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EVALUATION OF THE WOOD STRENGTH CLASS USING THE EXPERIMENTAL APPROACH

BY

ION FLORENȚA*, NICOLAE ȚĂRANU, ALEXANDRU SECU, IOANA-SORINA ENȚUC, MARIA-CRISTINA SCUTARU and DRAGOȘ UNGUREANU

“Gheorghe Asachi” Technical University of Iași,
Faculty of Civil Engineering and Building Services

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Abstract. The physical and the mechanical properties of wood as building material are the key parameters for the design of timber structures. Also, based on these parameters the wood products may be classified into several strength classes.

This paper presents the outcomes of an experimental program that focuses on the properties of wood required for the design of structural timber construction members. Thus, 40 wood specimens were prepared according to the current standard requirements and tested for tensile, compression and static bending. Also, using the results of the static bending tests, the global modulus of elasticity in bending was computed. Finally, the strength class of the wood specimens was determined.

Keywords: wood specimens; experimental tests; design properties; strength classes; global modulus of elasticity.

1. Introduction

Wood is an anisotropic and non-homogeneous material with different mechanical properties in each of its three main directions. The principal

*Corresponding author: *e-mail:* florenta.john@yahoo.com

directions of wood are defined by three main axes (Fig. 1), as follows: the longitudinal axis (parallel to the direction of the fibres), the radial axis (perpendicular to the direction of the fibres and normal to the growth rings) and the tangential axis (perpendicular to the direction of the fibres and tangent to the growth rings), respectively (Kretschmann, 2010; Isopescu & Stănilă, 2014).

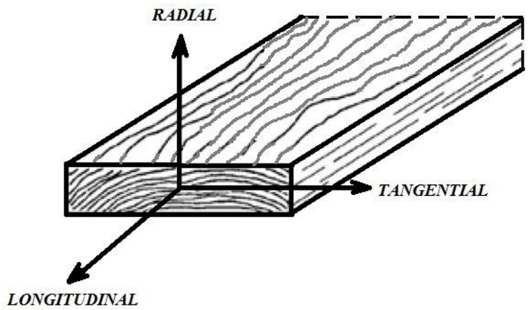


Fig. 1 − Principal directions of timber elements (Kretschmann, 2010).

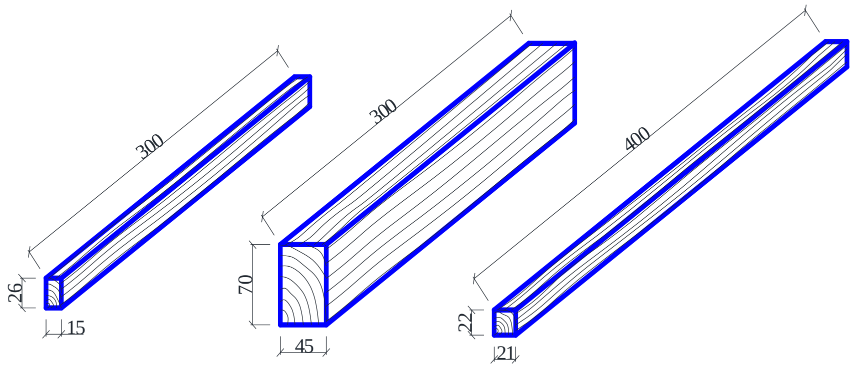
The mechanical properties of wood are influenced by a set of specific factors which include: the type of the wood species, the volumetric mass, the moisture content, the degree of the structural defects and the loading direction. These factors can be described and characterised by experimental programs conducted on standardized wood specimens (Ciornei, 2008; Furdui, 2005; Marusciac, 1997).

The European Standard EN 338 "Wood structural elements – Strength classes" establishes a system of strength classes for general use in structural codes; it also provides the characteristic strength and stiffness properties as well as the density values for each strength class and the rules and the regulations for the assessment of the timber populations (*i.e.* combination of species, source and grade) to the classes (Isopescu *et al*., 2012).

The experimental program presented in this paper was developed at the Faculty of Civil Engineering and Building Services from Iasi, and it was focused on the evaluation of the structural response of wood specimens loaded in tension, compression and axial bending, respectively. Based on the determined experimental results and on the provisions of the norm EN 338, the strength class of the wood specimens was determined.

2. Experimental Set-Up

The specimens were prepared from spruce wood. The pine spruce is a soft wood, widely used for construction applications. The geometries of the specimens (Fig. 2) were chosen according to the specifications of the norm EN 408: 2004.



a *b* *c*

Fig. 2 – Specimens geometric configurations for: *a* – tensile (parallel to grain) test; *b* – compression (parallel to grain) test; *c* – static bending test.

The geometric features and the dimension limit system were checked by measuring each specimen with a digital vernier calliper, (Fig. 3 *b*), and by weighing. The moisture content was determined using a LG 43 - pin type moisture meter for wood (Fig. 3 *c*). During the experimental tests, the room temperature was 21°C and the relative air humidity was 58 % (EN 408: 2004; Isopescu & Stănilă, 2014; Isopescu *et al.*, 2012).

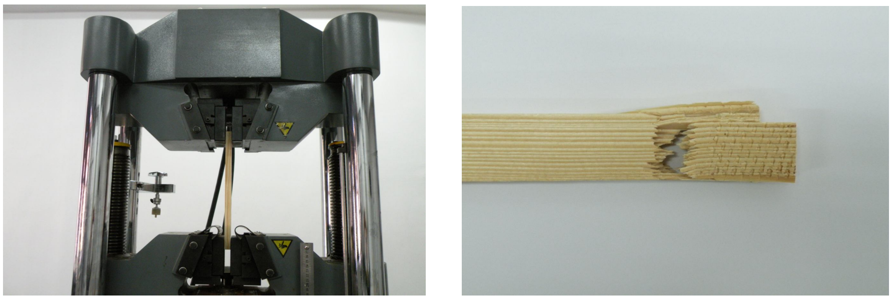
The specimens were loaded in tension, compression and simple bending using a WAW-600E hydraulic test machine (Fig. 3 *a*), from the structural laboratory of the Faculty of Civil Engineering and Building Services from Ia□i.

a *b* *c*

Fig. 3 – Testing equipment: *a* – WAW-600E hydraulic test machine; *b* – digital calliper; *c* – LG 43-pin moisture meter.

The tensile test (Fig. 4) was performed according to the norm EN 408: 2004. Thus, 15 prismatic (Fig. 2 *a*) specimens with the nominal dimensions of: b = 15 mm, h = 26 mm and l = 300 mm had been prepared (Isopescu & Stănilă, 2014).

The tensile test was force controlled, with a 0.026 kN/s loading speed (EN 408: 2004). The failure of the specimens has occurred abruptly, without the development of plastic deformations. The average duration of a tensile test was 293 s, and in most of the cases, the failure occurred in the close vicinity of the clamping jaws (Fig. 4 *b*).

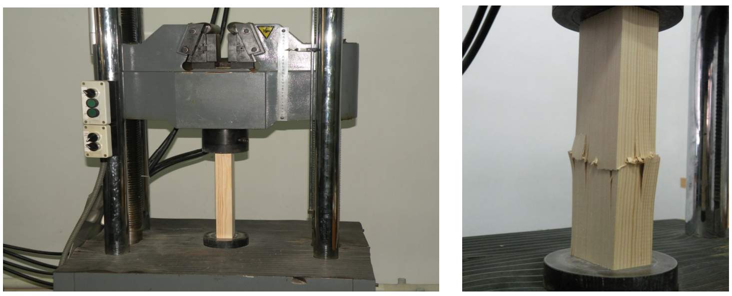


a *b*

Fig. 4 – Tensile parallel to grain test: *a* – arrangement of specimen; *b* – principal failure mode.

The compression test (Fig. 5) was performed according to the norm EN 408: 2004. Thus, 15 prismatic specimens (Fig. 2 *b*) with the nominal dimensions of: b = 45 mm, h = 70 mm and l = 300 mm were prepared and tested.

The compression test was force controlled, with a 0.026 kN/s loading speed. For most of the cases, the failure of the specimens occurred by the lateral buckling and the local rupture of the wood fibres, Fig. 5. The average duration of a compression test was 331 s.



a *b*

Fig. 5 – Compression parallel to grain test: *a* – arrangement of specimen; *b* – principal failure mode.

The static bending test (Figs. 6 and 7) was performed according to the norm EN 408: 2004. Thus, 10 specimens with the cross-section of 21 mm × 22 mm ($b \times h$) and 400 mm in length had been prepared. The specimens were loaded in bending (Fig. 6) by the action of two concentrated forces applied symmetrically to the centre and the ends of the specimens.

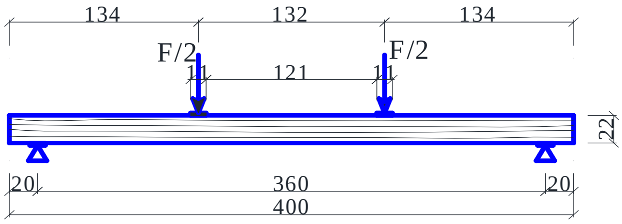
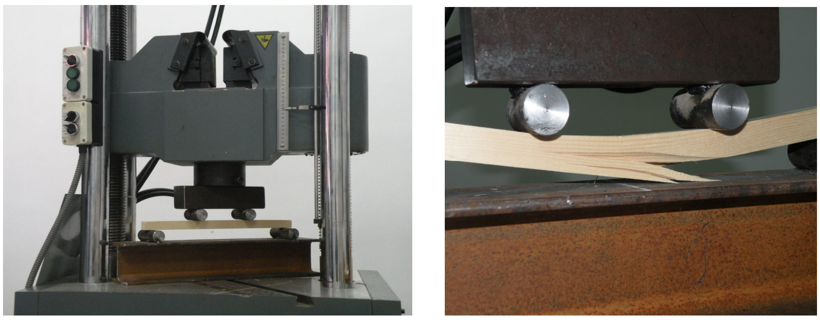


Fig. 6 – Loading system for simple bending test.

The concentrated forces were applied at a loading rate of 0.008 kN/s. The average duration of a bending test was 338 s. For most of the cases, the specimens failed by fibre rupture in the tension area (Fig. 7 *b*).



a *b*

Fig. 7 – Static bending test: *a* – arrangement of specimen; *b* – principal failure mode.

3. Results and Discussion

3.1. Experimental Results

The results obtained through the experimental tests are shown in Tables 1, 2 and 3, respectively. The experimental results were normalized considering the characteristic values for 12% moisture content provided by the norm EN 384: 2004. Thus, for each percent in difference between the 12% moisture content and the specimen recorded moisture, the compression strength was diminished with 3%. According to norm EN 384, for the tensile and the bending tests, the normalization of the results is not required (EN 384: 2004).

The second normalization of the experimental results was performed according to the norm ISO 3129: 2012 and consists in the statistical processing. The parameters that are used for the statistical analysis are described by Eqs. 1 and 2 (ISO 3129: 2012).

$$s_r = \frac{s}{\sqrt{n}} \tag{1}$$

where : s_r is the standard deviation of the arithmetic mean, s – the standard deviation and n – the number of individual values

$$s = \sqrt{\frac{\sum (x_i - \overline{X})^2}{(n-1)}} \tag{2}$$

where: x_i is the individual value of the specific observation "i" and $\overline{X}$ is the arithmetic mean of the observations.

According to the statistical analysis, the *real* (final) value of the x_i property is computed using:

$$x_{i,\text{final}} = x_{i,12} \pm s_r \tag{3}$$

where: $x_{i,12}$ is the individual value of the specific observation i for 12% moisture content.

Table 1

Tensile Strength Parallel to Grain Test Data

No. of specimens	b [mm]	h [mm]	L [mm]	m [kg]	ρ_{rel} [kg/m^3]	ω [%]	F_{max} [kN]	A [mm^2]	$f_{t,0}$ [N/mm^2]	$f_{t,0,12}$ [N/mm^2]	s_r	Real value $f_{t,0,12}$ [N/mm^2]
1	14.43	25.06	300	0.053	488.55	5.7	8.13	361.62	22.48	22.48	1.28	23.76
2	14.52	25.28	300	0.053	481.29	5.9	12.15	367.07	33.10	33.10		31.82
3	14.66	25.31	300	0.057	512.07	5.5	8.19	371.04	22.07	22.07		23.35
4	14.61	25.47	300	0.055	492.68	5.7	7.09	372.12	19.05	19.05		20.33
5	14.72	25.18	300	0.052	467.65	5.3	7.63	370.65	20.59	20.59		21.87
6	14.51	24.98	300	0.058	533.39	5.5	7.90	362.46	21.80	21.80		23.08
7	14.45	25.09	300	0.054	496.48	5.5	9.39	362.55	25.90	25.90		24.62
8	14.66	24.92	300	0.058	529.21	5.3	9.89	365.33	27.07	27.07		25.79
9	14.59	25.01	300	0.053	484.16	5.7	12.49	364.90	34.23	34.23		32.95
10	14.69	25.18	300	0.054	486.63	5.5	9.12	369.89	24.66	24.66		25.94
11	14.55	24.92	300	0.059	542.40	5.3	10.12	362.59	27.91	27.91		26.63
12	14.79	25.38	300	0.038	337.44	5.7	6.50	375.37	17.32	17.32		18.60
13	14.42	24.98	300	0.052	481.20	5.7	10.60	360.21	29.43	29.43		28.15
14	14.37	25.13	300	0.053	489.22	5.9	10.67	361.12	29.55	29.55		28.27
15	14.58	25.37	300	0.039	351.45	5.7	10.33	369.89	27.93	27.93		26.65
Mean value										25.54		**25.45**

where: b – section width of the specimens; h – section height of specimens; L – length of specimens; m – mass of specimens; ρ_{rel} – relative density of specimens; ω – specimens moisture content; F_{max} – ultimate load; A – cross section area of the specimens; $f_{t,0}$ – tensile strength (parallel to grain) for ω moisture content:

$$f_{t,0} = \frac{F_{max}}{A} \tag{4}$$

$f_{t,0,12}$ – tensile strength (parallel to grain) for 12% moisture content.

Table 2
Compressive Strength Parallel to Grain Test Data

No. of specimens	b [mm]	h [mm]	L [mm]	m [kg]	ρ_{rel} [kg/m^3]	ω [%]	F_{max} [kN]	A [mm^2]	$f_{c,0}$ [N/mm^2]	$f_{c,0,12}$ [N/mm^2]	s_r	Real value $f_{c,0,12}$ [N/mm^2]
1	44.26	68.94	300	0.383	418.403	6.4	134.9	3051.28	44.21	36.78	1.66	38.44
2	43.81	68.93	300	0.367	405.101	5.9	165.4	3019.82	54.77	44.75		43.09
3	44.04	69.07	300	0.401	439.427	5.9	165.7	3041.84	54.47	44.50		42.84
4	44.3	68.57	300	0.407	446.617	5.5	154.3	3037.65	50.80	40.89		39.23
5	44.12	68.89	300	0.374	410.165	5.7	115.2	3039.43	37.90	30.74		32.40
6	43.52	68.6	300	0.386	430.976	6.4	168.5	2985.47	56.44	46.96		45.30
7	43.56	68.59	300	0.416	464.113	6.4	173.6	2987.78	58.10	48.34		46.68
8	44.3	69.07	300	0.379	412.881	5.9	126.3	3059.8	41.28	33.72		35.38
9	43.98	68.95	300	0.359	394.624	5.9	134.2	3032.42	44.26	36.16		37.82
10	43.9	69.07	300	0.364	400.153	6.6	126.5	3032.17	41.72	34.96		36.62
11	43.69	69.12	300	0.361	398.474	6.6	125.8	3019.85	41.66	34.91		36.57
12	44.01	69.06	300	0.305	334.503	5.5	120	3039.33	39.48	31.78		33.44
13	44.17	69.25	300	0.335	365.07	5.5	100.2	3058.77	32.76	26.37		28.03
14	44.39	68.84	300	0.384	418.875	5.5	130.8	3055.81	42.80	34.46		36.12
15	43.73	68.94	300	0.387	427.897	6.2	111.4	3014.75	36.95	30.52		32.18
Mean value										37.06		**37.61**

where: $f_{c,0}$ is the compressive strength (parallel to grain) for ω moisture content.

$$f_{c,0} = \frac{F_{max}}{A} \tag{5}$$

$f_{c,0,12}$ – compressive strength (parallel to grain) for 12% moisture content.

Table 3
Static Bending Strength Test Data

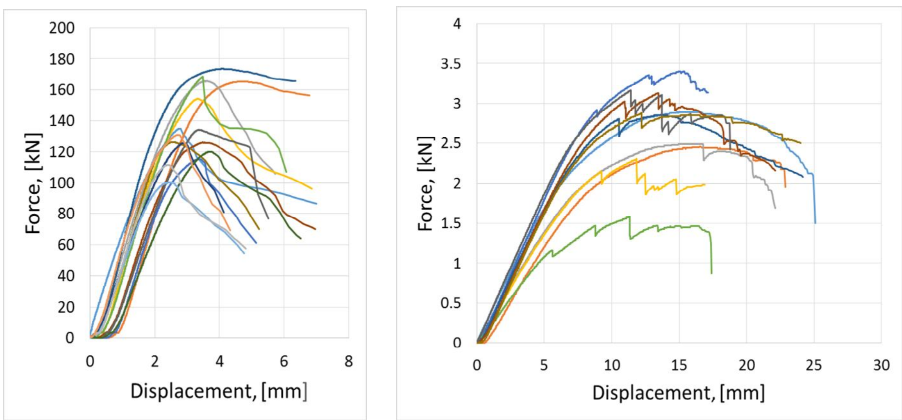
No. of specimens	b [mm]	h [mm]	L [mm]	m [kg]	ρ_{rel} [kg/m^3]	ω [%]	F_{max} [kN]	W [mm^3]	f_m [N/mm^2]	$f_{m,12}$ [N/mm^2]	s_r	Real value $f_{m,12}$ [N/mm^2]
1	20.52	21.68	400	0.092	517.00	5.5	2.89	1607.48	118.66	118.66		111.74
2	20.96	21.7	400	0.075	412.24	5.3	2.46	1644.98	98.70	98.70		105.62
3	20.96	21.69	400	0.076	417.93	5.3	2.49	1643.46	100.00	100.00		106.92
4	21.03	21.38	400	0.079	439.26	5.7	2.31	1602.15	95.16	95.16		102.08
5	20.77	21.33	400	0.091	513.52	5.3	3.40	1574.95	142.48	142.48	6.92	135.56
6	20.83	21.35	400	0.080	449.72	5.5	1.58	1582.46	65.90	65.90		72.82
7	20.5	21.77	400	0.099	554.58	5.7	2.85	1619.27	116.16	116.16		109.24
8	20.75	21.61	400	0.097	540.80	5.9	3.13	1615.01	127.91	127.91		120.99
9	20.92	21.49	400	0.092	511.60	5.3	3.17	1610.21	129.93	129.93		123.01
10	20.53	21.72	400	0.098	549.44	5.7	2.88	1614.20	117.75	117.75		110.83
Mean value										111.27		**109.8816**

where: W is the strength modulus; f_m – static bending strength for ω moisture content:

$$f_m = \frac{aF_{\max}}{2W} \tag{6}$$

$f_{m,12}$ – static bending strength for 12% moisture content, and a is the distance between the vertical forces F

The characteristics curves, force *vs* displacements obtained through the compression and the bending tests of the specimens are presented in Fig. 8.



a *b*

Fig. 8 – Force *vs.* displacement characteristic curves for: *a* – compression (parallel to grain) test; *b* – static bending test.

3.2. Strength Class

The assessment of the wood specimens to a specific strength class is performed according to the normalized experimental results. The minimum necessary data are: the global modulus of elasticity in bending, the density and the moisture content, respectively. In order to confirm the strength class, the strength and the stiffness parameters that were experimentally evaluated must be at least equal to or higher than the corresponding values for the strength class specified in SR EN 338: 2010.

The global modulus of elasticity in bending ($E_{m,g}$) is computed for the interval defined by $0.1 \times F_{\max}$ and $0.4 \times F_{\max}$ (Fig. 9). The value of the $E_{m,g}$ is computed using Eq. 7 (EN 408: 2004; Nocetti *et al.*, 2013).

$$E_{m,g} = \frac{l^3(F_2 - F_1)}{bh^3(w_2 - w_1)}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right] \tag{7}$$

where: l is the distance between bearings; a – distance between forces; $F_2 - F_1$ – increment of load on the straight-line portion of the load deformation curve; $w_2 - w_1$ – increment of deformation corresponding to $F_2 - F_1$.

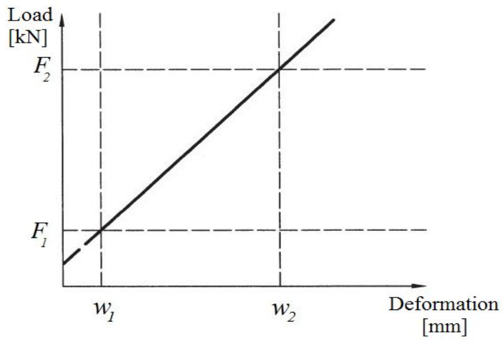


Fig. 9 – Load *vs*. deformation graph within the range of elastic deformation (EN 408: 2004).

According to the norm EN 384: 2004, the global modulus of elasticity in bending is corrected with 2% for each 1% (percent) difference in the moisture content. The final value of the global modulus of elasticity in bending is computed using:

$$E_{m,g,12,\text{final}} = \overline{E_{m,g,12}} \pm s_r \tag{8}$$

where: $\overline{E_{m,g,12}}$ is the average value of the global modulus of elasticity in bending corresponding to 12% moisture content:

$$\overline{E_{m,g,12}} = \left[\sum \frac{E_{m,g,12,i}}{n} \right] 1.3 - 2690 \quad (9)$$

The results obtained for the global modulus of elasticity in bending are given in Table 4.

Table 4
Global Modulus of Elasticity in Bending

No. of specimens	b [mm]	h [mm]	ω [%]	l [mm]	a [mm]	F_{max} [kN]	F_1 [kN]	F_2 [kN]	w_1 [mm]	w_2 [mm]	$E_{m,g}$ [N/mm^2]	$E_{m,g,12}$ [N/mm^2]	$\overline{E_{m,g,12}}$ [N/mm^2]	s_r	Real value $E_{m,g,12}$ [N/mm^2]
1	20.52	21.68	5.5			2.89	0.50	1.00	0.73	3.30	9801.60	8527.39	8395.61		8758.80
2	20.96	21.70	5.3			2.46	0.50	1.00	1.63	4.17	9693.85	8394.88	8223.34		8586.53
3	20.96	21.69	5.3			2.49	0.50	1.00	0.91	3.55	9335.47	8084.52	7819.87		8183.06
4	21.03	21.38	5.7			2.31	0.50	1.00	0.97	3.35	10782.20	9423.64	9560.74		9197.55
5	20.77	21.33	5.3	360	132	3.40	0.50	1.00	1.14	3.85	9649.81	8356.74	8173.76	363.19	8536.95
6	20.83	21.35	5.5			1.58	0.50	1.00	0.81	2.85	12763.47	11104.22	11745.49		11382.30
7	20.50	21.77	5.7			2.85	0.50	1.00	1.13	3.45	10748.52	9394.20	9522.46		9159.27
8	20.75	21.61	5.9			3.13	0.50	1.00	1.32	3.83	10029.50	8805.90	8757.68		9120.87
9	20.92	21.49	5.3			3.17	0.50	1.00	0.88	3.40	10079.40	8728.76	8657.39		9020.58
10	20.53	21.72	5.7			2.88	0.50	1.00	1.37	3.66	10948.93	9569.36	9750.17		9386.98
Mean value												9038.96	9060.65		**9133.29**

As a result of the calculations, it follows that the real value of the global modulus of elasticity in bending is 9,133.29 N/mm^2. Therefore, the strength class of the tested wood specimens, according to EN 338: 2010 is C18.

3. Conclusions

This paper presents the outcomes of an experimental study which focuses on the physical and the mechanical properties of wood specimens. Thus, 40 wood specimens were prepared and tested by loading in tension, compression and bending, respectively. Based on the experimental results the following conclusions can be formulated:

a) the experimental values should be normalized to the characteristic values corresponding to 12% moisture content provided by norms;

b) for the assessment of the strength class, the minimum data required are: the elasticity modulus in bending, the density and the moisture content;

c) following the experimental program carried out on wood specimens in the structural laboratory of the Faculty of Civil Engineering and Building Services from Iasi resulted the C18 wood class.

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EVALUAREA CLASEI DE REZISTENȚĂ A LEMNULUI PRIN ÎNCERCĂRI EXPERIMENTALE

(Rezumat)

Proprietățile mecanice şi fizice ale lemnului sunt parametrii esențiali, necesari la proiectarea elementelor şi structurilor din lemn. Aceşti parametri asigură, de asemenea, clasificarea lemnului în mai multe clase de rezistență.

Lucrarea prezintă rezultatele unui program experimental destinat evaluării proprietăților mecanice şi elastice ale lemnului ca material de construcție, caracteristici

utilizate la proiectarea elementelor structurale din lemn. Astfel, au fost realizate 40 de epruvete din lemn în conformitate cu cerințele standardelor în vigoare şi testate la tracțiune, compresiune şi încovoiere statică. De asemenea, pe baza rezultatelor obținute din testele la încovoiere statică, a fost calculat modulul de elasticitate la încovoiere global. În final, pe baza acestor valori, a fost determinată clasa de rezistență a lemnului.