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Full Length Research Paper

Effects of layer arrangements on bending strength properties of laminated lumber made of poplar (*Populus nigra* L.)

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In this study, the effects of layer arrangements on bending properties of laminated wood products have been investigated. Poplar (*Populus nigra L.*) and polyvinyl acetate (PVA) were used as wood and adhesive, respectively. Bending static properties (MOE and MOR) of laminated products comprising various combinations of layer arrangements resulting in 5 combinations were measured. The results of this study showed that sawn lumber (control sample) had better bending properties (MOE and MOR) than lumber made from laminated layers. On the whole, using layers as constitution for layered systems decreased MOR more than MOE. Using thick layers reduced the MOR and MOE of the products. Finally, the proper layer arrangements should be selected with respect to their final application in the production of laminated products.

Key words: Laminated wood products, bending properties, layer arrangement, poplar wood.

INTRODUCTION

The shrinking supply of harvestable high grade trees/logs has led to using fast growing trees as a raw material for wood industry. Poplar species are one of the fast growing species planting around the world to ease the pressure on natural forests. Poplar is vastly planted in Iran to supply wood industries with sustainable raw materials. Fast-growing trees such as poplar grown on managed plantations are being seriously considered for future supply needs. The genus *Populus* includes trees that are commonly called “poplar.” The genus has a very wide distribution in Iran with various species including: *P. nigra L*., P*. alba L., P. ouramirica L., P. caspica Bornm., P. euphratica Oliv.* and others. All of these species can be characterized as fast-growing. Hybrid poplars are the fast-growing species compared with native poplars. Wood of poplar has a loose texture and raised grains. The wood of poplar is very soft and its specify gravity is 0.35 to 0.55 and diffuse porous structure. The strength properties of poplars are relatively low. Poplar wood is used for variety of primary and secondary forest products in Iran. Despite of low specify gravity of poplar, this wood is very strong and used for many application such as lumber, solid wood, composite panels (hardboard, particle board and fiber board, veneer and plywood), pulp and paper industries and manufacturing of furniture components. Wood is a one of the oldest and naturally renewable construction materials that is used for many purposes such as bridges, waterfront structures, poles and pole frames, electric and telephone lines and many other uses. A number of factors such as simplicity in fabrication, lightness, reusability and environmental compatibility have made this material one of the most popular in light construction. Today wood remains important to the engineer and the builder by reason of

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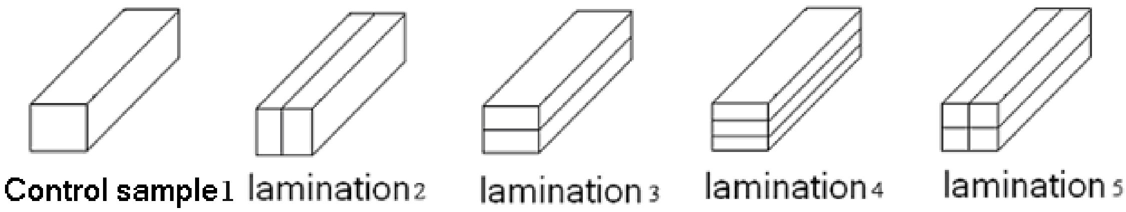

Figure 1. Combination of layer arrangement.

improved technology (Camille and Kmeid, 2005).

Glued laminated timber, or Glulam is the oldest member of the engineered wood products (EWP) family. Manufacture of this product began in Europe at around the turn of the Century, in the U.S. in the 1940's and in Canada in 1952. Glulam is manufactured to strict standard of material grading based on stiffness rating of the individual laminations which are machined to fine dimensional tolerances to ensure proper glue bond adjacent to the finger joints. Glulam members can be manufactured to very long lengths (Williams, 2002). Glulam is defined in ASTM D3737 standard method for establishing stresses for structural glued-laminated timber (Glulam) as "a material glued up from suitably selected and prepared pieces of wood either in a straight or curved form with the grain of all pieces essentially parallel to the longitudinal axis of the member". A stress-rated structural product, glued-laminated timber consists of two or more layers of lumber called lamination that are nominally 1 or 2 inches thick. The maximum lamination thickness permitted in the United States under ANSI/AITC A190.1 American National Standard for wood products Structural Glued-Laminated Timber is 2 inches (Moody and Hernandez, 1997). Glulam can be fabricated in many shapes and sizes, and has been used in numerous application including keels for boats, arches for airplane hangers, churches, timbers for floor and roof systems, dome structures, transmission poles, along with girders and decks for timber bridges. With recent changes in availability of forest resources, high quality laminations necessary for glulam design have become increasingly difficult to procure, and more expensive as well (Dagher et al., 1996).

Glulam can be manufactured from any softwood or hardwood species provided it meets necessary strength and stiffness requirements (Ritter et al., 1994). Although use of softwood in laminated wood production has been exclusively studied, limited information is available regarding using hardwoods in laminated products. As commercializing the utilization of hardwoods in production of laminated wood products needs some technical information, this study has focused on the use of popular in laminated products. The main objective of this study is to establish technical information regarding the use of poplar (*Populus nigra L.*) in laminated wood products. The information is gathered by determining bending properties of the products having different layer arrangements. The results of this research can be very useful in realizing the potential usage of hardwoods namely: poplar in laminated products.

MATERIALS AND METHODS

Poplar (*P. nigra L.*) planted in a large scale in north of Iran was used as sample. Wood specimens were non-deficient, proper, knotless, normally grown (without reaction wood and decay, insect/mushroom damages). Age of trees was 15 years and wood samples were prepared in mature wood and without heartwood. Samples were taken from the bottom of the log. After sawing the materials, they dried until a moisture content of 9%. The specimens did not put in climate room (condition 20° and humidity of 65%). Moisture content and density of samples were determined according to ASTM D 2395-93. The average moisture content and density of the samples were 8.5% and 450 kg/m^3, respectively. A commercial polyvinyl acetate (PVAc) adhesive was supplied by a company located in Mashhad, Iran. Variables are specimens that its layers arranged have various configuration. The combinations of layer arrangement were shown in Figure 1. Layers arrangement includes: control sample 1 and laminations 2 to 5. The adhesive was applied by brush on one side of the joints. The applied end pressure was accomplished with manually operated press and lasted for 24 h. The jointed specimens were conditioned and cut to final dimensions of 30 × 27 × 380 mm. 10 replications were used for each test. The layers arrange with various configurations together to make layered systems. The bending properties of the specimens were determined according to the ISO/NP 13061-1 to 4 standard. The bending properties of each piece were then measured by a DANP4 machine.

The modulus of elasticity (MOE) and modulus of rupture (MOR) of samples were calculated by the following formulas (Yang et al., 2008):

$$MOE = \frac{P_{pl}\, l^3}{4\delta_{pl}\, b h^3}, MOR = \frac{3P_u l}{2bh^2}$$

Where P_{pl} (N) is the loading in the proportional limit region, δ_{pl} (mm) is the deflection with respect to P_{pl}, L (mm) is span, b (mm) is the width of the samples, h (mm) is the height of the samples and P_u (N) is the maximum load.

A one-way analysis of variance (ANOVA) from SPSS was performed on the data. The results were analyzed by analysis of variance (ANOVA) using the Duncan's multiple range test to test for significant differences. The difference in MOE or MOR between the different types of samples was significant at 95% confidence level. Results of multiple Duncan's test are A, B, AB and suchlike. The

Table 1. Analysis of variance and results of multiple Duncan's test for MOE and MOR of specimens.

Source of variation	Samples	Mean	Std. deviation	Std. error	Minimum	Maximum	Duncan's	Sig.
	Control sample 1	7999.1	711.47	224.99	6808	9173	A	
	Lamination 2	6895.9	548.85	173.56	6187	7710	B	
MOE (MPa)	Lamination 3	6946.8	1452.91	459.45	4295	9952	AB	**
	Lamination 4	6967.9	1628.34	514.93	2772	8844	AB	
	Lamination 5	6587.6	823.43	260.39	4975	7631	B	
	Control sample 1	74.83	9.78	9.78	58.10	90.40	A	
	Lamination 2	49.62	9.55	9.55	31.59	59.60	C	
MOR (MPa)	Lamination 3	57.37	11.41	11.41	42.19	82.00	BC	*
	Lamination 4	61.95	9.21	9.21	46.26	77.10	B	
	Lamination 5	54.86	6.149	6.15	46.50	66.40	BC	

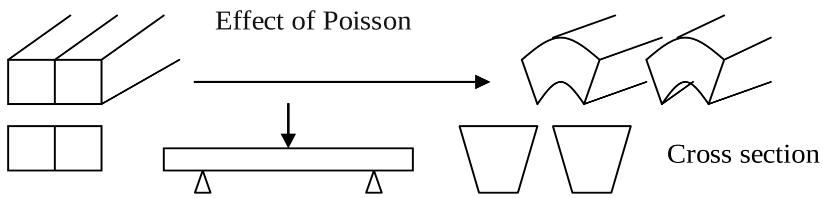

Figure 2. Passive deformation of lamination 2 sample.

English alphabet is treatment groups. Here, A and B groups are different, but these are the same with the AB group.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) indicates that the layers arrangement had effect on modulus of rupture of laminated samples, but results of multiple Duncan's test for MOR and for MOE were significant at 95% confidence level (Table 1). Values of MOE and MOR of samples having different layer arrangements are given in Table 1. Control samples have higher MOE and MOR than laminated products. Using layer as a constitution for the products decreased bending properties. The reduction is more obvious in terms of MOR. MOR and MOE measurements proved that side to side joint along with thick layer have sever effects on bending properties of the final products. Table 1 shows that the highest bending strength properties (MOR) was determined in control samples and then samples laminated with three layers (lamination 4), the lowest value was observed in samples bonded with slab having four layers and jointed side by side (lamination 2). The difference between groups regarding the Poisson ratio (µ coefficient) of side by side joint (lamination 2) on MOR is significant at 5% level. Among samples made of layers, the highest value was obtained in samples laminated with thin layers (laminations 4 and 3). The effect of Poisson (µ coefficient) on the specimens can be seen in Figure 2. Presence of local stress concentration leads to the initiation of failure at the joint base and, as a consequence, a lower strength is obtained. The effects of local stress concentration or the effect of Poisson (µ coefficient) on the specimens and joint configuration on the bending properties were invested and proved in literature reviews (Bohnhoff et al., 1998; Custdio et al., 2009; Pena, 1999). Failure was mostly initiated in the glue line of the specimen, that is, at the side by side-joint location. Samples had a deformation as can be seen in Figure 2. It was observed that the highest MOR (7999 MPa) and MOE (75 MPa) were obtained in control samples (solid wood) and then samples made of three-ply (lamination 4). The sample of three-ply has more MOE (6968 MPa) and MOR (62 MPa) than laminated samples (Table 1). The combinations of layer arrangement were shown in Figure 1.

Comparison testing at the 0.05 level showed that there was no significant difference between the bending properties values of samples with two and three layers. Literature review shows that increase in layer number in LVL did not affect the bending strength (Ozcifci, 2007) and average MOE at beam was not affected by number of laminations (Wolfe and Moody, 1979).

Conclusions

The information is gathered by determining bending properties of the products having different layer arrangements. The results of this study clearly demonstrate that layer arrangements play important roles in determining bending properties of laminated wood products. Control samples (sawn lumber) displayed the highest MOR and MOE and samples made of layers had inferior bending properties over sawn lumber. Using layers as constitutes for fabrication of lumber lowered much more MOR than MOE. Samples with short and thick layers had the lowest MOR and MOE. In order to improve bending properties and minimize the adverse effect of laminated wood lumber, long and thin layers should be used. Results of this study revealed an increase layer thickness adversely affect MOR and MOE of the final products. The results of this research can be very useful in realizing the potential usage of hardwoods, namely: poplar in laminated products.

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