Jiangsu Higher Education Institutions and Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, Nanjing Forestry University, Nanjing 210037, China.

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