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CORRELATION BETWEEN PHYSICAL AND MECHANICAL PROPERTIES OF THE WOOD

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ABSTRACT

The results of testing for the presence of correlation and how strong it is between some physical – mechanical properties - bending strength, modulus of elasticity in bending and density are established. This analysis compared the coefficients of correlation between one or more pairs of variables in order to determine statistical correlations between them. The results reflect the behavior of the test specimens made from the wood of various tree species common in Bulgaria – white pine, spruce, black pine, beech and oak.

Key words: correlation coefficient, physical - mechanical properties of wood.

1. STATE OF THE PROBLEM

The properties of the wood of each specific type are predetermined and depend on the chemical composition of the peculiarities of the construction of the building conductive elements of communication between them, the type and amounts of postponed secondary substances in cellular and intercellular gaps (tanning, mineral, resins, dyes, essential oils), [1, 5]. Due to its properties the timber is used for making various products and articles. To the physical properties are included: density, humidity, shrinkage, swelling, permeability, color, texture, shine, smell, heat capacity, thermal conductivity, thermal expansion, calorific value, flammability, conductivity, coefficient of dielectric losses, abrasion, friction, resistance to radiation, resonance and other acoustic properties. To mechanical properties are included: hardness, modulus of elasticity, tensile strength, flexural strength, compressive strength, impact strength, shear strength, resistance to splitting and retention of nails. Because of anisotropic and inhomogeneous structure of wood strength of tension, compression, bending and shear is different, [1, 3, 7]. Furthermore, it is the less, as more acute angle that the current effort concludes with the direction of the fibers. The timber showed the strongest strength at tensile load longitudinally (parallel) to the fibers. The compressive strength of the longitudinal fibers of the timber is 2–2.5 times higher than the corresponding tensile strength. The flexural strength of the timber is 1.4 to 2 times greater than the compressive strength and slightly lower than the tensile strength. Furthermore, the construction of the timber, which is associated with its type on the mechanical properties of the wood affect the length of the load, the natural disadvantages of wood and the physical factors volume weight, moisture and temperature. The modulus of elasticity (E) is the property of a material that reflects his stiffness, [6]. It is known as the Young modulus, deformation module or module deformations. It is defined as the ratio of change of normal stresses corresponding to a small change in the relative deformation. The modulus of elasticity allows the calculation of many parameters of the behavior of the material examined. For example, it is used in determining the extension of the stretched thread or load, in which the pressured column loses stability. Therefore, in this study is set as an objective the finding of a correlation between strength, modulus of elasticity in bending and the density of the wood.

2. MATERIALS AND METHODS OF STUDY

The survey was conducted on a universal testing machine HECKERT FP 10/1, which has a range of test (maximum strength) = 1000 kg (Fig. 1).

Additional devices:

- Electronic digital indicator (digital machine system) DYNATEST 9999, which is designed to work with the test machine (Fig. 2). The measuring range is 9999 N ~ 1000 kg. Furthermore, the measured force, the instrument must read more and the rate of change of the load, and is able to indicate the maximum value during the measurement. There is also the opportunity to work with a PC via RS 232 interface.
- Micrometer EDI – INSIZE, which account deflection (deformation) of the test specimen in mm. The device attaches magnetically to stand the test frame machine. The scope of the indicator is 0 to 50 mm, accuracy of thousandths of a millimeter.
- To eliminate the effect of the environment, the experiments were carried out in ambient conditions, where by means of a conditioning device temperature is maintained at $20 \pm 1\ ^{o}C$, a relative humidity - 60 ± 5 %.

Figure 1: Test machine

Figure 2: Electronic indicator

All studies were performed in compliance with the requirements specified in standard BSS EN 408: 2012 + A1, [2]. The dimensions of the samples for initial measurements: b x h x l – 30x15x285 mm, the final length of the fibers. The used tree species are white pine (Pinus sylvestris), beech (Fagus sylvatica), oak (Quercus), spruce (Picea abies) and black pine (Pinus nigra). For the purpose of each option are made 10 specimens.

Accounted are the forces F_1 and F_2 (at 200 N and 800 N; 10 and 40 % of maximum destructive force F_{max} ~ 2000 N on the details of white pine) and respectively deformation (deflection w_1 and w_2) at the indicated load. In the wood of beech maximum destructive force is 3000 N and ~ respectively according to BS EN 408: 2012 + A1 account F_1 at 300 N (10% of F_{max}) and F_2 at 1200 N (40 % of F_{max}), as well as distortions and w_1 w_2 in these values.

Of each test piece are cut prisms with dimensions 30x15x15 mm, the latter along the fibers to determine the density and humidity (dried in an electric drying oven at 102 ± 3 °C temperature to constant mass). After reaching the constant weight (after about 72 h), the prisms were placed in desiccator for another 24 h to final conditioning. To prevent wetting of the bottom of the desiccator is put calcium chloride ($CaCl_2$). The mass of all specimens is established by means of an electronic scale with an accuracy of 0.01 g.

The density of wood is calculated by the following formula:

$$\boldsymbol{D} = \frac{\boldsymbol{m}}{\boldsymbol{V}}, \text{ kg/m}^3 \qquad \textbf{(1)}$$

where: D – density of wood, kg/m^3;
m – mass of test pieces, kg;
V–volume of the samples, m^3.

Figure 3 shows schematically the experimental setting, and all the dimensions required for the conduct of the study.

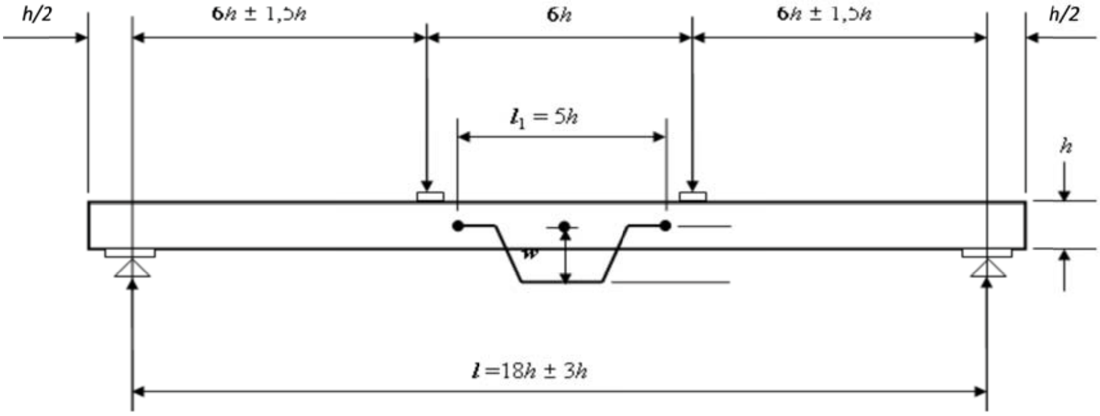
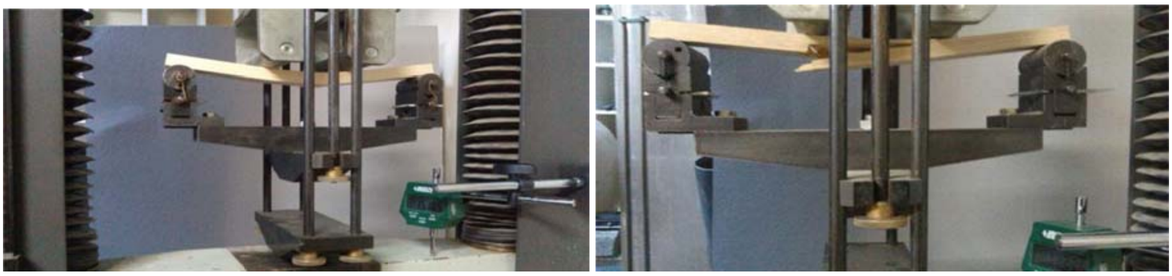


Figure 3: Scheme and the size of the test setting

Fig. 4 (A and B) can be seen testing and breaking load of the samples in bending. To comply with the time necessary to destroy each test piece, the test is performed with a loading rate of 6 to 18 N/s, where the destruction was achieved for 300 ± 120 s [BDS EN 408: 2012].



A B

Figure 4: Time of measurement of the modulus of elasticity (A) and the bending strength (B) of the test pieces of softwood

Fig. 5 shows graphically the relation between the load and the bending deformation within the limits of elasticity (elastic deformation).

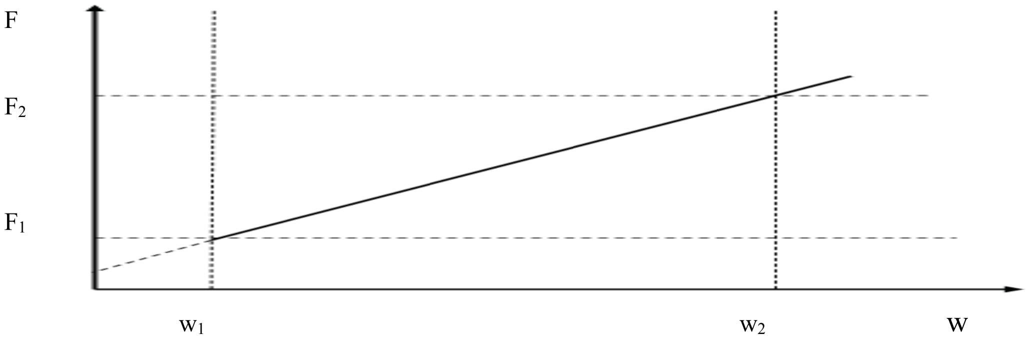


Figure 5: Load-deformation within the elastic deformation according to BDS EN 408

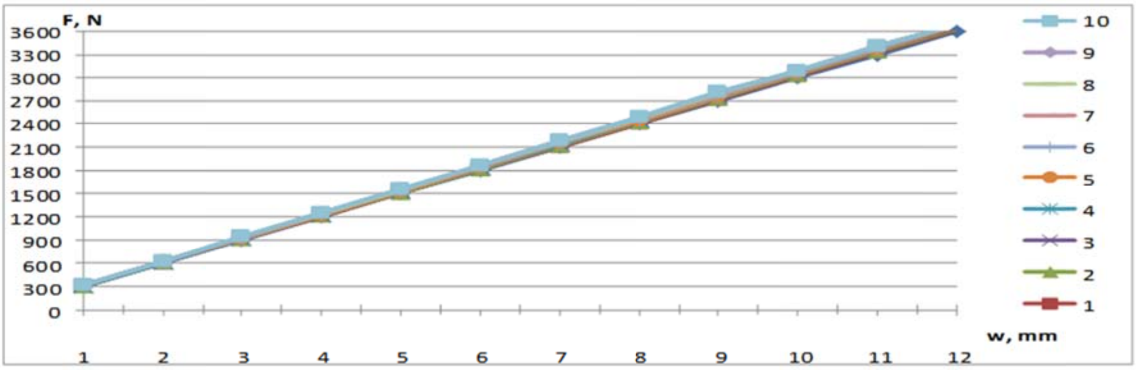


Figure 6: Relation between load and deformation in solid beech wood

Figure 6 shows the straight-line relation between load (force F) and deformation (deflection w) in solid beech wood, which fully correspond to the standard – in Fig. 5. This shows that with the increase of the force (load) increases its deformation (deflection) until the F_{max}, where the destruction occurs.

The bending strength (σ) and the modulus of elasticity in bending (E) are calculated by the formulas:

$$E = \frac{3.a.l_i^2 - 4.a^3}{2.b.h^3.\left(2.\frac{w_2 - w_1}{F_2 - F_1} - \frac{6a}{5.G.b.h}\right)} \quad (2)$$

$$\sigma = \frac{3.F_{max}.a}{b.h^2}, \quad (3)$$

where: E – modulus of elasticity in bending, N/mm^2;

σ – bending strength, N/mm^2;

F_{max} – maximum load, N;

a – distance between the loading plates in bending, mm;

h – the thickness of the test specimen (tangential size), mm;

b – width of test specimen (radial size), mm;

G – shear modulus (assumed to be infinite and the expression 6a/5G.b.h ignore), N/mm^2;

l – length of the workpiece to determine the modulus of elasticity, mm (19 h);

F_2–F_1 – is an increase in the load in Newtons, respectively at 40 and 10 % of F_{max} with a correlation coefficient of 0.99 or better;

w_2–w_1 – an increase of deformation mm, corresponding to F_2 and F_1.

The density of wood is determined by the stereometrical (weight) method according to BSS ISO 3131: 199 [1]. The obtained values of the tested parameters (density, σ and E) are converted to 12 % moisture equilibrium, [3]. For adhering together of compounds are used polyvinyl acetate glue – Jowacol 107 with resistance class D3. Figure 7 shows the samples of beech wood finger joint teeth and universal milling machine, which made the models. Figure 8 shows the degraded samples of some of the series specimens immediately following the test report.

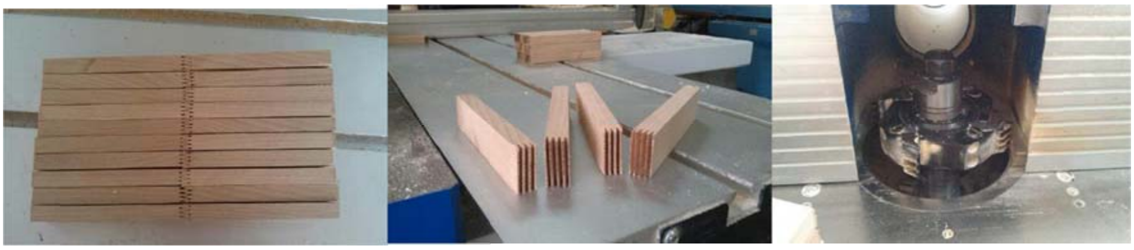


Figure 7: Samples with wedge teeth and milling machine

Figure 8: Destroyed specimens after testing

Figure 9 shows a compound of pinewood with a vertical position of teeth. They reach their maximum force of destruction: 1113 N.

Figure 9: Finger joint pine with vertical teeth

The statistical measure to describe the relation between two random variables is the coefficient of correlation [4]. This is a variable which describes the extent to which the two sets of values are linearly related. The correlation coefficient may take any value in the interval from -1 to 1, where the sign indicates the direction of the connection, and the absolute value of the coefficient indicates the size of the connection. To determine the correlation must exist measurements of two variables on the same set of objects. Correlation analysis is a method for processing of statistical data used for the study of coefficients (correlations) between variables. Usually x means the independent variable (factor), and y – the dependent variable (the result). When analyzing is compared the coefficients of correlation between one or more pairs of parameters (variables) to establish statistical relation between them. The correlation (R) is a variable which describes the extent to which the two sets of values are linearly related. The correlation is an indicator of the strength of the linear connection between two variables. Depending on the size of the value of the correlation is: $0 < R < 0.3$ – poor correlation; $0.3 < R < 0.5$ – moderate correlation; $0.5 < R < 0.7$ – significant correlation; $0.7 < R < 0.9$ – high correlation and $0.9 < R < 1$ – very high correlation.

The formula for determining the correlation is as follows:

$$R = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2].[n\sum y - (\sum y)^2]}} \quad (4)$$

where n – number of attempts (or test pieces);

x, y – two variables between which interconnection is sought.

3. RESULTS OF RESEARCH

The obtained values of the examined parameters (flexural strength (σ) and (E) modulus of elasticity in bending) are processed variance – statistically the least – squares. The results of the arithmetic average ($\dot{x}$), standard deviation S_x, coefficient of variation V_x, the average error m_x and indicators of accuracy P_x are presented in Table 1.

Table 1: Variation – statistical parameters of σ and E

				Variational parameters			
Wood type	**n, num.**	**Indica-tions**	$\dot{x}$	$S_{tdev}\pm$ N/mm^2	$m_x\pm$ N/mm^2	V_x, %	P_x, %
White Pine	10	σ	84.020	21.55	6.88	26.3	8.19
	10	E	12692.930	18.36	5.26	21.37	9.16
Beech	10	σ	114.380	13.66	3.29	13.93	5.61
	10	E	13943.960	11.56	4.43	12.89	5.49
Oak	10	σ	96.250	26.18	7.59	17.65	7.29
	10	E	13 015.200	22.74	8.26	25.88	9.13
W.p.fin. joint	10	σ	54.952	28.65	9.13	29.78	8.87
	10	E	9 528.060	25.34	7.33	18.99	7.59
Beech f.j.	10	σ	77.480	17.69	5.66	19.77	6.18
	10	E	9763.200	18.21	6.14	17.35	7.71
B.p. f.j.	10	σ	70.130	12.50	2.33	17.91	4.97
	10	E	9105.330	10.49	2.78	15.63	5.98
Spruce 1f.j.	10	σ	59.160	18.13	11.78	21.43	8.39
	10	E	9127.960	16.95	10.56	20.10	8.87
Spruce 2f.j.	10	σ	62.102	28.72	9.41	20.68	7.48
	10	E	9246.940	24.85	7.56	17.43	9.11

where: W.p. f.j.; Beech f.j.; B.p. f.j.; Spruce 1f.j.; Spruce.2 f.j. respectively – White pine finger joint (splice); Beech finger joint; Black Pine finger joint; Spruce first finger joint variant and Spruce second finger joint variant.

The sample is approximately homogeneous (the value of V_x is from 10 to 30 %).

Table 2 presents the average the bending strength (σ), the modulus of elasticity in bending (E) and density D_{12}, and correlation dependencies between them. As can be seen from the table, the bending strength, the density and modulus of elasticity in bending of the timber are interconnected. The correlation between the bending strength and the modulus of elasticity in bending in the solid wood from pine is moderate to significant (σ/E = 0.5). The correlation between the bending strength and density of the wood of pines is moderate (σ/D = 0.39). Most powerful proved interdependence (correlation) between the modulus of elasticity and density (E/D = 0.791-high correlation). Maximum deformation model which reached 1.4., before destroy is 15.11 mm. The average value of the time required for destruction of the samples is 213s. Indicators of the average maximum bending strength and modulus of elasticity in bending of beech wood are the highest (σ = 114.38 N/mm^2; E = 13943.96 N/mm^2). The maximum deflection (deformation) in these specimens also with highest values w = 16.255 mm. The average maximum force at which the sample destroyed beech samples is 2709 N. The average time needed to destroy each piece is 292 s.

Table 2: Mean values of the tested parameters and correlation coefficients

Wood type	**Fmax,** N	**Σ,** N/mm^2	**E,** N/mm^2	**w_{max},** mm	**D_{12}**, kg/m^3	**correl E/σ**	**correl σ/D**	**correl E/D**
White pine	1937.0	84.020	12692.93	12.800	484.55	0.500	0.390	0.791
Beech	2709.0	114.380	13943.96	16.255	730.77	0.917	0.810	0.748
Oak	2239.5	96.250	13015.20	13.650	776.13	0.488	0.600	0.760
W.p.f. joint	1301.5	54.952	9528.06	7.180	492.48	0.463	0.627	0.905
Beech F.j.	1835.0	77.480	9763.20	10.790	729.95	0.640	0.631	0.486
B.P. f.j.	1661.0	70.130	9105.33	8.930	561.54	0.723	0.240	0.330
Spruce1.f.j.	1401.0	59.160	9127.96	7.540	469.23	0.460	0.248	0.288
Spruce2f.j.	1471.0	62.102	9246.94	7.670	469.95	0.490	0.310	0.170

As clearly seen from Table 2 in solid beech wood is the most pronounced correlation between the bending strength, modulus of elasticity in bending and the density of the samples.

Most significant is the correlation between bending strength and modulus of elasticity in bending (0.917), which is a very high correlation, followed by the relation between the bending strength and the density (0.81) and finally, but again with a strong correlation - between the modulus of elasticity and density of the timber (0,748). According to the results the lowest is the correlation between modulus of elasticity in bending and the density of the wood in finger glued details pine (0.17), which is a weak correlation. The bending strength, the maximum force of destruction and modulus of elasticity in bending finger spliced test pieces of white pine about 65 % of the tensile strength and modulus of elasticity in bending, and the average maximum force at break of solid wood of pine are found out. In jointed spruce, the samples differ in the location of teeth along the test specimen. In the first case we have two rows of teeth, which are situated at equal distances from the edge of the sample and are within exactly to the compression zone (1/3 on both sides of the test piece), whereas the second teeth are situated exactly in the center of the sample. Test specimens made of oak, where there is a greater percentage sapwood have less strength than those with only core.

CONCLUSIONS

Based on experimental studies can be drawn the following conclusions:

- The strongest correlation is between bending strength and modulus of elasticity in bending of solid beech wood (0.917 – very strong correlation), followed by the relation between bending strength and density of the wood (0,81 – high correlation) and strong is the correlation between modulus of elasticity and density of the wood (0.748);
- The bending strength, the maximum force of destruction and modulus of elasticity in bending finger spliced test pieces of white pine about 65 % of the strength and modulus of elasticity in bending, and the average maximum force at break of solid wood of pine are established;
- When teeth are located outside the compression zone, the details withstand greater load (1471N – spruce 2 finger joint), but when loaded right on splicing – destruction occurs faster and there is less load (1401N – spruce 1 finger joint).

It is necessary for future research to verify the influence of the moisture content, the type of adhesive and the pressure in the compression in the longitudinal direction on the values of the test parameters and the correlation between them when gluing wood.

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