REINFORCED GLULAM BEAMS USING SELECTED AND QUALITY SORTED WOOD LAMELLA

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ABSTRACT

THE MANUFACTURING PROCESS OF GLUE LAMINATED TIMBER PRESCRIBES THE DETERMINATION OF WOOD LAMELLA STRENGTH CLASS BEFORE GLUING. THIS OPERATION TAKES PLACE IN GRADING MACHINES INTEGRATED IN THE FABRICATION TECHNOLOGY. STRESS GRADING MACHINES DETERMINE THE STRENGTH CLASS IN FUNCTION OF WOOD SPECIES, DENSITY AND MODULUS OF ELASTICITY IN BENDING OF THE MEASURED LAMELLA.

HOWEVER, THIS METHOD IS NOT RECOMMENDED FOR LABORATORY SCALE EXPERIMENTS OR IN CASES WHERE THE SPECIMEN NUMBER IS REDUCED. THE REASON OF METHOD REJECTION LAYS IN THE HIGH PRICE AND THE UNEXPLOITED CAPACITY OF THE EQUIPMENT.

THE PRESENT STUDY INTRODUCES THE NON-DESTRUCTIVE METHOD TO CLASSIFY THE WOOD LAMELLA USING THE PLG (PORTABLE LUMBER GRADER) DEVICE DEVELOPED IN THE FACULTY OF WOOD SCIENCES FROM SOPRON. THE MEASURED VALUES ARE COMPARED THEREAFTER WITH THE RESULTS OBTAINED BY DESTRUCTIVE METHOD.

KEYWORDS: LAMELLA, STRESS GRADING, NON-DESTRUCTIVE METHOD, REINFORCED GLULAM, BENDING.

INTRODUCTION

Glue laminated timber or the so called glulam is a beam type structural product produced by gluing together parallel oriented and finger jointed wood lamellas with similar width and thickness. Glulam is mostly used for long span applications such as residential, industrial or farm structures, sport arenas, swimming pools, etc. They are made of lamellas of the same thickness, joined the length, width and thickness by gluing.

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The most important characteristics of glulam are as follows :

- parallel orientation of the lamellas with the main axis of the beam;
- horizontal or rarely vertical orientation of the component lamellas;
- straight, tapered, plain or spaced curved shape of the beam with uniform or variable cross section;
- provide the utilization of low quality or small dimensional lumber, makes possible the uniform distribution of solid wood defects;
- the structure of these beams can integrate lamellas with different quality;
- the most stressed zones (faces) are made of superior quality lamellas without any defect, in the less stressed zone (core) low quality lamellas are placed.

Major advantage of the glulam structures lays in their high strength and stiffness providing increased loadbearing capacity and permits the utilization for high span applications[2].

According to the standards and dimensioning rules the quality class determination of lamellas is mandatory during the manufacturing process assuring the designed strength of the final product, glulam. Beside the afore mentioned restriction by the designed placement of lamellas with different quality classes the superior utilization of wood is realized (non-homogenous structures).

The European norms, namely Eurocode 5 introduces tables with strength quality classes of the glulam's in function of application fields. According to these two main categories are distinguished: H – with homogenous structure and C – non-homogenous structure, both with 5 quality classes.

In the manufacturing process, the stress grading machine is located just before the trimming operation and measures the force-displacement values obtained by bending. Having known the geometry, wood species and density of the boards the stiffness can be easily determined.

Because of the reduced number of reinforced laminated specimens[3] the strength class was determined using a non-destructive method, i.e. the longitudinal vibration method.

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[2] Moțoc, GLULAM - Technical guide, 4.

[3] Issa and Khmeid, Advanced wood eng., 101.

OBJECTIVES

In the present study sought to determine the strength class of wood lamella to be embedded in the beams. Nondestructive method with Portal Lumber Grader (PLG)[4] is based on longitudinal wave propagation in solid elements.

The main objective is the design of structures for symmetric laminated beams, reinforced and unreinforced so that the samples arranged in cross section to be constructed similarly sized for each beam. This may make a comparison of the results more accurate, in that test pieces are constructed using symmetrical lamella of the same strength class. Differences in resistance of the lamella will be eliminated or minimized hub and capacity reinforcement material embedded in the structure for much more precise.

The method is applicable as a glued beams compared to results from tests in bending - modulus of elasticity - the results can be compared with data by non-destructive analysis of beams.

MATERIALS AND METHODS

For modulus of elasticity (MOE) determination of specimens we used the vibration method. The elastic modulus characterizes the material tendency to be deformed elastically when a force is applied to it. This value is a key parameter in the case of structure dimensioning for bending based on Eurocode 5 (for example: roof structure)[5]. Modulus of elasticity correlates well with bending strength; therefore it can be used for strength quality class determination.

Theory of elastic vibration propagation in long beams

In the case of elastic vibration propagation elastic connections between volumetric parts of material plays an important role[6]. The propagation speed of elastic vibration in long beams it can be easily determined by dynamics laws. A beam with length l cross section $\boldsymbol{A}$, density $\boldsymbol{\rho}$, modulus of elasticity $\boldsymbol{MOE}$ is loaded with a force $\boldsymbol{F}$ parallel with the main axis at one of the ends for a short time $\boldsymbol{\tau}$ (for example hammering). This shock compress the material and induce a longitudinal wave with the speed c and after the time $\boldsymbol{\tau}$

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[4] Portable lumber grader, 2.

[5] Porteous and Kermani, Structural timber design, 12.

[6] Divós, Non-Destructive wood analisys, 5-6.

reaches distance ***l* = *c**τ**; When the beam length is equal with ***l***, at the time ***t* = *τ*** the opposite end of the beam displaces with ***Δl*** and the first end return in the relaxed position. At the time ***t* = *2*τ*** the first end displaces with the distance ***Δl*** because of the wave reflection.

According to the Hooks low:

$$\Delta l = \frac{l*F}{MOE*A}\ [\text{mm}] \quad \text{or} \qquad F = MOE*\frac{\Delta l}{l}*A\ [\text{N}] \tag{1}$$

where: Δ*l* – displacement after hit, in [mm];

l – sample lenght, in [mm];

MOE – modulus of elasticity, in [MPa];

A – cross sectional area, in [mm^2];

F – sample action force, in [N].

As a result of the force ***Fτ*** action each segment of the cross section will shift with the speed of ***v* = *Δl* / *τ***. In conclusion the whole mass moves ***m* = *ρAcτ***. After the law of impulse displacement:

$$F\tau = m*v = \rho*A*c*\tau*\frac{\Delta l}{\tau} \tag{2}$$

where: *ρ* – material density, in [kg/m^3] ;

c – velocity of wave propagation, in [m/sec];

τ – time of F force action, in [sec].

Substituting ***F*** with the previous relation and after simplification we obtain the sound velocity:

$$c = \sqrt{\frac{MOE}{\rho}}\ [\text{m/sec}] \tag{3}$$

It is very important to underline that the above relation is valid just for long beams and longitudinal vibrations. In the case of large dimensions and other directions than parallel, the vibration propagation speed differs in function of direction:

$$c_{long} = \sqrt{\frac{MOE}{\rho} * \frac{1-\mu}{(1+\mu)*(1-2\mu)}} \text{ [m/sec]} \tag{4}$$

$$c_{trans} = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{MOE}{\rho} * \frac{1}{2*(1+\mu)}} \text{ [m/sec]} \tag{5}$$

Where: μ – Poisson’s ratio;

G – modulus of rigidity, in [MPa].

In this case the vibration propagation speed will be determined from the frequency of the longitudinal vibration using the following equation:

$$c = 2*l*f \text{ [m/sec]} \tag{6}$$

Where: l – beam length, in [mm];

f – the longitudinal vibration frequency, in [Hz].

Using the sound speed relation we have:

$$MOE = \rho * c^2 = 4*l^2*f^2*\rho \tag{7}$$

In PLG user guide, specific gravity is determined by the following term:

$$\rho = \frac{m}{l*b*h*(1+\frac{u}{100})} \text{ [kg/m}^3\text{]} \tag{8}$$

Where: ρ – specific density, in [kg/m^3];

l – element lenght, in [mm];

b – element width, in [mm];

h – element height, in [mm];

u – moisture difference, in [%].

The EN-338 norm is dealing with static ***MOE***. The Portable Lumber Grader software determine the dynamic ***MOE*** first then apply a correction factor to calculate the static ***MOE***. The following term defines the $\boldsymbol{MOE_{static}}$:

$$\mathrm{MOE}_{\mathrm{static}} = \frac{m}{l*b*h} * (2*l*f)^2 * 0{,}92 * (1+\frac{U}{50}) \ [\mathrm{MPa}] \qquad (9)$$

In this case, ***U*** represent moisture difference between sample moisture content (measured) and beam element moisture content in use, for different use conditions, that will be make by these samples. Because we designed this beams for open building, but covered, moisture content in use is: $U_{use} = 15 \pm 3\%$ [7]. For example, when we have sample moisture content 10%, U will be: 15 – 10 = 5%.

Principle of measurement

Using the method of determination is shown in the (fig. no. 1):

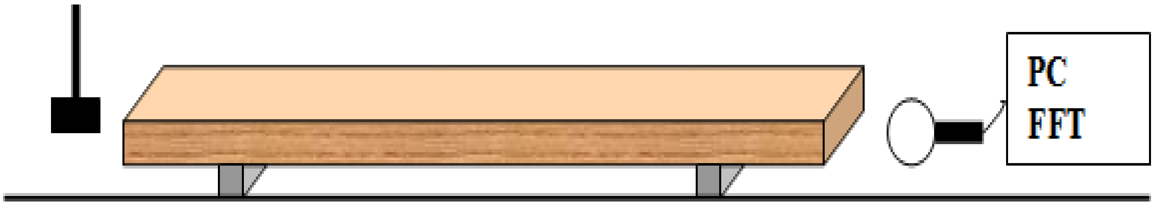

Fig. 1: The principle of samples measure

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[7] Götz et al, Construire en bois, 26.

Specimen being tested is resting on a scale, with contacts of polyurethane foam (sponge) to eliminate transmission of vibration. End of the bar is hit with a small hammer in the longitudinal direction. At the other end there is a microphone that receives sound propagated. Apply a low hit, so it does not cause displacement of the specimen at supports.

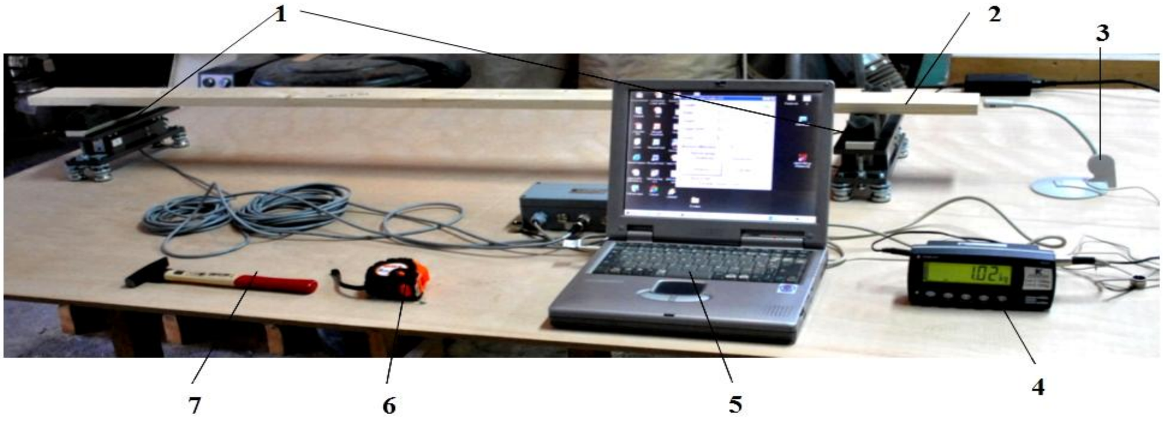

Fig. 2: Test equipment: 1 – balance; 2 – sample; 3 – microfon; 4 – balance control equipement; 5 – computer; 6 – measure tape; 7 – hummer

The material

The material tested is represented by a stock wood stock, in spruce species (Picea Abies), previously dried at U=12±3%, processed to final dimensions: L=1640±20mm, l=76mm, g=18mm.

RESULTS

There were two sets of specimens analyzed as a total of 176 lamellas processed to final size in advance. The standard error of strength estimation by PLG is 8.0 MPa[8]. The measurement data were grouped in sets of 10 rows of data, an example is given in (Table no. 1):

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[8] Divós and Sismándy, Strength grading..., 7.

Table 1: Data set obtain for Ist serie of lamellas *(cross section lamellas dimension: b = 76 mm, h = 18 mm)*

Serie I	Density	Mass	Lenght	Velocity	Frequency	MOE$_{static}$	Grading class
Sample no.	(kg/m3)	(kg)	(mm)	(m/s)	(hz)	(MPa)	-
1	454,6	1,02	1640	4844	1476	10491	C22
2	436,8	0,98	1640	5293	1613	10937	C22
3	436,8	0,98	1640	4307	1313	8290	C16
4	358,1	0,80	1633	4624	1416	8114	C16
5	520,2	1,16	1630	4572	1402	10479	C22
6	439,5	0,98	1630	4791	1469	9886	C20
7	412,6	0,92	1630	4474	1372	7898	C14
8	412,6	0,92	1630	4481	1373	7834	C14
9	395,9	0,88	1625	4880	1501	8876	C16
10	401,2	0,90	1640	5050	1539	9913	C20

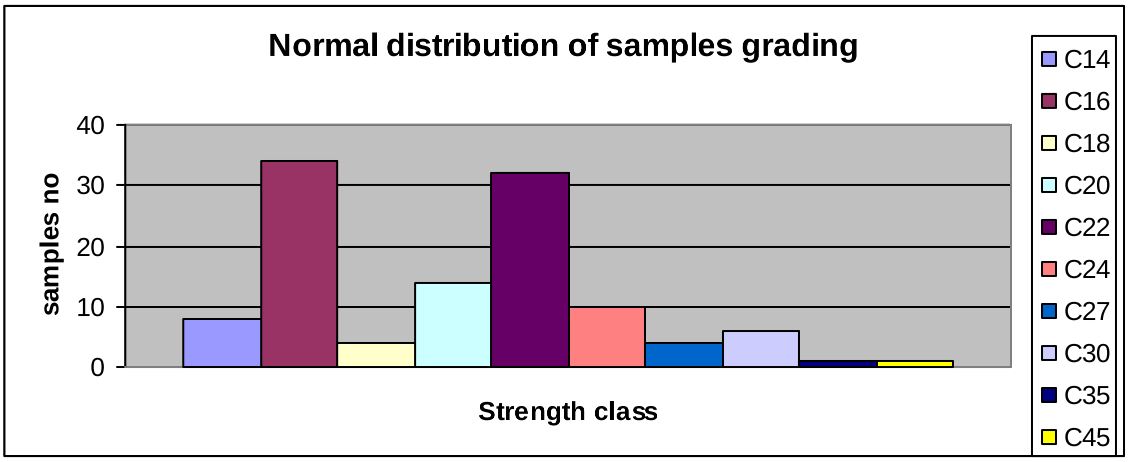

Fig. 3: Normal distribution of samples

In (fig. no. 3) reveals that most lamellas are between classes C16 and C24 and the most representative of the C16 and C22, including more than 50% of all sample analyzed.

Following results were laminated beams designed structures, presented in (Table no. 3), so that from lots of beams which will be compared to no significant differences on the quality of lamellas, such differences will appear only due to the reinforcing material embedded in beam structure. On the other hand, knowing the features of each blade resistance were constructed finite element models for comparison.

Table 3*: *Lamella characteristics in glulam structures

		lamella code	Density	Humidity	Length	MOE	Grading class
Beam notation		-	(kg/m3)	%	(mm)	(MPa)	-
Unreinforced, horizontally laminated beams	FO1	I 1	454,6	11,0	1640	10699	C22
		I 9	386,9	13,5	1625	8133	C16
		II 3	439,5	13,2	1630	8894	C16
		I 5	520,2	12,5	1630	10160	C22
	FO2	III 3	471,9	12,0	1642	10100	C22
		II 10	420,3	14,7	1635	8973	C16
		III 4	433,2	11,5	1620	8909	C16
		IV 6	515,8	13,0	1644	10176	C22
	FO3	V 6	458,8	11,9	1625	10353	C22
		III 10	518,3	13,6	1636	8904	C16

		IV 9	436,8	13,2	1640	8202	C16
		V 7	410,6	12,5	1638	10082	C22
	FO4	VIII 8	404,9	12,5	1625	10510	C22
		VI 2	422,1	13,2	1628	8233	C16
		VI 3	421,6	13,2	1630	8396	C16
		X 1	472,5	12,5	1640	10101	C22
	FO5	X 10	411,3	12	1635	11862	C27
		VII 5	448,5	10,8	1630	8964	C16
		VII 6	422,3	13,7	1627	8428	C16
		XI 6	429,2	12,5	1635	11813	C27

		lamella code	Density	Humidity	Length	MOE	Grading class
Jute reinforced, horizontally laminated beams	JO1	II 8	413	11,0	1630	10699	C22
		II 4	422	13,5	1630	8133	C16
		II 5	431	13,2	1630	8894	C16
		II 9	492	12,5	1633	10160	C22
		IV 8	460	12,0	1620	10100	C22
		III 6	422	14,7	163	8973	C16

	JO2				0		
		III 8	499	11,5	1640	8909	C16
		IV 10	457	13,0	1630	10176	C22
	JO3	VII 8	412	11,9	1633	10353	C22
		V 5	475	13,6	1630	8904	C16
		V 8	385	13,2	1632	8202	C16
		VIII 7	414	12,5	1623	10082	C22
	JO4	X 6	447	12,5	1636	10510	C22
		VI 7	466	13,2	1630	8233	C16
		VI 8	465	13,2	1635	8396	C16
		X 9	441	12,5	1626	10101	C22
	JO5	IV 5	466	12	1630	11862	C27
		VIII 6	421	10,8	1633	8964	C16
		VIII 9	430	13,7	1632	8428	C16
		IV 4	439	12,5	1633	11813	C27

The beams with jute fiber reinforcement were prepared in a similar way, the lamellas were oriented horizontally. The measured modulus of elasticity was compared thereafter with the non-reinforced beam values. 75 fibers of jute was utilized as reinforcement material, distributed uniformly in gluline no 1 and 3, like (fig. no. 4):

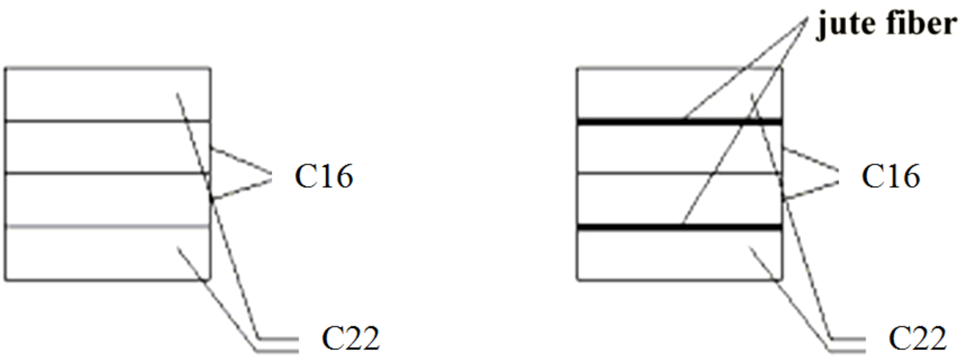

Fig. 4: Lamella position in horizontally glulam beams

For the beams with lamellas oriented vertical C24 strength class for faces and C14 in core was used both for the reinforced or unreinforced beams. Five specimens were prepared for each beam type (unreinforced and reinforced with jute) and for two directions: horizontally and vertically.

In (fig. no. 5) we have presented an comparative diagram with failure data of 4 point bending test. After data analising we have 15% a strenght difference on jute reinforced beam in comparision with unreinforced beam.

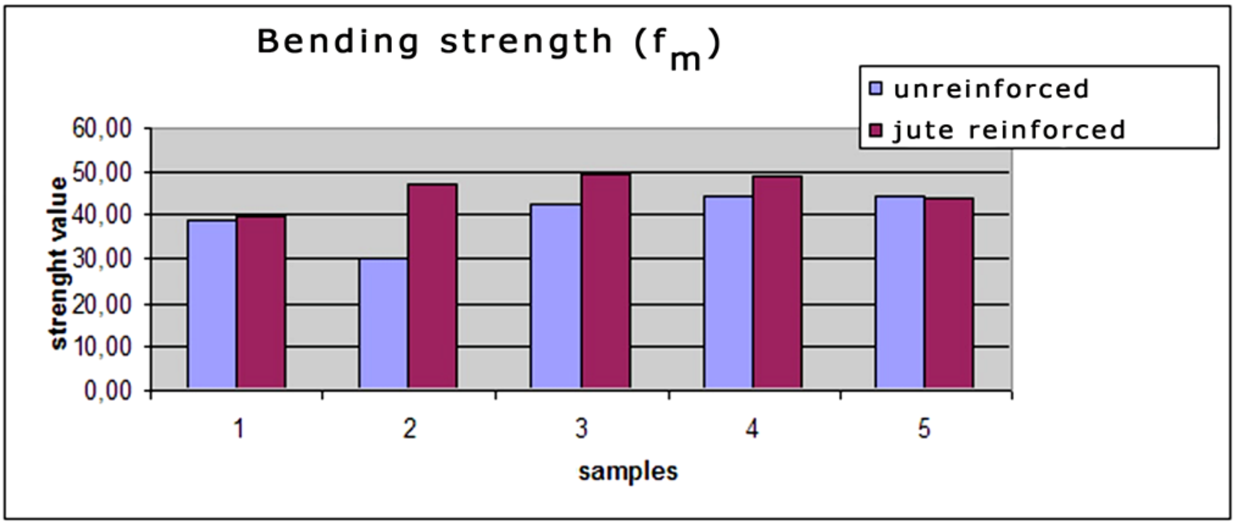

Fig. 5: Bending strenght, horizontally laminated beam

CONCLUSIONS

According to the results we can state that the non-destructive method used in this study is able to classify the embedded lamella’s quality class and makes possible to design of beam structures with planned properties. Taking into account the higher accuracy of the model the reinforcing effect of jute fibers is more comparable.

The method can be utilized to determine the elastic properties of the beams and for the comparison of static and dynamic data.

Because of its usefulness, this method is planned to be used for lamella classification, reinforcement effect of different materials such as striated metallic bands, fiberglass and carbon fiber.

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