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ORIGINAL ARTICLE

Effects of layer lengths and arrangements on bending strength properties (MOE and MOR) of laminated lumber made of *Pinus sylvestris*

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ABSTRACT
Glued laminated lumber (Glulam) is one of the most widely used engineered wood products in structural applications. Glulam is made by joining individual pieces of lumber with different length/arrangement and laminated together with industrial adhesives under pressure to form large lumber elements. In this study, the effects of layer length and arrangement on bending properties of Glulam have been investigated. For construction of laminated lumbers, Pinus sylvestris *and EPI (emulsion polymer isocyanate) / PVA (polyvinyl acetate) were used as wood and adhesives respectively. Bending properties (MOE and MOR) of laminated products comprising various combinations of layer arrangements and adhesives in 16 combinations (8 arrangements and 2 adhesives) were measured. The results of this study showed that addition of layer as constitution for laminated lumber lead to lower bending properties. Using shorter layers reduced the MOE and MOR of the products. Finally, the proper layer arrangements should be selected with respect to their final application in the production of laminated products.*
Keywords: *Glulam, MOE, MOR,* Pinus sylvestris

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INTRODUCTION

Wood is one of the oldest and naturally renewable construction materials, used for many purposes such as bridges, poles, electric and telephone lines and many other uses. Because of its beauty, strength and ease of handling and assembly, wood has long been in demand as an important building material. However, the shrinking supply of harvestable trees has led to using engineered/composite wood products.

Glued laminated lumber (Glulam) is one of the most widely used engineered wood products in structural applications. Glulam is defined in ASTM D3737 standard method for establishing stresses for structural glued-laminated lumber (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".

Glulam is made by joining individual pieces of lumber, laminated together with industrial adhesives under pressure to form large lumber elements. 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. With The introduction of Glulam in construction industry, it is possible to use smaller wood members with lower grades of wood to be substituted for larger members made completely of wood. However, the ability to utilize laminated wood members for massive structural applications is often limited by their relatively low bending strength and stiffness. The main objective of this study is to establish technical information regarding the use of *Pinus sylvestris* in laminated wood products. The information is gathered by determining bending properties (MOE and MOR) of the products having different layer length, arrangements and adhesive (EPI/PVA). The results of this research can be very useful in realizing the potential usage of Glue Laminated products.

MATERIALS AND METHODS

For construction of laminated lumbers, Pinus sylvestris were used as wood. 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/m3, respectively.
A commercial EPI and PVA adhesives were supplied by a company located in Tehran, Iran. Variables are specimens that its layers length and arrangements were shown in Figure 1. In each layer the, specimens were attached using Farsi joints. The combinations of layer length and arrangement in laminated lumber were as follow (Table 1):

Table1: combination of layer lengths and arrangements in laminated lumber

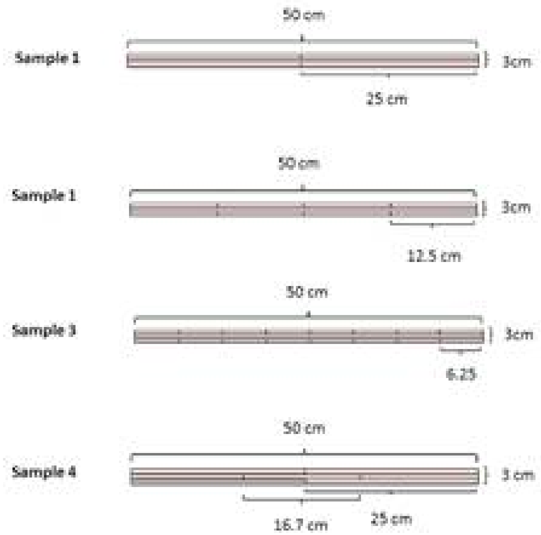
Sample number	Upper layer (cm)	Middle layer (cm)	Lower layer (cm)
1	25 - 25	50	25 – 25
2	12.5 - 12.5- 12.5- 12.5	50	12.5 - 12.5- 12.5- 12.5
3	6.25-6.25-6.25-6.25-6.25-6.25	50	6.25-6.25-6.25-6.25-6.25-6.25
4	25- 25	16.7 – 16.7 – 16.7	25- 25
5	12.5 - 12.5- 12.5- 12.5	16.7 – 16.7 – 16.7	12.5 - 12.5- 12.5- 12.5
6	6.25-6.25-6.25-6.25-6.25-6.25	16.7 – 16.7 – 16.7	6.25-6.25-6.25-6.25-6.25-6.25
7	50	16.7 – 16.7 – 16.7	50
8	50	50	50

The adhesive was applied by brush on one side of the joints. The applied pressure was accomplished with manually operated press and lasted for 24 h. The bending properties of the specimens were determined according to the ASTM D198-D4761-96 standard. The modulus of elasticity (MOE) and modulus of rupture (MOR) of samples were calculated by the following formulas [1].

$$MOE = \frac{P_{pl} l^3}{4\delta_{pl} bh^3}$$

$$MOR = \frac{3P_u l}{2bh^2}$$

Where P_{pl} (N) is the loading in the proportional limit region, δ_{pl} (mm) is the deflection with respect to Pp_l, 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 two-way analysis of variance (ANOVA) from SPSS was performed on the data to test for significant differences. The difference in MOE or MOR between the different types of samples was significant at 95% confidence level.



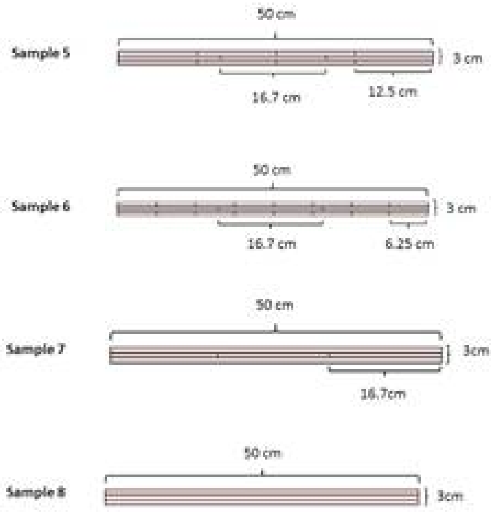


Fig1. Combination of lengths and arrangement of laminated lumber

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) indicated that the layers arrangement had effect on MOE and MOR of samples. The results are presented in Table 2 and Table 3.

Table 2: comparison of MOE in samples

MOE					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**f**	**Sig.**
Corrected Model	170413491.667[a]	15	11360899.444	8.183	.000
Intercept	2326254840.333	1	2326254840.333	1675.483	.000
Layer lengths and arrangements	129247322.333	7	18463903.190	13.299	.000
Type of Glue	5254956.750	1	5254956.750	3.785	.061
Layer lengths and arrangements/Glue	35911212.583	7	5130173.226	3.695	.005
Error	44429078.000	32	1388408.687		
Total	2541097410.000	48			
Corrected Total	214842569.667	47			

Table 3: comparison of MOR in samples

MOR					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**f**	**Sig.**
Corrected Model	30221.338a	15	2014.756	41.450	.000
Intercept	119111.650	1	119111.650	2450.506	.000
Layer lengths and arrangements	29456.332	7	4208.047	86.573	.000
Type of Glue	264.422	1	264.422	5.440	.026
Layer lengths and arrangements/Glue	500.583	7	71.512	1.471	.213
Error	1555.423	32	48.607		
Total	150888.411	48			
Corrected Total	31776.761	47			

The results of this study showed that, Control samples have higher MOE and MOR than laminated products. Using layer as a constitution for the products decreased bending properties. The highest bending strength properties (MOR) was determined in samples 8 and 7 respectively.

It is observed that the highest MOE (10475 MPa) and MOR (102 MPa) were obtained in Sample 8 with PVA adhesive. In the second place, Sample 7 with the MOE (9304 MPa) and MOR (87 MPa) and PVA adhesive were placed (Fig. 2). 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 [2].

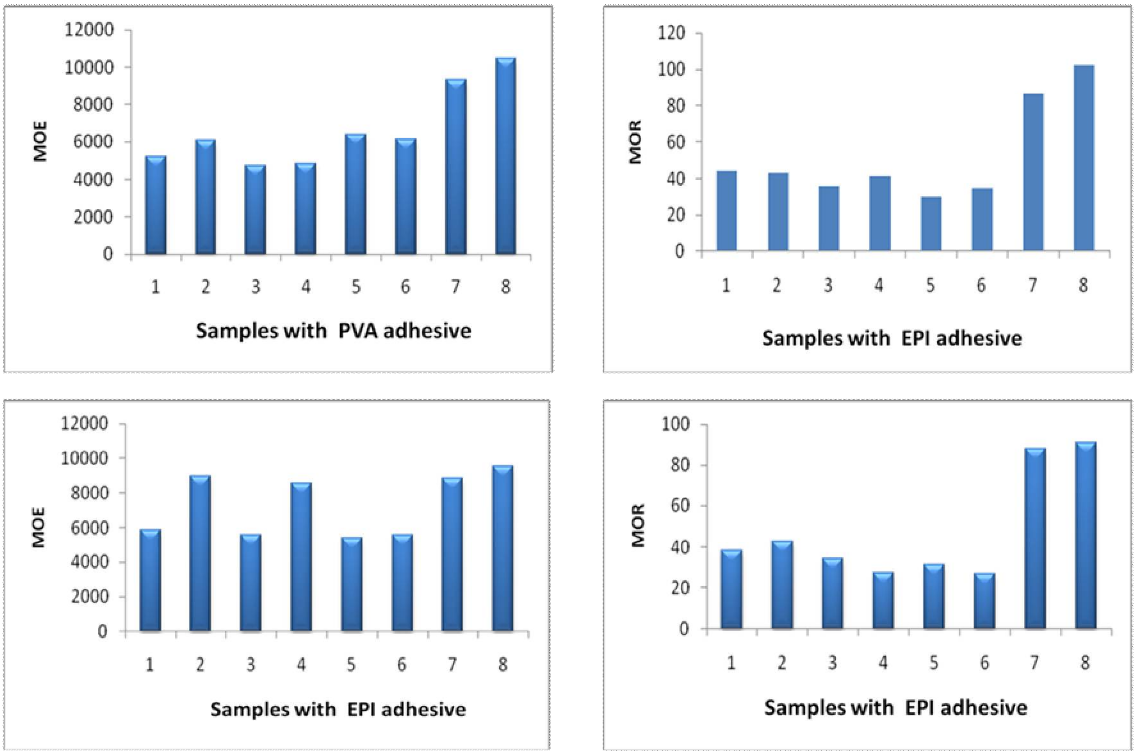


Fig 2: comparison of MOE and MOR between samples

CONCLUSIONS

The information is gathered by determining bending properties of the products having different layer arrangements. Among the different combination of layer lengths and arrangements, the one which demonstrated the highest bending strength (MOE and MOR) was undoubtedly the sample 7 and 8, in which a single pair of outer lamination is used.

The results of this study clearly demonstrate that layer arrangements play important roles in determining bending properties of laminated wood products. The samples with minimum layer specimens (Sample 8 and 7) displayed the highest MOR and MOE and samples made of multi specimens had inferior bending properties. Using layers as constitutes for fabrication of lumber lowered much more MOR than MOE. Samples with short layers had the lowest MOR and MOE. In order to improve bending properties and minimize the adverse effect of laminated wood lumber, long layers should be used. The results of this study were in accordance with the results of Bayatkashkoli [3]. In his study, the effect of layer arrangements on bending strength properties of laminated lumber made of poplar were examined. They found that using layers decreased MOR more than MOE.

The results of this research can be very useful in realizing the potential usage of Glulam in construction industry.

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