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Probing measurements of the Meyer hardness index of radial, tangential and cross section of various types of wood

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Abstract: The Meyer index is a power exponent appearing in Meyer hardness power law, which describes the dependence of the indenting force on the diameter of the indentation caused by the ball (or alternatively a cylinder). A perfectly plastic material should have a Meyer hardness index of 2 and a perfectly elastic material of 3. Previous research by the author and co-workers indicated that the Meyer index of beech wood is 2.5 and for metals aluminum 2.25, copper 2.0. This gave rise to the hypothesis that the hardness index of each wood is about 2.5. It was decided to verify this hypothesis for different types of wood, different anatomical cross-sectional directions. Research on such diversity must therefore be of a probing nature. Nevertheless, these probing measurements indicate that different types of wood in given sectional planes have similar Meyer indexes, but in each section it is a different value. The measured mean value in the radial section was 2.41, in the tangential section 2.28 and in the cross section 1.98. Thus, the initial hypothesis of the value 2.5 was confirmed only for the radial section, and for the tangential and cross sections, new values of 2.25 and 2.0 were hypothesized. Only the extreme values of the Meyer indexes (on the radial and cross section) turned out to be statistically significantly different.

Keywords: beech, birch, oak, pine, merbau, tangential section, radial section, cross section, Meyer hardness index

INTRODUCTION

Wood hardness tests are based on indenting a ball, less often a cylinder or other shape. Dynamic methods, such as the Leeb test, are less popular for wood [Bembenek, Kowalski, Pawlik 2021]. The best known are the Brinell and Janka methods using a ball with a diameter of 10 mm or 11.284 mm (with a cross-sectional area of 1 cm^2). The measure of the hardness of the Janka method is the maximum force needed for complete indentation or the pressure (stress) caused by this force related to the cross-sectional area of the ball (indentation projection area). The measure of Brinell hardness is inversely proportional to the depth of the indentation, and thus inversely proportional to the total area of the indentation [Koczan, Karwat, Kozakiewicz I2021]. Despite the phenomenon of the Brinell measure, which consists in simultaneously referring to the depth of the indentation and the area of the indentation, this phenomenon has no physical theoretical justification.

To verify the phenomenon of the Brinell measure, Meyer discovered and studied the law, known today as Meyer law, describing the power (exponent) dependence between the indenting force and the diameter of the indentation made by a ball [Meyer E. 1908; Jimeno Terraza 1950; Vörös, Németh 2020]:

$$F = Ad^n \tag{1}$$

where: F – maximum value of the indenting force, A – proportionality coefficient, d – indentation diameter, n – Meyer index. More source details can be found in a German prewar textbook on inorganic chemistry [Meyer R. J., Pietsch 1937], the first author of which was probably related to the discoverer of the law (1). An exemplary determination of Meyer indexes for wood can be found in [Huber K. 1938]. However, the results of wood indentations in [Miyajima 1955], obtained under the influence of four or five different loads, can be used to determine the Meyer indexes.

The author determined Meyer indexes twice, the first time for beech wood [Koczan, Karwat, Kozakiewicz I2021], the second time for aluminum and copper [Koczan, Karwat, Kozakiewicz IX2021]. The second study initiated the idea of verifying the constancy of the Meyer index value for wood. The first study suggested a value of 2.5 on a longitudinal (oblique: radially tangential) section. On the other hand, the work [Huber K. 1938] gives a value of about 3.0 Meyer index for a longitudinal section, and a value of about 2.0 or less for a cross section.

MATERIAL AND METHODS

In addition to the reference beech wood, it was decided to study the representatives of the four basic structural types of wood (Tab.1): birch (diffuse-porous), oak (ring-porous), pine (coniferous wood), merbau (exotic hardwood). The research include tangential (T), radial (R) and cross-section (L) planes of wood in one states of absolute humidity (about 7.0–8.5%). Thus, each type of wood was tested in three potentially different ways. If these methods are included for the four types of wood tested, along with the reference beech, this gives 15 independent measurements of the Meyer hardness index.

Table 1. Characteristics of the examined wood species

Ordinary name	Scientific name	Type of wood	Density [kg/m^3]	Absolute moisture
European Beech	*Fagus sylvatica* L.	diffuse-porous	667.0±5.7	(7.20±0.04)%
Silver Birch	*Betula pendula* Roth	diffuse-porous	540.0±6.5	(6.96±0.12)%
Pedunculate Oak	*Quercus robur* L.	ring-porous	600.7±17.1	(7.95±0.07)%
Scots Pine	*Pinus sylvestris* L.	coniferous	623.9±6.3	(7.77±0.05)%
Merbau	*Intsia bijuga* Kuntze	exotic diffuse-porous	831.6±5.0	(8.56±0.05)%

± standard deviation

The measurement of one Meyer index is based on 10 indentations in the diameter range from 3 mm to 8 mm, made with a ball with a diameter of 10 mm, subjected to the pressure of the maximum force with a value appropriately selected for the size of the indentation and the type of wood. The main wood samples were size of 20 × 20 × 300 mm, but each was cut into 10 smaller samples of 20 × 20 × 28 mm. Thus, each wood species was represented in the probing tests by ten elementary samples (N=10).

The samples are about two times smaller than the Brinell test standard for flooring materials [EN 1534:2010] (50 × 50 mm × board thickness) and the Janka test standard [PN-D-04109:1954] (50 × 50 × 40 mm). However, if we take into account that in the standard [PN-D-04109:1954] of the Janka method, the distance of the indentation edge from the edge of the sample should not exceed 10 mm, then theoretically the minimum sample size could be 30 × 30 × 30 mm. Due to the incompleteness of the indentations (3–8 mm), the minimum sample is reduced to 28 × 28 × 28 mm. Thus, a 20 × 20 × 28 mm test sample may be exceptionally acceptable due to its probing nature, the more so that the maximum possible forces are not used, as in the Janka method. However, the standard [EN 1534:2010] assumes a larger distance of 20 mm, between the center of the indentation and the edge of the sample. This gives a minimum board sample area of 40 × 40 mm. However, the standard allows smaller samples for smaller floor elements, but states that indentations must then be made on the axis of the element (in the middle). Therefore, 20 × 20 × 28 mm specimens made from available 20 × 20 × 300 mm bars may be conditionally accepted if indentations are made in the center of the walls.

Indeed, the indentations were made in the middle of the walls of the T, R, L sections. Opposite walls were not used so as not to deform the earlier indentations in any way. The speed of the head movement was 1.5 mm/min, and after stopping it, the indentation was waited for about 1 minute until the indentation was fixed and the tension was partially relaxed and stabilized. An Instron testing machine with a maximum force of 100 kN (10 t) was used for the measurements, but its capacity was used up only to 4.022 kN.

Then, using a magnifying glass on a tripod and appropriate lighting, the indentations were outlined with rectangular grids with a 0.3 mm mechanical pencil. Two sides of this rectangle d_1 and d_2 (distances of the inner sides of the lines) were measured with an electronic caliper with a reading accuracy of 0.01 mm. The measured values were averaged:

$$d = \sqrt{d_1 d_2} \tag{2}$$

It seems that indentation diameter shows less tendency to elastic recovery than indentation depth (Sydor, Pinkowski, Kučerka, Kminiak, Antov, Rogoziński 2022).

Then, the power correlation for the relationship F=F(d) was examined. After taking the logarithm of dependence (1) on both sides, it can be considered as a linear regression:

$$\log(F) = \log(A) + n\log(d) \quad \leftrightarrow \quad y = a_0 + a_1 x \tag{3}$$

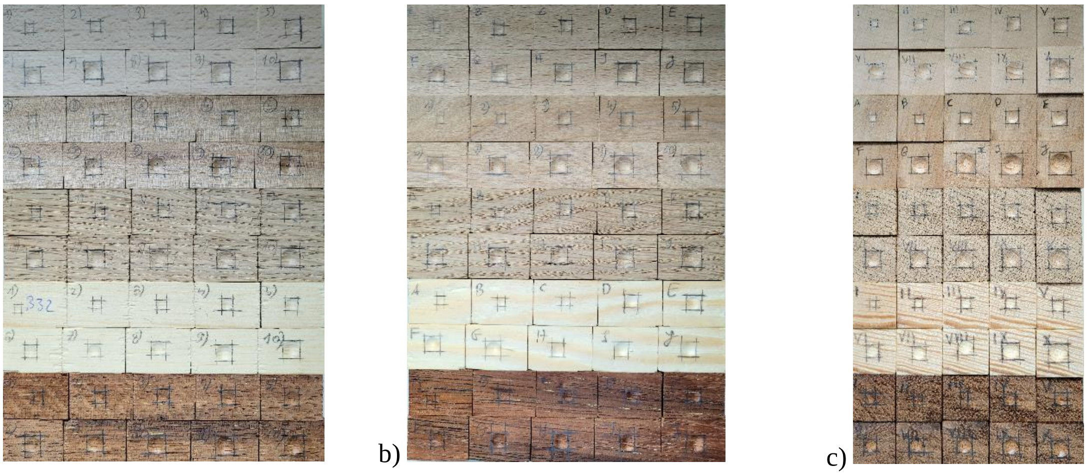
So the Meyer index is a slope in linear regression, just like the standard deviation, basically the standard error:

$$n = a_1 \quad , \quad \sigma(n) = \sigma(a_1) \tag{4}$$

Thus, on the basis of 10 measurement points, the Meyer index can be determined and its standard error can be estimated.

RESULTS AND DISCUSSION

Photographs of the samples and all their indentations in these probing measurement are shown in Fig.1. The small size of the samples in relation to the largest indentations has already been justified in the methodology based on the availability of the material and the considerations of the two hardness standards.



a) b) c)

Figure 1. View of all indentations on beech, birch, oak, pine and merbau wood samples in planes: a) radial R, b) tangential T, c) cross L

In the photo of cross sections (Fig.1c), it can be seen that the cut of some samples (especially oak) deviates from the ideal behavior of radial and tangential directions. This inaccuracy can be justified by the fact that initially the measurements were planned only on longitudinal and cross sections without distinguishing between radial and tangential sections. However, measurements carried out on beech and birch indicated that there are measurable differences in hardness and Meyer index between these sections.

Fig.2 (a,b,c) presents graphs of the dependence of the load force on the indentation diameter for three cross-sectional planes of beech wood. As the fourth comparative graph (Fig.2d) a graph for a birch cross section has been attached. The lower force values show that birch is significantly softer than beech, especially that the birch indentations exceeded 9 mm in diameter. In all four graphs, the coefficient of determination exceeded 0.98, so we can talk about a very good correlation of force with the power function of the diameter of the indentation.

Perhaps it would be more natural to consider the correlations in reverse order d=d(F). Then, it would be possible to experimentally determine the relative uncertainty of diameter measurements d and assess whether the applied caliper measurement methodology worked. However, in the probing studies, a simpler order of variables was adopted for the determination of the Meyer index.

All 15 determined Meyer indexes along with standard errors are included in Tab.2. Coefficients of determination (R^2) are placed next to these values to show how well the experimental points fit the power curve. A value lower than 0.9 was shown only by measurements of pine on the tangential plane. This result was predictable, because pine has a very unequal hardness of late and early wood, which is most noticeable at the tangential section.

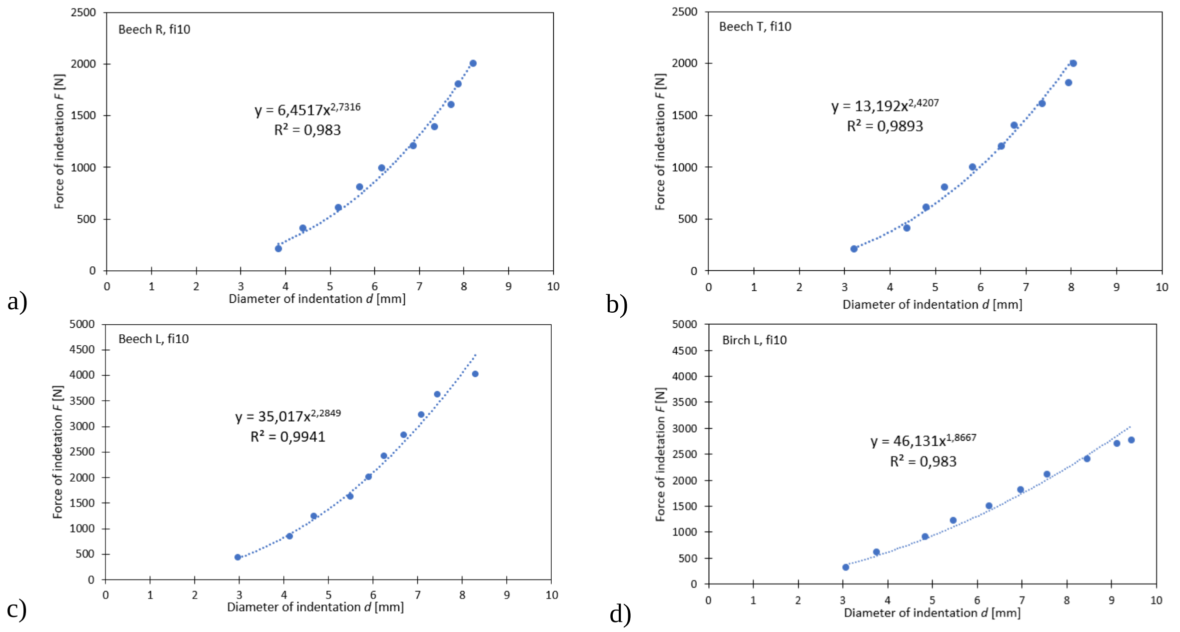


Figure 2. Power regression of the measured pressing force against the indentation diameter in three anatomical planes of beech wood and in the cross plane of birch: a) radial R, b) tangential T, c) cross L, d) cross L for birch

Table 2. Results of Meyer hardness index measurements for five types of wood in three planes R, T, L

Wood name	Meyer harndness index ± standard error (and coefficient of variation)		
	Radial plane R	Tangential plane T	Cross plane L
Beech	2.73±0.13 (0.9830)	2.42±0.09 (0.9893)	2.28±0.06 (0.9941)
Birch	2.54±0.07 (0.9941)	2.27±0.11 (0.9805)	1.87±0.09 (0.9830)
Oak	2.44±0.18 (0.9592)	2.26±0.13 (0.9744)	2.22±0.03 (0.9983)
Pine	2.14±0.18 (0.9468)	1.75±0.29 (0.8213)	1.80±0.11 (0.9729)
Merbau	2.21±0.5 (0.9952)	2.73±0.15 (0.9754)	1.71±0.05 (0.9922)
Arithmetic mean	2.41±0.11	2.28±0.16	1.98±0.12

Tab.2 also gives the arithmetic mean of the Meyer indexes for the R, T, L sections. The standard deviation of the mean, i.e. the standard error, was also calculated for these means. It turns out that the standard errors calculated by other methods have similar values.

The Meyer indexes from Tab.2 along with their standard errors are shown in the column chart in Fig.3. This chart shows that in addition to the already discussed pine, the merbau results also break out, especially for the tangential plane. It's hard to tell what caused it. This merban measurement did not have a small coefficient of determination of 0.9754 or a large standard error of 0.15. Perhaps the method of surface processing was important here [see Bembenek, Kowalski, Pawlik 2021]. The T face was planed to a high gloss and the R face was sawn smooth with a good quality saw. Both surfaces were smooth, so there was no reason to correct them at that time.

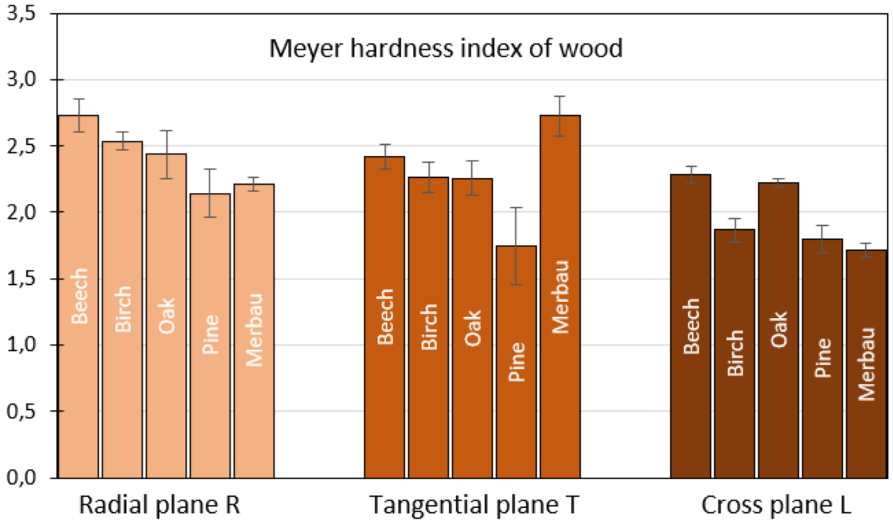


Figure 3. Comparison of Meyer indexes of five wood species in three anatomical planes using a column chart

At the end of the presentation of the results, it is worth seeing the graphs of the dependence of forces and diameters of indentations for a species other than the reference beech. Fig.4 shows the graphs for the radial section, which showed the highest Meyer index on average.

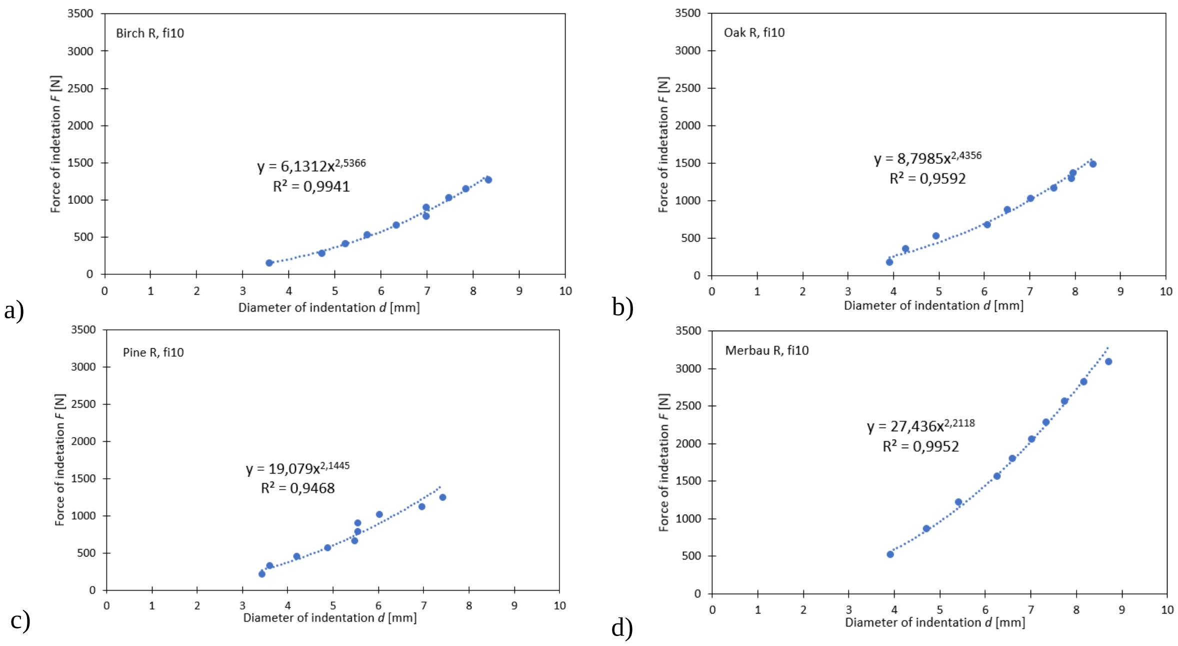


Figure 4. Power regression of the measured pressing force against the indentation diameter in the radial plane R for wood species: a) birch, b) oak, c) pine, d) merbau

The correlation for birch and merbau showed a coefficient of determination of over 0.99. This coefficient in the case of a radial section has a high value of 0.95 even for pine. Unfortunately, for pine, a somewhat small range of diameter indentations (3.5–7.5 mm) was measured. Large and small diameter indentations can be crucial to the value of the Meyer index. Probably the small diameter range of indentations is the reason for the low measuring value of the Meyer index of pine.

CONCLUSIONS

On the basis of performed measurements the following conclusions were drawn:

1. The averaged Meyer index of wood on the radial section R (n=2.41≈2½) is statistically significantly greater than the averaged Meyer index on the cross section L (n=1.98≈2).
2. The averaged Meyer index of wood on the tangential section T (n=2.28≈2¼) is intermediate to the radial R and cross L sections, but this result is not yet statistically significant.
3. The obtained measurements indicate that the Meyer index depends more on the arrangement of wood fibers and wood rays than on the type of wood, its density and hardness.
4. Probing tests should be extended with appropriate more accurate tests characterized by: more samples, more indentations with a wider range, larger sample sizes, precise cutting of the sample surfaces in R/T/L planes, as well as measurements of samples with higher humidity.

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Streszczenie: *Pomiary sondażowe wskaźnika twardości Meyera przekroju promieniowego, stycznego i poprzecznego różnych rodzajów drewna.* Wskaźnik Meyera jest to wykładnik potęgi w zależności siły wgniatającej od średnicy wcisku pochodzącego od kulki. Materiał idealnie plastyczny winien mieć wskaźnik twardości Meyera równy 2, a idealnie sprężysty wartość 3. Dotychczasowe badania autora i współpracowników wskazały, że wskaźnik Meyera drewna bukowego wynosi 2.5, aluminium 2.25, zaś miedzi 2.0. Zrodziło to przypuszczenie, że wskaźnik twardości każdego drewna wynosi około 2.5. Postanowiono zweryfikować tą hipotezę dla różnych rodzajów drewna na różnych płaszczyznach anatomicznych przekroju. Badania takiej różnorodności musiały mieć zatem charakter sondażowy. Niemniej te badania sondażowe wskazały, że różne rodzaje drewna w danych płaszczyznach przekroju mają zbliżone wskaźniki Meyera, ale w każdym przekroju jest to inna wartość. Zmierzona wartość średnia w przekroju promieniowym wyniosła 2.41, w stycznym 2.28 i poprzecznym 1.98. Zatem wyjściowa hipoteza wartości 2.5 potwierdziła się tylko dla przekroju promieniowego, zaś dla przekroju stycznego i poprzecznego powstały hipotezy nowych wartości 2.25 i 2.0. Jedynie skrajne wartości wskaźników Meyera (na przekroju promieniowym i poprzecznym) okazały się statystycznie istotnie różne.

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