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THE EFFECT OF THE JANKA BALL INDENTATION DEPTH ON THE HARDNESS NUMBER DETERMINED FOR SELECTED WOOD SPECIES

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SYNOPSIS. The paper presents results of a study of wood hardness for 13 tree species (4 coniferous, 3 ring-porous and 6 diffuse-porous) measured along and across the fibres. The measurements were performed by the Janka method by indenting a steel ball at a depth of its radius and half of its radius.

KEY WORDS: wood, Janka hardness, depth of indentation, conversion factor

INTRODUCTION

One of the most important technological characteristic of wood is its hardness measured as the wood resistance to indentation made by a rigid indenter. The static hardness of wood is most often measured by the method proposed in the first decade of the 20th century by G. Janka from Austria (Kollmann 1951). The method is also most often recommended by national standard organisations of different countries. In this method a steel ball indenter of the diameter of 11.284 mm is indented into the wood sample. The Janka hardness is equivalent to the force expressed in newtons needed to indent the steel ball into the depth of its radius (Janka 1915, Kollmann 1951, Krzysik 1978). When it is probable that the wood sample may break up on indentation to the depth of 5.642-5.64 mm, the Polish standard on the wood hardness determination by the Janka method of 1990 (PN 90/D-04109) admits measurements by indentation to half of the radius of 2.821-2.82 mm. The static hardness of a sample (HJ) is calculated from the formula:

$$HJ = KP \text{ [N]} \tag{1}$$

where: P – the load needed to indent a ball into a certain depth [N], K – the coefficient equal 1 when the ball is indented to the depth of the radius or $4/3 = 1.33$ when the ball is indented to half of the radius.

Recommendation of the admission to indent the ball to a lower depth is in agreement with the international ISO standard (ISO 3350-1975E).

In order to verify the conversion factor value $K = 1.33$, preliminary measurements of wood hardness were performed by indenting the Janka ball into the depth of its radius and half of its radius. The results of the preliminary measurements indicated that the empirical values of the conversion factor differed from the standard value. The empirical values were usually higher than the standard and depended on the direction of indentation, i.e. whether it was indented along or across-to-the-grains. The results prompted us to undertake a study aimed at determination of a relationship between the wood hardness measured on indentation of the Janka ball into the depth of its radius and half of its radius for wood from different wood species.

THE METHOD

The measurements were performed on samples of wood taken from 13 wood species of different structure and density. The common and botanical names of the trees are given in Table 1 and arranged according to structural groups and increasing density within a given group. The wood samples chosen have been for a long time conditioned in a closed room and were characterised by the moisture content of about 10%.

Table 1. The common and botanical names of the wood species used in the study
Tabela 1. Zestawienie nazw potocznych i botanicznych gatunków drewna użytych do doświadczeń

Common names Nazwa potoczna		Botanical names Nazwa botaniczna
Spruce – Świerk	SP	*Picea abies* Karst.
Pine – Sosna	PI	*Pinus sylvestris* L.
Larch – Modrzew	LA	*Larix decidua* Mill.
Douglas-fir – Daglezja	DO	*Pseudotsuga menziesii* Franco
Oak – Dąb	OA	*Quercus robur* L.
Ash – Jesion	AS	*Fraxinus excelsior* L.
Black locust – Robinia	BL	*Robinia pseudoacacia* L.
Poplar – Topola	PO	*Populus* sp.
Alder – Olsza	AL	*Alnus glutinosa* Gaertn.
Aspen – Osika	AP	*Populus tremula* L.
Birch – Brzoza	BI	*Betula pendula* Roth.
Beech – Buk	BE	*Fagus sylvatica* L.
Hornbeam – Grab	HB	*Carpinus betulus* L.

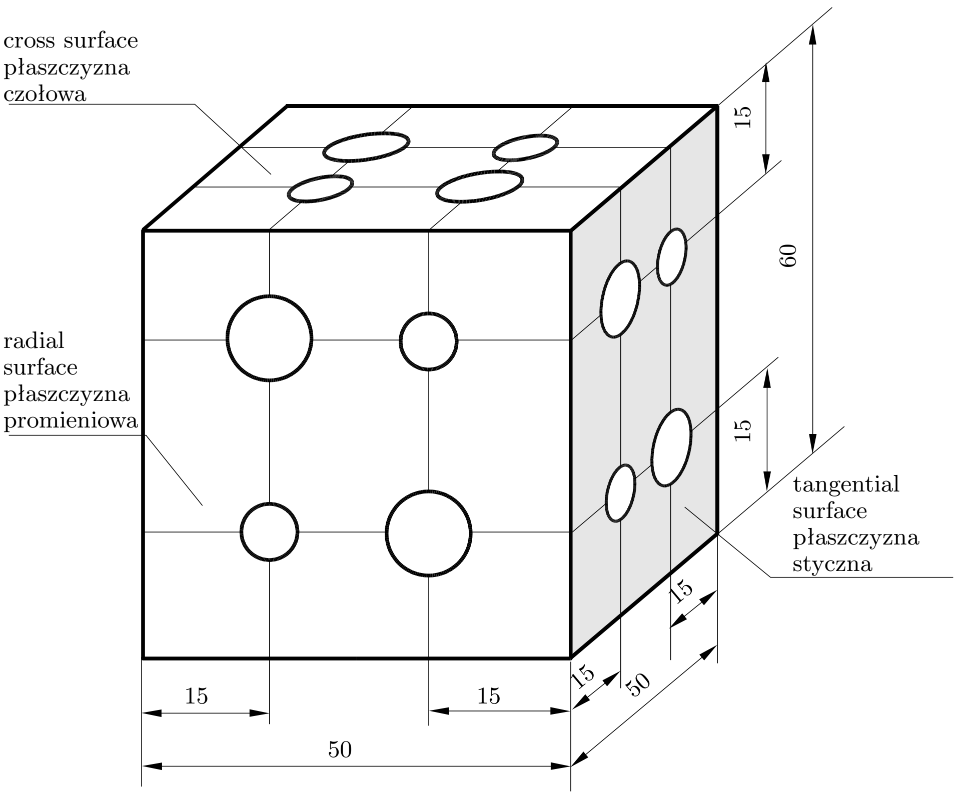

Fig. 1. The arrangement of the indentation sites on the sample
Rys. 1. Sposób rozmieszczenia wcisków w próbce

The samples were rectangular prisms of the size: 50(T) × 50(R) × 60(L) mm^3, according to the Polish standard (PN 90/D-04109). The Janka hardness of the wood samples was measured on indentation of the ball to the depth of its radius and half of its radius in three anatomic directions: along-to-the-grains (into the two cross section), in the radial direction (into one tangential surface) and in the tangential direction (into one radial surface).

The steel ball was indented into each of the planes at a distance of 15 mm from the sample edge. Four indentations were made into each plane: two to the depth of the ball radius 5.64 mm and two to the depth of a half of its radius 2.82 mm. A scheme of the indentations arrangement is shown in Figure 1. The steel ball was indented at a constant rate so that a desired depth would be achieved in the time of 2 and 1 minute, respectively. The measurements were made on a testing machine FPZ-100 for three samples representing each species. The total number of indentations was 624 and the total number of samples studied was 39.

RESULTS AND ANALYSIS

The results of direct measurements of the hardness number obtained for the wood species studied on indentation of the Janka ball to the depth of its radius (HJ) and 1/2 of its radius (HJ*), without the use of the standard coefficient (K), are given in Table 2. As the measurements were carried out for twin samples of each tree species and the results were characterised by a small scatter, the table gives mean values. The samples of the wood species studied showed density consistent

Table 2. Mean values of the Janka hardness obtained on indentation of the ball to the depth of its radius (HJ) and 1/2 of its radius (HJ*) for different anatomical directions
Tabela 2. Średnie wartości liczby twardości Janki przy wciskaniu kulki na głębokość promienia (HJ) i na głębokość 1/2 promienia (HJ*) w zależności od kierunku anatomicznego

Wood species Gatunek drewna	Density Gęstość ρ_{10} [kg·m^{-3}]	HJ			HJ*		
		L	R	T	L	R	T
		kN [MPa*]					
Spruce – Świerk	510	3.30 / 33.0	2.51 / 25.1	2.50 / 25.0	2.75 / 36.6	1.45 / 19.3	1.43 / 19.0
Pine – Sosna	540	3.01 / 30.1	2.84 / 28.4	2.28 / 22.8	2.71 / 36.0	1.54 / 20.5	1.63 / 21.7
Larch – Modrzew	600	4.77 / 47.7	3.37 / 33.7	2.89 / 28.9	3.65 / 48.5	1.72 / 22.9	1.89 / 25.1
Douglas – Daglezja	610	4.38 / 43.8	3.01 / 30.1	3.25 / 32.5	4.04 / 53.7	1.68 / 22.3	2.33 / 31.0
Oak – Dąb	640	5.26 / 52.6	4.51 / 45.1	4.51 / 45.1	3.72 / 49.5	2.50 / 33.3	2.40 / 32.0
Ash – Jesion	670	8.59 / 85.9	6.86 / 68.6	6.08 / 60.8	5.12 / 68.3	3.31 / 44.1	3.08 / 41.1
Black locust – Robinia	730	5.95 / 59.5	5.04 / 50.4	4.50 / 45.0	3.58 / 47.7	2.44 / 32.5	2.69 / 35.9
Poplar – Topola	400	3.14 / 31.4	2.48 / 24.8	2.07 / 20.7	2.21 / 29.4	1.48 / 19.7	1.16 / 15.5
Alder – Olsza	470	4.09 / 40.9	2.96 / 29.6	2.65 / 26.5	2.88 / 38.4	1.47 / 19.6	1.17 / 15.6
Aspen – Osika	500	3.76 / 37.6	3.21 / 32.1	2.72 / 27.2	2.61 / 34.8	1.59 / 21.2	1.27 / 16.9
Birch – Brzoza	610	5.58 / 55.8	4.69 / 46.9	4.42 / 44.2	3.88 / 51.7	2.37 / 31.6	2.53 / 33.7
Beech – Buk	720	8.84 / 88.4	7.32 / 73.2	6.91 / 69.1	5.44 / 72.5	3.75 / 50.0	3.21 / 42.8
Hornbeam – Grab	770	11.67 / 116.7	9.27 / 92.7	8.60 / 86.0	6.67 / 88.9	4.82 / 64.2	3.67 / 48.9

*Applicable to the values in denominator.
*Dotyczy wartości podanych w mianowniku.

with the values typical of the national species from 400 kg·m^{-3} for poplar wood to 770 kg·m^{-3} for hornbeam wood. The hardness numbers determined for the samples on indenting the ball to the depth of its radius are, as expected, the highest in the direction along-to-the-grain. The values obtained on indenting the ball across-to-the-grain are usually higher than those obtained for the tangential direction. For all wood species studied, the hardness measured in the radial direction is on average 10% higher than that measured in the tangential direction. When the ball was indented to the depth of 1/2 of its radius, the value of the ratio HJ_R*/HJ_T* was somewhat lower and equal to 1.06.

In the discussed table, apart from expressing hardness, as it is recommended by the applicable standard, in force units this quantity was also presented in MPa. They show that only in case of measuring of hardness along fibres of coniferous species, obtained results are similar for both methods of determination. For other investigated species or while determining hardness across to the grain, the lover values were obtained during ball indentation to the depth of 1/2 of its radius, then to the depth of its whole radius. This fact indicates the need of correction of normative conversion factor.

Of practical value are mostly the hardness numbers measured across-to-the-grain (e.g. The strength properties... 1974), as they are taken into regard in the assessment of wood suitability for making floors. Table 3 gives also the hardness numbers across-to-the-grain calculated as arithmetic mean of the values measured in the tangential and radial directions. On the basis of the data from Table 3, the plots were made illustrating the relation between the hardness numbers along-

Table 3. Mean values of the Janka hardness obtained for the wood species studied in the directions along-to-the-grains and across-to-the-grains on indentation of the ball to the depth of its radius (HJ_L, $HJ_\perp$) and 1/2 of its radius (HJ_L*, $HJ_\perp*$)
Tabela 3. Średnie wartości liczby twardości Janki badanych gatunków drewna wzdłuż i w poprzek włókien przy wciskaniu kulki na głębokość promienia (HJ_L i $HJ_\perp$) i na głębokość 1/2 promienia (HJ_L* i $HJ_\perp*$)

Wood species Gatunek drewna	HJ		HJ*		HJ_L/HJ_L*	$HJ_\perp/HJ_\perp*$
	HJ_L	$HJ_\perp$	HJ_L*	$HJ_\perp*$		
	kN				–	–
Spruce – Świerk	3.30	2.51	2.75	1.44	1.2	1.74
Pine – Sosna	3.01	2.56	2.71	1.58	1.11	1.62
Larch – Modrzew	4.77	3.13	3.65	1.80	1.31	1.73
Douglas – Daglezja	4.38	3.13	4.04	2.00	1.08	1.56
Oak – Dąb	5.26	4.51	3.72	2.45	1.41	1.84
Ash – Jesion	8.59	6.47	5.12	3.20	1.68	2.02
Black locust – Robinia	5.95	4.77	3.58	2.56	1.66	1.86
Poplar – Topola	3.14	2.28	2.21	1.32	1.42	1.72
Alder – Olsza	4.09	2.80	2.88	1.32	1.42	2.12
Aspen – Osika	3.76	2.97	2.61	1.43	1.44	2.07
Birch – Brzoza	5.58	4.56	3.88	2.45	1.44	1.86
Beech – Buk	8.84	7.12	5.44	3.48	1.63	2.04
Hornbeam – Grab	11.67	8.93	6.67	4.25	1.75	2.10

-to-the-grain (Fig. 2) and across-to-the-grain (Fig. 3) determined on indentation of the ball to the depth of its radius and 1/2 of its is radius and the wood density. The relations were approximated by a power function of the type $y = ax^n$ at the determination coefficient from the range 0.72 to 0.84. This type approximation of the relations between the wood hardness and density is commonly used in literature (e.g. Wood Handbook 1974). A careful analysis of these relations shows that with increasing wood density the absolute difference between the hardness number obtained on the ball indentation to the depth of its radius and that obtained on its indentation to 1/2 of its radius increases.

The relationship between the hardness number obtained on indenting the Janka ball to the depth of its radius and 1/2 of its radius in the along-to-the-grain direction is shown in Figure 4, and in the across-to-the-grain direction in Figure 5. The relations are linear and characterised by a high correlation coefficient. The tangent of the lines slope to the x axis is the so-called slope coefficient, which for the line in Figure 4 is 1.53, and for the line in Figure 5 – 1.94.

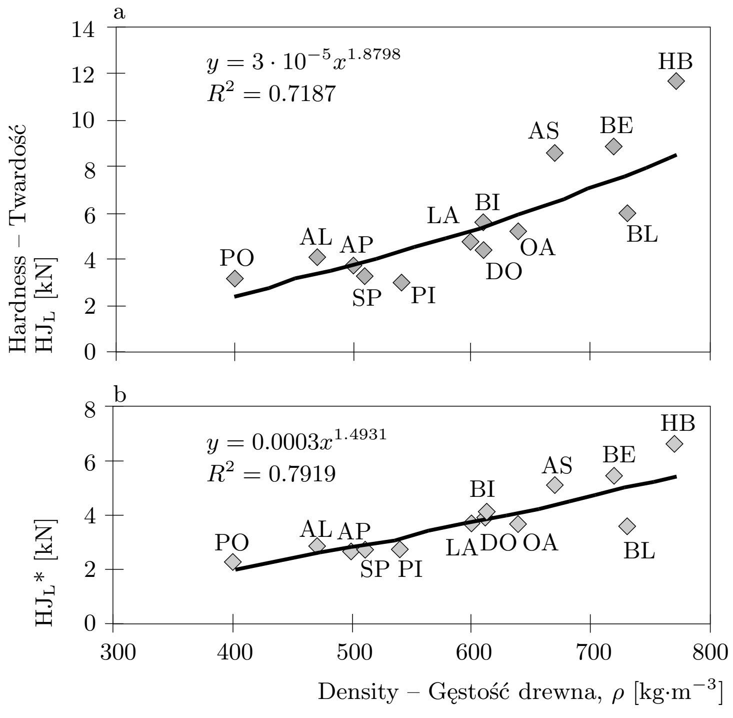

Fig. 2. The Janka hardness of selected tree species measured along-to-the-grains on tha ball indentation to the depth of its radius (a) and half of its radius (b) versus the wood density
Rys. 2. Zależność liczby twardości Janki wybranych gatunków drewna w kierunku wzdłużnym od gęstości drewna przy wciskaniu kulki na głębokość promienia (a) i 1/2 promienia (b)

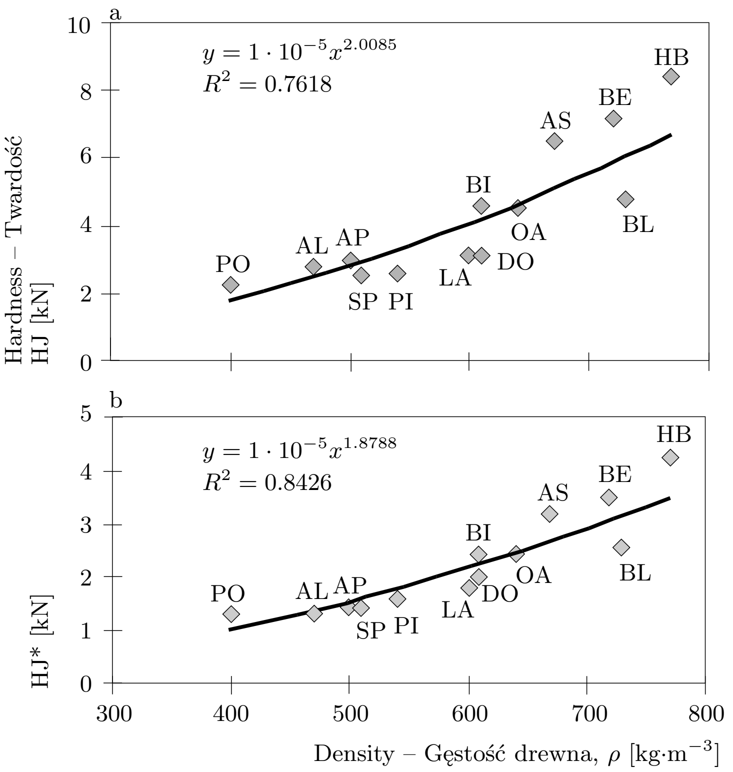

Fig. 3. The Janka hardness of selected tree species measured across-to-the-grains on the ball indentation to the depth its radius (a) and half of its radius (b) versus the wood density
Rys. 3. Zależność liczby twardości Janki wybranych gatunków drewna w poprzek włókien od gęstości drewna przy wciskaniu kulki na głębokość promienia (a) i 1/2 promienia (b)

Knowing the hardness numbers on indenting the Janka ball to the depth of 1/2 of its radius it is possible to estimate the hardness on indenting the ball to the depth of its radius in the along-to-the-grain direction from the relation:

$$HJ_L = 1.517\ HJ_L^* \tag{2}$$

and in the across-to-the-grain direction from the relation:

$$HJ = 1.944\ HJ^* \tag{3}$$

The above relations imply a significant divergence between the value of K = 1.33 recommended by the Polish standard PN-90/D-04109 (1990), and the experimentally determined values. For the hardness numbers determined along-to-the-grains the experimental conversion coefficient is higher than the standard one by about 20%, and for the hardness numbers determined across-to-the-grains it is

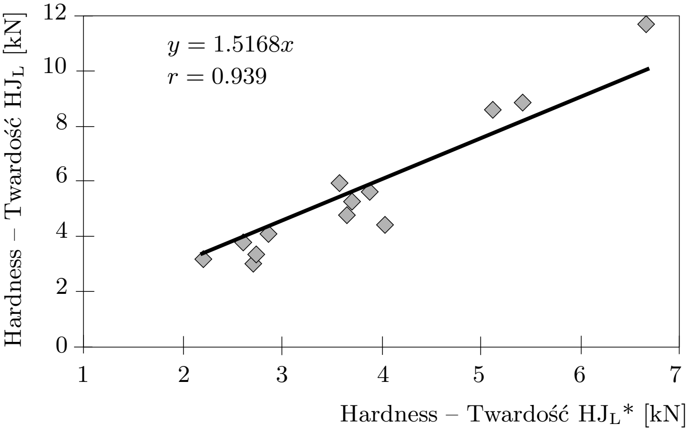

Fig. 4. The relation between the Janka hardness measured along-to-the-grains on indentation of the ball to the depth of its radius and that measured on indentation to the depth of 1/2 of its radius.
Rys. 4. Zależność między liczbą twardości Janki przy wciskaniu kulki na głębokość promienia i 1/2 promienia w kierunku wzdłuż włókien

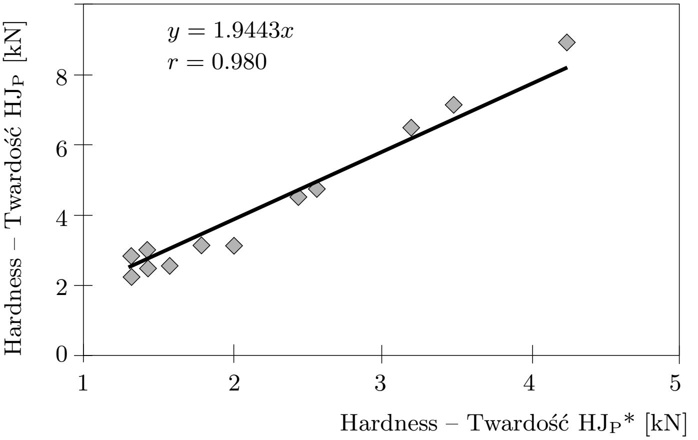

Fig. 5. The relation between the Janka hardness measured across-to-the-grains on indentation of the ball to the depth of its radius and that measured on indentation to the depth of 1/2 of its radius
Rys. 5. Zależność między liczbą twardości Janki przy wciskaniu kulki na głębokość promienia i 1/2 promienia w poprzek włókien

higher by about 60%. The mean ratio of the hardness number obtained along-to--the-grains on indentation of the ball to the depth of its radius to that obtained on indenting the ball to the depth of 1/2 of its radius (Table 3) is 1.43 (1.11-175). The same ratio for the direction across-to-the-grains increases to 1.87 (1.56-212), which are the values close to those following from the regression equations (Figs 4 and 5).

Looking for the possible reasons for the values of the experimentally determined conversion coefficient being higher than the standard, it should be realised that the value of the standard coefficient (K = 1.33) follows from a relation between the area of the projection of the indentation obtained on indenting the ball to the depth of its radius (100 mm^2) to that obtained on indenting the ball to the depth of 1/2 of its radius (75 mm^2). It has been disregarded that the force needed to indent the ball to a desired depth, because of the coherence of the wood, also depends on its reaction beyond the site of the direct contact of the ball with the wood surface. The volume responding to the ball indentation is the larger the deeper the ball is indented. For this reason the wood resistance to indentation (partial compression) is higher than its resistance to compression (e.g. Krzysik 1978). Hence, it is understandable that the relation between the force needed to indent the Janka ball to the depth of its radius and 1/2 of its radius is higher than that assumed in the standard.

The above discussed results indicate the need to correct the value of the conversion coefficient (K) of the hardness number obtained on indenting the Janka ball to the depth of 1/2 to that obtained on indenting the ball to the depth of its radius.

CONCLUSIONS

1. The experimentally determined conversion coefficient (K) of the hardness numbers on the Janka ball indentation to the depth of 1/2 of its radius to the hardness number on the Janka ball indentation to the depth of its radius is higher than that recommended by the Polish standard on static hardness of wood.
2. The experimentally found mean value of K is 1.52 for the hardness numbers determined along-to-the-grain (HJ_L) and 1.94 for the hardness numbers determined across-to-the-grain ($HJ_\perp$).
3. The experimentally found value of K for the direction along-to-the-grain is about 20% higher than the standard value of K, and for the direction across-to-the--grain it is about 60% higher.
4. The results of the study indicate the need to correct the value of the standard conversion coefficient (K).

REFERENCES

ISO 3350-1975 E: Wood – determination of static hardness. It. Org. For. Standardization.

Janka G. (1915): Die Härte der Hölzer. Mitt. Forst. Versuchswes. Österr. Wien: 39.

Kollmann F. (1951): Technologie des Holzes und der Holzwekstoffe. Bd. 1. Springer, Berlin.

Krzysik F. (1978): Nauka o drewnie. PWN, Warszawa.

PN-90/D-04109. (1990): Drewno – oznaczanie twardości statycznej. Wyd. Normal. „Alfa", Warszawa.

The strength properties of timber. (1974). Forest Products Research Laboratory. MTP Construction, St. Leonard's House, Lancaster.

Wood Handbook. (1974). Wood as an engineering material. USDA Agric. Handbook 72. U.S. Forest Prod. Lab., Washington, D.C.

WPŁYW GŁĘBOKOŚCI WCISKU KULKI JANKI NA WYZNACZONE WARTOŚCI TWARDOŚCI DREWNA WYBRANYCH GATUNKÓW

Streszczenie

W pracy przedstawiono wyniki pomiarów twardości drewna metodą Janki przy wciskaniu kulki na głębokość promienia i 1/2 promienia. Badano twardość wzdłuż i w poprzek włókien 13 gatunków drewna (czterech iglastych, trzech pierścieniowonaczyniowych i sześciu rozpierzchłonaczyniowych) Stwierdzono, że oznaczony doświadczalnie współczynnik przeliczeniowy (K) liczb twardości uzyskiwanych przy wciskaniu kulki na głębokość 1/2 promienia do liczb twardości uzyskiwanych przy wciskaniu kulki na głębokość promienia jest większy od zalecanego przez Polską Normę współczynnika oznaczania statycznej twardości drewna (K = 1,33). W przypadku liczb twardości wzdłuż włókien oznaczony doświadczalnie współczynnik przeliczeniowy jest większy od normatywnego o ok. 20%, a w przypadku liczb twardości w poprzek włókien – większy od normatywnego o ok. 60%. Wyniki przeprowadzonych badań sugerują potrzebę dokonania korekty wartości normatywnego współczynnika przeliczeniowego.

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