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RELATION BETWEEN STRENGTH OF WOOD PARALLEL AND PERPENDICULAR TO THE GRAIN

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The relationship between wood strength in parallel to the grain compression test and in perpendicular to the grain tensile test were investigated. Perpendicular to the grain tensile strength was determined in diametral compression test with cylindrical samples. The samples of the same type were used for parallel to the grain compression test. Experiments included test on 13 wood kinds, both softwoods and hardwoods. There increase in across to the grain wood tensile strength was observed, particulary in tangential direction, corresponding to increase in its along to the grain strength. The dependence was of linear nature.

INTRODUCTION

As we know there is a very characteristic macroscopic appearance of fractured surface in wood being a subject of compressive loads acting along to the grain. There on tangential surfaces of prismatic wood samples which were exposed to failure stresses, one can observe the folds of rupture running usually at angle of 45 to 60 degrees to the sample's axis. At radial surfaces then the folds are almost perpendicular to long axis of the sample [2, 3, 4, 5]. The appearance of fracture which can be observed with a naked eye, is preceded by local failures and deformations in wood cell walls (distortions, microbuckling) which appear at relatively low stress level and are located at tangential direction. Those failures are leading to accomodate the axial cells to horizontally oriented wood rays [1, 4]. Microstructural fractographic investigations revealed the appearance of microbucklings and distortions of microfibrils within tangential walls of tracheids being under axial compressive stresses [7, 8, 9, 10]. In above mentioned studies same local delaminations were observed usually in secondery cell wall layers S1 and S2.

It can be assumed then, that the one of the fundamental mechanisms which crack creation and development in parallel compression depends on is the loss of stability by structural elements of wood tissue as well as their buckling and delamination. It emerges from failure process course for wood compressed along to the grain that the very important role is played by the transversal joints of anatomical elements and consequence by wood stiffness and strength to tension forces acting across to the grain. It was previously observed that the transverse forces effect was significant in wood along to the grain compression test in conditions of lowered friction between face surfaces of tested samples and loading block of the testing machine [11]. A supposition arises from the above that the increase of transversal tensile strength leads to increase of axial compressive strength. This assumption, although appears to be trite, seemingly, have not been experimentally verified jet – as it known to author. Its verification is the aim of this study.

MATERIAL AND METHODS

Tests of axial compression and transversal tension were performed on identical, cylindrical wood samples of diameter 30 mm and length 45 mm. Wood moisture content of tested samples was 10% on average. Compressive strength was tested accordingly to the procedure usual in that kind of test.

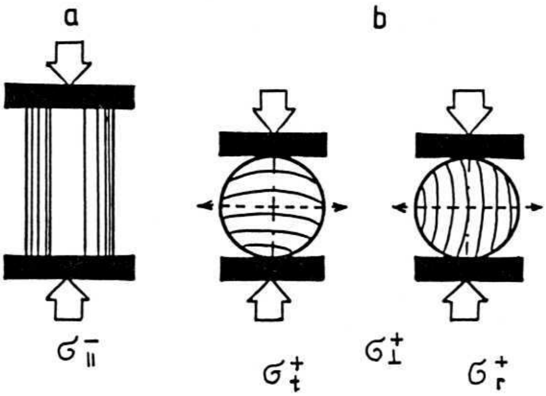

Fig. 1. Scheme of the axial compression test (a) and transversal tension test (b) in tangential and radial directions on cylindrical samples

Ryc. 1. Schemat próby podłużnego ściskania (a) i poprzecznego rozciągania (b) w kierunku stycznym i promieniowym walcowych próbek drewna

Tensile strength across to the grain was carried out in so called diametral compression test (Fig. 1) [13]. The test known as 'Brasilian test' is used for determining of tensile stress in concrete samples [12]. For diametral compression test of cylindrical wood samples, the testing machine type FPZ-100 (former GDR made) with loading frame block velocity of 3.5 mm per minute was applied. Wood transverse tensile strength in tangential (σ_t^+) or radial (σ_r^+)

directions was computed from formula:

$$\sigma_{t,r}^{+}=\frac{2P}{\pi LD}=0.637\frac{P}{LD}\ [\mathrm{N/mm^2}],$$

where P – limit load, L – sample length, and D – sample diameter. A stress distribution in diametrically compressed cylinder was considered in details by Timoshenko and Goodier [14]. Each test was repeated 5 times for axial compressive strength, and 10 times for radial or tangential tension test. Approximately 320 samples were tested all together.

RESULTS

Direct results of the experiments covering axial compressive strength, transversal tension strength of cylindrical samples of 13 wood kinds are presented in Table 1. Variability of measurements is included in range much

Table 1

Compressive strength in axial direction and tensile strength in transversal direction of some woods
Wytrzymałość na podłużne ściskanie i poprzeczne rozciąganie niektórych rodzajów drewna

Kind of wood Rodzaj drewna		Density Gęstość ρ_{10} [kg/m³]	Wood strength Wytrzymałość Axial compression Podłużne ściskanie $\sigma_{\parallel}^{-}$ [N/mm²]	Transversal tension Poprzeczne rozciąganie σ_t^{+} [N/mm³]	σ_r^{+}
1. Spruce [a)] Świerk	*Picea abies* Karst.	400	59±2.1[c)]	2.6±0.33	3.2±0.53
2. Pine [b)] Sosna	*Pinus sylvestris* L.	690	68±7.6	4.4±0.18	4.5±0.50
3. Larch [b)] Modrzew	*Larix decidua* Mill.	630	75±5.2	4.4±0.75	4.0±0.45
4. Oak [b)] Dąb	*Quercus* sp.	670	61±3.4	4.5±0.21	4.3±0.53
5. Ash [a)] Jesion	*Fraxinus excelsior* L.	680	70±0.7	6.7±0.98	6.1±0.61
6. Robinia [b)] Robinia	*Robinia pseudoacacia* L.	780	75±5.2	6.7±0.92	6.3±1.26
7. Aspen [a)] Osika	*Populus tremula* L.	500	56±2.3	3.0±0.12	– [d)]
8. Poplar [a)] Topola	*Populus* sp.	430	48±2.0	3.0±0.19	–
9. Alder [a)] Olsza	*Alnus glutinosa* Vill.	470	44±1.2	4.2±0.29	–
10. Basswood [a)] Lipa	*Tilia* sp.	560	64±5.1	4.3±0.17	5.9±1.13
11. Birch [a)] Brzoza	*Betula pendula* Roth.	680	68±2.5	5.9±0.28	7.2±0.48
12. Beech Buk	*Fagus silvatica* L.	700	63±1.0	7.8±0.21	10.4±0.77
13. Hornbeam Grab	*Carpinus betulus* L.	770	77±5.9	8.1±0.43	10.0±1.52

a) sapwood – biel, b) heartwood – twardziel,
c) $\bar{x}$ +/– standard deviation – odchylenie standardowe, d) uncertain data – dane niepewne

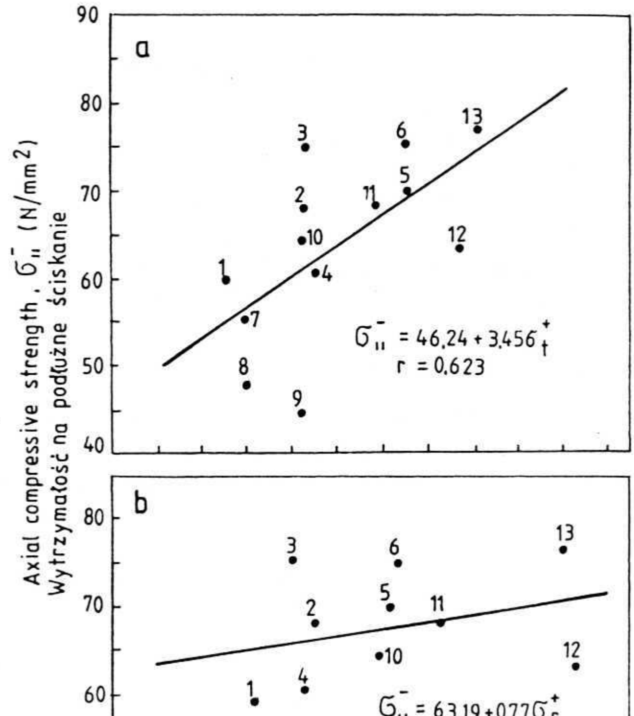

Fig. 2. Relationship between transversal tension strength of wood in tangential direction (a) and in radial direction (b) and wood compressive strength along to the grain (experimental points indexes reffer to the kind of woods in Table 1)

Ryc. 2. Zależność między wytrzymałością na poprzeczne rozciąganie drewna w kierunku stycznym (a) oraz promieniowym (b) i wytrzymałością na podłużne ściskanie (numery obok punktów doświadczalnych odpowiadają rodzajom drewna w tabeli 1)

below the variability ranges considered as natural those properties [15]. Average coefficient of variation equals 5.2 (1.0 ... 11.2)% for axial compresive strength and 9.3 (2.7 ... 17.0)% for transversal tension strength in tangential direction and 13.0 (6.7... 20.0)% for radial direction. The types of strength which were measured shown, due to previous expectation, a linear correlation in dependence on wood density ρ_{10}. Correlation coefficients were equal respectively: 0.799 for axial compression, 0.814 for tangential tension and 0.584 for radial tension. The relation between axial compressive strength and transversal tension strength are presented as diagrams at Fig 2. It is evident from the graphs that axial compressive strength increases in linear manner with increase transversal tension strength. That relation is more clear for tangential tension i.e. in radial plane (*RL*-plane) than in tangential plane (*LT*-plane). For the dependence function between axial compression and tangential tension the slope of regression line is 4.5-times higher than for axial compression and radial tension dependence. The value of correlation of the relationship between axial compression and radial tension is not enough to recognize this dependence as significant. It should be noticed here that in additional experiment an elasticity modulus in tangential direction was measured with ultrasonic method. The linear function of axial compressive strength ($\sigma_{\parallel}^{-}$) and elasticity modulus in tangential direction (E_t) was find with high correlation coefficient ($r=0.837$):

$$\sigma_{\parallel}^{-} = 45.83 + 0.012\, E_t \ [\text{N/mm}^2].$$

The experimental data presented here are confirm fact that the transversal strength and stiffness in direction of easy buckling of structural elements of wood i.e. in tangential direction, effect on the compressive strength parallel to the grain significantly. As Gordon [6] points out the material always finds a way to avoid too high increase of compression stresses by sliping from the load to anywhere aside.

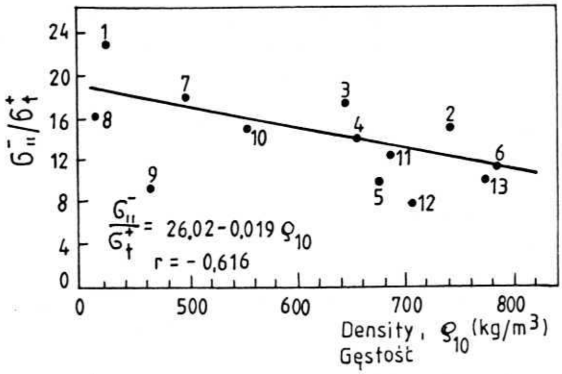

Fig. 3. Wood density effect on ratio: axial compressive strength to transversal tension strength in tangential direction (indexes as in Fig. 2)

Ryc. 3. Wpływ gęstości drewna na stosunek wytrzymałości na podłużne ściskanie do wytrzymałości na poprzeczne rozciąganie w kierunku stycznym (numery jak na ryc. 2)

It is worth to mention here that a rate of axial compressive strength to transversal tension strength in tangential direction is decreasing with increase of wood density (Fig. 3). In other words: for wood density 400 kg/m^3 the rate is

20:1, for increased density to 800 kg/m^3 the rate value drops to 10:1. The relations presented here reflect the fact that wood radial plane compared to tangential plane take a privileged position in aspect of creation and development of structural defects and cracks.

CONCLUSIONS

1. Parallel to the grain compressive strength for various kind of woods increases in linear manner with increase of perpendicular to the grain tension strength. This is especially observed in tangential direction i.e. in radial plane.

2. With the increase of wood density from 400 to 800 kg/m^3 the rate of parallel compressive strength to tangential tension strength decreases from 20 to 10.

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ZALEŻNOŚĆ MIĘDZY WYTRZYMAŁOŚCIĄ DREWNA WZDŁUŻ I W POPRZEK WŁÓKIEN

Streszczenie

Badano zależność między wytrzymałością drewna na ściskanie wzdłuż i na rozciąganie w poprzek włókien. Wytrzymałość na rozciąganie w poprzek włókien oznaczano w próbie średnicowego ściskania na próbkach walcowych. Na takich samych próbkach przeprowadzono próbę ściskania wzdłuż włókien. Doświadczenia wykonano na drewnie 13 rodzajów drzew iglastych i liściastych. Stwierdzono, że wraz ze wzrostem wytrzymałości drewna na rozciąganie w poprzek włókien, zwłaszcza w kierunku stycznym, zwiększa się jego wytrzymałość na ściskanie wzdłuż włókien. Zależność ta ma charakter prostoliniowy.

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