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VARIABILITY OF BLACK LOCUST HARDNESS IN RELATION TO DIFFERENT MEASUREMENT DIRECTION AND LOCATION ALONG THE STEM

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ABSTRACT

The variability of black locust wood hardness along the stem determines potential uses for this type of material. Characterization of this parameter was conducted based on samples taken from black locust stands in the western of Poland. Study material drawn from each sample tree was divided into three groups (lower stem part, center of the stem and base of live crown) and measuring was performed in three directions (radial, longitudinal and tangential). Due to bimodal distribution of the data, longitudinal direction was analyzed separately from radial and tangential directions. For the longitudinal direction, significance of differences between various stem parts was confirmed ($p<0.001$), as well as the significance of differences between study sites ($p<0.001$). For the radial and tangential directions, significance of differences between sites, stem parts and trees was confirmed ($p<0.001$; $p=0.001$; $p=0.005$, respectively). Preferred wood material should come from lower stem part, taking into account the highest hardness in the longitudinal direction.

KEYWORDS: Hardness, wood mechanical properties, black locust, measurement direction.

INTRODUCTION

The properties of wood may be defined based on different mechanical features, in relation to the expected use of the timber. One such feature is the hardness of wood – a trait of importance given the predisposition towards deformation in the species (Doyle and Walker 1985). Depending on species, the hardness of wood determined in the transverse directions may be of significance to the quality and technology of production of parquet flooring and furniture veneers (Heräjärvi 2004, Swaczyna et al. 2011). As with other wood durability features, values in the case of this feature have been found to vary in line with a gradient of tree height, the radial gradient, and a position within either earlywood or latewood (Hirata et al. 2001, Mareš and Blahovec 2004). Wood hardness correlates significantly with the direction of fibres (Holmberg 2000), as well as density (Heräjärvi 2004). In contrast, Grekin amd Verkasalo (2013) found that least significance in shaping variation in timber hardness are growth conditions associated with location of the given stand.

Research on the silver birch has in turn made it clear how hardness of wood in this species is related to tree age. According to Möttönen et al. (2004) changes in the density of the wood reflects with tree age). Variation in hardness in relation to structure are associated with age and growth conditions, has been confirmed for both coniferous species and some broadleaves, with this fact making it likely that similar relationships also apply to the black locust. However, only a few studies have confirmed the existence of link between the hardness of black locust wood and trends as regards the way in which this trait is measured (Keil et al. 2011, Dubovský and Rohanová 2007a, 2007b). Fuller determination of the relationship between hardness of wood and location of a sample along a stem, as well as tree age, would thus seem to be of importance if utilisation of black locust timber is to be optimised. It was for this reason that work was undertaken as regards the conditioning of variation in the hardness of black locust wood, in relation to the direction of measurement, the part of the stem being considered, tree age and growth conditions.

MATERIAL AND METHODS

Analysis of the hardness of black locust wood was carried out by reference to study material obtained from three straight-stemmed stands growing within the Forest Districts of Krosno (KRO), Wołów (WOL) and Mieszkowice (MIE) (Klisz et al. 2014). The methodology used in selecting the research objects is presented in earlier studies (Wojda et al. 2013, Klisz et al. 2015). The objects were characterised by similar stand ages and values for biometric features (Tab. 1). However, the WOL site was shown to stand out with its more-nutrient-poor habitat conditions compared with those present at the KRO and MIE sites (respectively representing fresh mixed/coniferous forest and fresh mixed/broadleaved forest). In turn, at the KRO site, as distinct from all others, the trunks of the sample trees were shaded by lower specimens of Norway spruce.

Tab. 1: Locations of analyzed stands and selected assessment and valuation features. FMBF – fresh mixed/broadleaved forest, FMCF – fresh mixed/coniferous forest.

Forest District	Compartment	Area (ha)	Forest site type	Age	DBH (cm)	Total height (m)	Crown length (m)	Site quality class	Stand stocking	Geographical location
Krosno (KRO)	90b	1.14	FMBF	31	24.7	24.8	9.21	I	0.9	N 52 5 40.2 E 14 58 13.7
Wołów (WOL)	194f	2.86	FMCF	38	21.1	22.7	9.85	I	0.8	N 51 25 12.5 E 16 34 41.8
Mieszkowice (MIE)	210j	1.31	FMBF	46	26.0	24.5	11.14	I	1.0	N 52 51 31.5 E 14 11 40.7

At each site, 10 sample trees were selected to represent the stand as a whole, from among trees of Kraft Classes I and II. The selected specimens had straight stems, as well as symmetrical and well-shaped crowns. Attention was also paid to ensuring that trees had a healthy assimilatory apparatus, also bearing no obvious signs of pathogen attack. The sample trees were cut, with the trunk between breast height and the base of the crown then being used to generate three sections of stem of 3 m in length (Fig. 1).

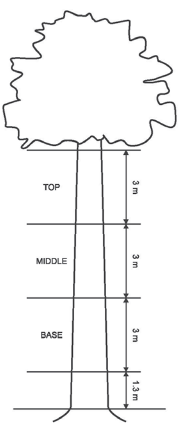

Fig. 1: Parts of tree using to collecting wood samples.

Stem sections were cut immediately at the sawmill. The lumber was kiln-dried to a humidity of 12±2%. From the material prepared in this way samples of dimensions 30 × 50 × 50 mm were cut in the following anatomical directions: longitudinal, radial and tangential. After exposure to a normal climate condition (65%/25C°), these were made subject to measurements of hardness in the longitudinal, radial and tangential directions, according to the Brinell method, and following the principles set out in the PN-EN 1534:2011 quality standard.

Given the bimodal nature to the distribution of results, separate analyses were made in the case of the longitudinal direction, as well as the radial and tangential directions. Account was taken of quality variables: site, part of the tree stem – as well as the possible interactions between these effects, plus the tree (nested within the site). In the case of the longitudinal direction to hardness measurements, analysis of variance was performed according to the linear model 1, i.e.

$$HB_{ijk} = \mu + S_i + SP_j + SSP_{ij} + T_k(S_i) + E_{ijk} \quad (1)$$

where: HB_{ijk} - share of hardness for the n^{th} tree at the i^{th} site (n=1,...,10; i=1,...,3) and with the j^{th} stem part (j=1,...,3),
μ - overall mean,
S_i - effect of the i^{th} site,
SP_j - effect of the j^{th} stem part,
SSP_{ij} I - effect of the interaction between the effect of the i^{th} site and the j^{th} stem part,
$T_k(S_i)$ - the k^{th} tree nested within the effect of the i^{th} site,
E_{ijk} - random error characterising the n^{th} tree at the i^{th} site and with the j^{th} stem part.

In the case of the radial and tangential hardness directions, analysis of variance was performed according to the linear model 2, i.e.

$$HB_{ijkl} = \mu + S_i + SP_j + D_l + SSP_{ij} + SD_{il} + SPD_{jl} + SSPD_{ijl} + T_k(S_i) + E_{ijk} \quad (2)$$

where: HB_{ijk} - share of hardness for the n^{th} tree at the i^{th} site (n=1,...,10; i=1,...,3) and with the j^{th} stem part (j=1,...,3),
D_l - effect of the l^{th} direction,
SD_{il} - effect of the interaction between the i^{th} site effect and the l^{th} direction effect,
SPD_{jl} - effect of the interaction between the j^{th} stem part and the l^{th} direction effect,
$SSPD_{ijl}$ - effect of the interaction between the effect of the i^{th} site and the j^{th} stem part and the l^{th} direction, with other effects being the same as in model 1.

The normality of the models' residuals was checked using Shapiro-Wilk test, while the equality of variances was made subject to Bartlett and Levene tests, homogeneous groups were determined using Tukey HSD Test.

Computations were performed using the GLM procedure, with SAS 9.3 software (SAS Institute 2011).

RESULTS AND DISCUSSION

Highest values of hardness were observed for measurements in the longitudinal direction while for the radial and tangential directions the values of hardness were similar (respectively: 76.62, 42.92, 43.60) (Tab. 2). Simultaneously the standard deviation reached the highest values for longitudinal direction, while the coefficient of variation was similar for all three directions.

Tab. 2: Descriptive statistics for hardness in the longitudinal, radial and tangential direction characterizing different parts of the stem for different site (SD – standard deviation, CV – coefficient of variation).

Site	Stem part	Longitudinal direction					Radial directions					Tangential directions				
		mean	SD	CV	min	max	mean	SD	CV	min	max	mean	SD	CV	min	max
KRO	LS	72.60	4.77	0.07	66.69	81.82	46.01	3.56	0.08	39.68	51.74	45.33	3.00	0.07	42.52	51.71
	CS	76.06	3.92	0.05	69.64	82.45	44.02	2.71	0.06	38.01	46.38	44.58	1.74	0.04	42.18	47.09
	TS	79.42	5.66	0.07	72.67	88.38	44.42	3.00	0.07	39.81	49.75	45.57	3.28	0.07	40.69	51.88
MIE	LS	74.43	3.05	0.04	68.69	79.20	44.42	3.00	0.07	39.81	49.75	41.09	2.21	0.05	37.70	43.82
	CS	76.24	4.27	0.06	71.15	83.12	38.75	1.94	0.05	36.29	41.78	40.29	2.28	0.06	36.83	43.31
	TS	78.33	6.41	0.08	67.51	88.28	38.81	4.75	0.12	29.74	45.76	42.15	4.42	0.10	36.47	51.71
WOL	LS	77.14	4.92	0.06	71.24	89.27	43.45	2.49	0.06	38.76	46.06	44.85	2.97	0.07	38.85	50.65
	CS	76.04	6.26	0.08	66.01	89.36	43.91	2.09	0.05	39.67	47.27	43.48	2.39	0.05	39.97	48.08
	TS	79.35	4.39	0.06	69.64	84.15	42.52	2.10	0.05	40.10	45.90	45.04	2.97	0.07	41.29	49.77
Multi-site		76.62	5.19	0.07	66.01	89.36	42.92	3.71	0.09	29.74	51.74	43.60	3.34	0.08	36.47	51.88

The longitudinal direction.

Analysis of variance confirmed the significance of factors relating to stem-part, as well as the tree within the site (at $p < 0.001$ in each case). At the same time, it could not confirm the significance of the factor of site, or of its interaction with the factor of stem-part (Tab. 3). Such results confirm the overriding importance of the factor of location of sample along the trunk when it comes to any determination of wood hardness. This factor would seem to be of greater importance to the shaping of the feature than tree-age, given that this is an indicator of changes in the anatomical structure of wood.

Tab. 3: Analysis of variance for hardness in the longitudinal direction characterizing different parts of the stem.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	p
Site	2	173.794	86.8968	1.52	0.221
Stem part	2	1381.19	690.596	12.05	<0.001
Site × Stem part	4	379.109	94.7772	1.65	0.160
Tree (Site)	27	4732.32	175.271	3.06	<0.001
Error	413	23662.2	57.2934		

The top parts of stems were found to differ significantly from the central and lower parts (Tab. 4). The observed variation in hardness with height of measurement up the stem had found confirmation previously in work on maritime and Scots pines (Dumail et al. 1998, Grekin and Verkasalo 2013). Longitudinal measurements for Scots pines of Scandinavian origin revealed the opposite trend for variation in hardness along the trunk than was obtained in the above studies, in that values for this feature were progressively lower higher up the tree. A similar relationship has been confirmed in the cases of both the silver and the downy birch (Heräjärvi 2004). Lower stem parts were characterized by the lowest values for hardness at the WOL and KRO sites, where the average age of trees does not exceed 40 years. The low value for hardness noted in trees from the two youngest sites would seem to confirm the relationship between this trait and trees' rates of growth. Young trees manifesting a high dynamic for growth generate low-density wood, with this feature being found to correlate closely with hardness (Dumail et al. 1998, Grekin and Verkasalo 2013).

Tab. 4: Means, homogeneous groups and descriptive statistics for hardness in the longitudinal direction in different stem parts (LS – lower stem part, CS – central stem part. TS – top stem part, SD - standard deviation, CV - coefficient of variation); means with the same letter are not significantly different at p ≤ 0.05.

Stem part	Mean ($N \cdot mm^{-2}$)	Homogeneous groups	SD	CV	Min	Max
LS	74.85	a	4.59	0.06	66.69	89.27
CS	76.11	a	4.75	0.06	66.01	89.36
TS	79.04	b	5.38	0.07	67.51	88.38

The radial and tangential directions

In the case of the radial and tangential directions, it proved possible to confirm significance in the case of the effects of site, stem part and wood within the site, as well as in relation to the stem part × site interaction and the stem part × direction interaction (respectively at the levels P <0.001; <0.001; 0.005; 0.002 and 0.002). In contrast, no confirmation was offered for the idea that direction was of significance, or else the site × direction interaction (P>0.05 in all case; Tab. 5).

Tab. 5: Mean value for hardness in the radial and tangential directions at experimental sites; means with the same letter are not significantly different at p ≤0.05.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	p
Site	2	2795.76	1397.88	55.06	<0.001
Stem part	2	468.13	234.065	9.22	<0.001
Direction	1	35.572	35.572	1.4	0.237
Site × Stem part	4	253.361	63.3403	2.49	0.042
Site × Direction	2	42.6079	21.3039	0.84	0.432
Stem part × Direction	2	321.204	160.602	6.33	0.002
Site × Stem part × Direction	4	429.946	107.486	4.23	0.002
Tree (Site)	27	1286.3	47.6407	1.88	0.005
Error	413	21580	25.3882		

The highest average values for hardness were as noted in trees from the WOL site, while the lowest characterized the KRO-site specimens. At the same time, all the sites were found to differ significantly from one another (Tab. 6).

Tab. 6: Mean values for hardness in the radial and tangential directions in different stem parts (LS – lower stem part, CS – central stem part. TS – top stem part); means with the same letter are not significantly different at p ≤0.05.

Site	Mean ($N \cdot mm^{-2}$)	Homogeneous groups	SD	CV	Min	Max
KRO	40.89	a	2.90	0.06	38.01	51.88
MIE	43.82	b	3.72	0.09	29.74	51.71
WOL	45.12	c	2.57	0.06	38.76	50.65

Unlike in the case of the longitudinal direction to the measurement of hardness, measurements in the radial and tangential directions involving the lower part of the stem were characterized by the highest average values for hardness, with these differing significantly from the values obtained in the case of the central and top parts of stems (Tab. 7).

Tab. 7: Means, homogeneous groups and descriptive statistics for hardness in the radial and tangential directions in different stem parts (LS – lower stem part, CS – central stem part. TS – top stem part); means with the same letter are not significantly different at p ≤ 0.05.

Stem part	Mean ($N \cdot mm^{-2}$)	Homogeneous groups	SD	CV	Min	Max
CS	42.54	a	3.21	0.07	37.70	51.74
TS	43.03	a	3.05	0.07	36.29	48.08
LS	44.26	b	4.09	0.09	29.74	51.88

Dumail et al. (1998) found in 11-years old and 20-years old *Pinus pinaster* trees grown in France a strong relationships between radial position of specimens and wood mechanical properties. The authors referred to an observed increase in hardness and basic density values along the radial gradient, in association with progressively greater distances from the pith. This relationship resembles the one involving higher density of wood in an outward direction in being linked with progressively more-limited widths of growth rings, as well as a greater share in rings accounted for by the thick-walled cells of latewood (Mareš and Blahovec 2004). Above findings are in accordance with our previous study on hardness-density relationships in black locust (Klisz et al. 2015b). The largest difference between the lower stem part and the central and upper stem parts was to be observed among trees from the KRO site, while such differences were in turn most limited at the MIE site.

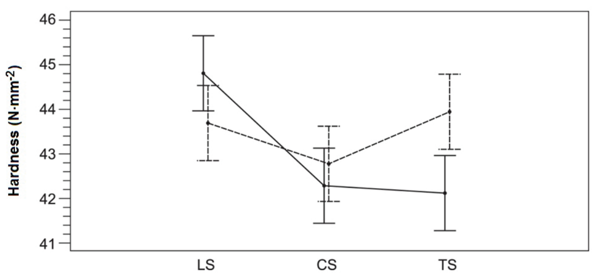

Fig. 2: The stem part × site interaction in the case of hardness measured in the radial and tangential directions (WOL –Wołów site, KRO –Krosno site, MIE –Mieszkowice site; continuous line – lower part of stem, dotted line – top part of stem, dashed line – central stem part).

The comparison in question is one between the sites with the youngest and oldest stands (Fig. 2), with the above relationship seemingly confirming the significance capable of being attached to the age-related trend as black locust trees are selected from the point of wood hardness. Only in the case of the top stem part was hardness measured in the radial direction found to differ significantly from that measured in the tangential direction (P<0.05) (Fig. 3).

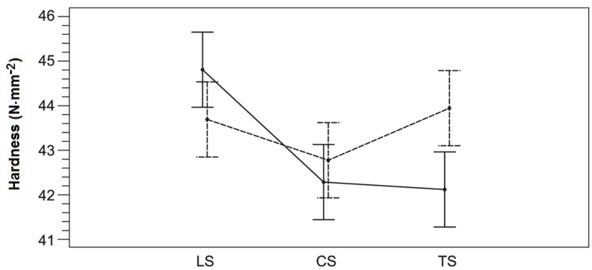

Fig. 3: The stem-part × direction interaction for measurements of hardness made in the radial and tangential directions (LS – lower stem part, CS – central stem part, TS – top stem part, continuous line – radial direction, broken line – tangential direction).

The comparison based on directions

Hardness defined in terms of N·mm^{-2} in the longitudinal direction was characterised by mean values that were significantly higher ($p<0.001$, analyses not presented) and with the highest coefficient of variability, as compared with the radial and tangential directions (the respective figures being 76.62 and 8.29%, 42.92 and 6.19%, 43.60 and 5.29%). This results correspond with this finding having being confirmed in the course of other research (Keil et al. 2011, Dubovský and Rohanová 2007a, 2007b). In the work carried out by Keil et al. (2011), a high degree of mean hardness in the case of the longitudinal direction was noted, with the coefficients of variation being lowest (88.52 and 5.23% respectively). In contrast, in the work by Dubovský and Rohanová (2007a, 2007b), wood hardness was found to be highest where the coefficient of variation was highest (the respective figures being 100.32 and 11.60%). While the authors of the research referred to use the Janka method to determine the hardness of wood, the confirmed correlation between Janka and Brinell hardness justifies the making of comparisons between results obtained using the two different methods (Bektas et al. 2001). However, as information is also lacking as regards the ages and origins of trees sampled by the cited authors for hardness examinations, it remains difficult to account for the disparities between the results.

Work on the hardness of black locusts from Belgium, carried out in line with the NBN 225 standard, in turn confirmed that values for this feature are higher in the case of the tangential direction, as set against the radial (Pollet et al. 2012). Taking account of an average age for trees from the research sites in Belgium that far exceeds those at the Polish sites (with values of 61 – 100 years comparing with 31 – 46 years respectively), it may be presumed that the trend for higher hardness values in the tangential direction as compared with the radial direction is maintained in mature stands of the black locust irrespective of age. A similar trend for the highest value for hardness to apply in the longitudinal direction has been confirmed in studies conducted for coniferous species (Dubovský and Rohanová 2006).

CONCLUSIONS

The hardness of wood in the black locust is characterised by a trend involving variation with the height up the trunk at which the measurement is made. In the case of measurements made in the longitudinal direction, hardness is seen to increase with tree-height, albeit with the top part of the stem found to differ significantly from the central and lower parts. In contrast, where the measurements made involved the radial and tangential directions, it is possible to observe the reverse trend, with hardness being lower in trees that have attained greater heights. These relationships would seem to have their basis in the mechanics of the trunk, as determined by the ring-porous nature of wood's anatomical structure and the presence of simple fibrosity arising as a result of the remodelling of the spiral fibrosity that developed at the outset. The black locust is a species capable of generating diffuse-porous wood structure of braided fibrosity, on condition that there are growth conditions optimal for this kind of anatomical structure, stable climatic conditions, and growth in the circumstances of the trunks of trees being shaded by others, and with crowns being sheltered from the action of gusts of wind. Such conditions work to encourage straightness of the stem in trees with a highly-cleaned stem, with this in turn encouraging a uniformity of wood durability traits, including as regards hardness. The lowest values for hardness of wood observed in trees at the two youngest sites can be associated with low-density, as in turn determined by the high rate of growth to be observed in this species in their first 30 years. Such a relationship allows for the formulation of guidelines for optimal age of utilisation in the case of black locust wood destined for use in the manufacture of products characterised by a high degree of durability. Differentiation to the hardness of wood from black locust trees originating at different heights up the trunk, as well as trees with different densities of wood reflecting rates of growth both point to the importance of selectivity when it comes to the timber utilised in applications associated with a high degree of durability of wood. Wood from markedly hard-wooded black locusts should therefore be harvested from trees with a stabilised rate of growth (aged 40 and over), from the lower part of the stem.

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REFERENCES

1. Bektas, I., Alma, M.H., As N., 2001: Determination of the relationships between Brinell and Janka hardness of eastern beech (*Fagus orientalis* Lipsky), Forest Products Journal 51(11-12): 84–88.
2. Doyle, J., Walker, J.C.F., 1985: Indentation hardness of wood, Wood and Fiber Science 17 (3): 369–376.
3. Dubovský, J., Rohanová, A., 2006: Static hardness of chosen coniferous species wood, Annals of Warsaw Agricultural University, Forestry and Wood Technology 243(58): 239–43.
4. Dubovský, J., Rohanová, A., 2007a: Static and dynamic hardness of chosen wood species, pp. 27–32 in Proceedings of the 2nd International Scientific Conference Woodworking Technique, Zalesina, Croatia.
5. Dubovský, J., Rohanová, A., 2007b: The hardness of ring-porous wood of chosen tree species, Acta Facultatis Xylologiae 49(1): 5–17.
6. Dumail, J. F., Castéra, P., Morlier, P., 1998: Hardness and basic density variation in the juvenile wood of maritime pine, Annals of Forest Science 55(8): 911–923.
7. Grekin, M., Verkasalo, E., 2013: Variations in and models for Brinell hardness of Scots pine from Finland and Sweden, Baltic Forestry 19(1): 128–136.

8. Heräjärvi, H., 2004: Variation of basic density and Brinell hardness within mature Finnish *Betula pendula* and *B. pubescenstems,* Wood and Fiber Science 36(2): 216–227.
9. Hirata, S., Ohta, M., Yasuo, H., 2001: Hardness distribution on wood surface, Journal of Wood Science 47(1): 1–7.
10. Holmberg, H., 2000: Influence of grain angle on Brinell hardness of Scots pine (Pinus sylvestris L.), Holz Als Roh- Und Werkstoff 58(1-2): 91–95.
11. Keil, G., Spavento, E., Murace, M., Millanes, A., 2011: Black locust (*Robinia pseudoacacia* L.) and Honey locust (*Gleditsia triacanthos* L.): technological aspects in relation with the use in solid wood products, Forest Systems 20(1): 21–26.
12. Klisz, M., Ukalska, J., Wojda, T., Jastrzębowski, S., Mionskowski, M., Szyp-Borowska, I., 2014: Radial growth of selected stands of black locust in Poland, Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology 85: 123–130.
13. Klisz, M., Wojda T., Jastrzębowski S., Ukalska J., 2015: Circumferential variation of heartwood in stands of Black locust (*Robinia pseudoacacia* L.). Drewno 58(195): 31–44.
14. Klisz, M., Ukalska, J., Noskowiak A., Wojda, T., Jastrzębowski, S., Mionskowski, M., Szyp-Borowska, I., 2015b: Correlations between Brinell hardness and basic density in Black locust - differences along the stem, Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology 91: 81–86.
15. Mareš, V., Blahovec, J., 2004: Variation of the tree ring micro-hardness demonstrated on spruce wood, Journal of Forest Science 50(3): 135–141.
16. Möttönen, V., Heräjärvi, H., Koivunen, H., Lindblad, J., 2004: Influence of felling season, drying method and within-tree location on the Brinell hardness and equilibrium moisture content of wood from 27–35-year-old *Betula pendula*, Scandinavian Journal of Forest Research 19(3): 241–249.
17. Pollet, C., Verheyen, C., Hébert, J., Jourez, B., 2012: Physical and mechanical properties of black locust (*Robinia pseudoacacia*) wood grown in Belgium Canadian Journal of Forest Research 42(5): 831–840. DOI:10.1139/x2012-037
18. SAS Institute Inc. 2011: SAS/STAT® 9.3 User's Guide. Cary, NC: SAS Institute Inc.
19. Swaczyna, I., Kędzierski, A., Tomusiak, A., Cichy, A., Różnańska, A., Policińska-Serwa, A., 2011: Hardness and wear resistance tests of the wood species most frequently used in flooring panels, Annals of Warsaw Agricultural University, Forestry and Wood Technology 87(76): 82–87.
20. Wojda, T., Klisz, M., Mionskowski, M., Szyp-Borowska, I., Szczygieł, K., 2013: Występowanie robinii akacjowej w Polsce oraz badania IBL nad tym gatunkiem (The occurence of black locust in Poland and the investigation on that species in Forest Research Institute), Proceedings of: Robinia akacjowa w krajobrazie Ziemi Lubuskiej, 29.10.2013. Łagów: 22–29.
21. PN-EN 1534, 2011 Podłoga z drewna. Oznaczanie odporności na wgniecenie (metoda Brinella). Metoda badania (Wood flooring - determination of resistance to indentation - test method)

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