

Dating and properties of subfossil oak wood

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Introduction

Dendrochronology of subfossil wood

Subfossil wood is unfossilized wood which has been deposited in rivers, swamps or moraine sediments for hundreds or thousands of years (Kaennel & Schweingruber 1995). In former literature, subfossil oak trunks are referred to as “black oak” because of their colour (Kalicki & Krapiec 1995). The change of the wood shade into black is caused by ferric components dissolved in water reacting with tannins present in oak. The intensity of the shade is primarily determined by the time for which the wood has been deposited and the nature of sediments. Besides the changes of the shade, there are also changes in physical and mechanical properties (Govorčin & Sinković 1995). Oak forests started appearing on the banks of central European rivers about 10,000 years ago, it means at the beginning of the Holocene (Becker 1982, Leuschner et al. 1986). However, the process in which the trunks were deposited is disputable. Most often it is considered that banks were eroded in meanders or during large floods (Kalicki & Krapiec 1995). The fallen trees then soaked up water and settled in deposited layers of channel alluvium under the water surface (Krapiec 1996). The trunks were gradually hidden beneath the accretion on the slip-off slope during the channel migration (Kalicki & Krapiec 1995). The slip-off slope is the relatively gentle slope at the inner edge of a meander. That is why subfossil oak trunks are often found in gravel pits when deposited sand and gravel is mined (Krapiec 1996). The lifespan of riverside oaks which grew on river banks during the Holocene is relatively short – 95% of the trees only have 150–400 growth rings. This fact is associated to the frequency of the above mentioned floods (Becker 1993). The age of wood is usually found out by the dendrochronological analysis. In the Czech Republic, this is a common method used for dating of wooden finds. To be able to date them there has to be a standard chronology available. The standard chronology is created for each tree species individually by gradual overlapping of growth ring sequences towards the past (Rybníček 2007). If the standard chronology for the particular species and the particular areas is not sufficiently long, dating is not possible and another way to establish the age has to be found. In such cases, the radiocarbon method is used; the method establishes the age of the organic material on the basis of the proportion of stable and unstable carbon (Libby 1955).

Subfossil wood properties

During the time subfossil wood is deposited in the specific conditions a number of complicated physical and chemical processes occur. These finally result in its fossilization (Habětín & Knobloch 1981). When the processes are in progress the wood structure changes which is naturally also reflected in the wood properties. Wood properties are affected by many factors, the most important of them being probably its chemical composition (Požgaj 1997). As regards the chemical composition, subfossil wood differs from recent wood by a considerably lower proportion of hemicelluloses. This is caused by the fact they are easily eluted in humid environment (Bednar & Fengel 1974, Govorčin & Sinković 1995, Wagenführ 2000). Therefore, when wood is deposited in the soil and water affects it, some substances are removed and carbonate of lime and silica sediment on the wood surface (Govorčin & Sinković 1995). For examinations we have chosen:

density, dimensional changes – swelling and shrinking, modulus of elasticity and compressive strength parallel to the grain, and hardness.

Physical properties

Density affects all the other physical and mechanical properties of wood to a considerable extent (Požgaj 1997, Gryc & Horáček 2007). When the measured density of subfossil oak wood is compared with recent wood, the values are more or less the same, or slightly rising (Govorčin & Sinković 1995). With regard to dimensional changes, there are considerable differences found when the values of recent and subfossil wood are compared. Wagenführ (2000) and Govorčin & Sinković (1995) present approximately twofold values of the percentage of subfossil oak shrinkage vis-à-vis recent oak.

Mechanical properties

Generally, mechanical properties of subfossil oak wood are smaller than the properties of recent oak (Govorčin & Sinković 1995). One of the most significant mechanical properties is compressive strength parallel to the grain. Compressive strength parallel to the grain is the basic ways of applying stress. The cross-section of wood is subjected to perpendicular pressure, i.e. the pressure is applied in the direction of the main building components of wood. Deformation takes a form of the material shortening (Matovič 1993). Compressive strength parallel to the grain of subfossil oak corresponds to about 70–80 % of the strength of recent oak (Bednar & Fengel 1974).

Because, as far as subfossil wood is concerned, the process of silicification, which means the replacement of wood cell structure by minerals, is involved, it is interesting to focus on wood hardness (Carrión 2003). The hardness is the ability of wood to resist indentation of another object into its structure. There are two tests used for establishing the hardness of wood: Brinell hardness test and Janka hardness test (Požgaj 1997). The professional literature states that the values of subfossil oak hardness are lower even though the cell structure was replaced by harder minerals.

Materials and methods

Sampling

Proper sampling for dendrochronological measuring is the main prerequisite for sample dating (Rybníček 2007). As the subfossil trunks were found at differing locations and differing positions, taking of individual samples demanded specific approaches. Sampling was carried out using a chain saw. This technique provided us with discs needed for dendrochronological analysis and larger pieces for the establishment of physical and mechanical properties.

Samples were taken in five locations; three of them were a river banks, two were gravel pits. The first location was the bed of the Bečva River, near Osek nad Bečvou. The village is located in the Přerov district, about 10 km to the east of Přerov. The second location was in the Morava River basin near Strážnice in South Moravia, which is close to Slovakian border. The last place where the samples were taken from a river basin was the Lužnice River near Majdalena in south Bohemia, at Austrian border. Further, samples were taken from gravel pit Tovačov, about 12 km to the west of Přerov. The last location is the gravel pit between the villages of Kostomlátky and Doubrava, located 5 km to the west of Nymburk. The pit lies on the Labe River.

Dendrochronology

At least two perpendicular directions were selected on the discs. The disc surface was worked in the two directions so that the ring borders were apparent. Samples prepared in such a way were measured using a specialized measuring table equipped with an adjustable screw device and an impulsemeter recording the interval of table top shifting, i.e. the tree ring width (Rybníček 2007). The tree ring width is measured in the direction perpendicular to the ring border with 0.01 mm

accuracy. The obtained tree-ring series were compared using the PAST 4 application. The synchronizable curves were used to create an average ring series which was then compared with available oak standard chronologies from Germany, Austria and Poland. The samples which could not be dated in this way were subjected to radiocarbon dating, the C14 method.

Wood density

The wood density is weight per unit volume with specific moisture (Požgaj 1997). The density was found out in compliance with ČSN 49 0108. For the actual measuring, we used testing samples of 20 × 20 mm in transversal dimensions and 25 ± 5 mm in length. Their weight was taken with accuracy of 0.01 g and dimensions with accuracy of 0.1 mm (Matovič 1993).

Dimensional changes

Wood shrinking is a process when wood dimensions are reduced as a consequence of a loss of bound water (Požgaj 1997). Shrinkage of subfossil wood was found out in compliance with ČSN 49 0128. For the actual testing, we used testing samples of 20 × 20 mm in transversal dimensions and 30 mm in length. The previously measured samples were dried in the temperature of 103 ± 2°C until the moisture content was 0% [completely dry] and then weighed again. Sample can be referred to as completely dry when there is no weight difference greater than 0.02 mm between two processes of weighing within the interval of 2 hours (ČSN 49 0128).

Swelling is the ability of wood to expand its dimensions by accepting bound water (Požgaj 1997). Swelling of subfossil wood was found out in compliance with ČSN 49 0126. The same samples were used for the testing of swelling as for the testing of shrinking. The completely dry samples obtained in the process of shrinkage measuring were used for the measuring of swelling. The samples that had cracked during drying were not included. The samples previously measured were drenched in distilled water with the temperature of 20 ± 2 °C until their dimensions were stable. Then they were measured again.

Mechanical properties

Mechanical properties were examined for normalized moisture of 12 %.

Compression strength parallel to the grain

The compression strength parallel to the grain was examined in compliance with ČSN 49 0110. Using ZWICK Z050 universal testing device pressure was applied to climatized/conditioned samples with the dimensions of 20 × 20 × 30 mm evenly with constant speed. Compression strength parallel to the grain was expressed in MPa (ČSN 49 0110). Results were rounded off to the nearest 0.5 MPa.

Static hardness

The static hardness of wood was examined using Janka method in compliance with ČSN 49 0136. We used climatized/conditioned samples with the dimensions of 50 × 50 × 50 mm and ZWICK Z050 universal testing device. A steel ball (an indenter) with the radius of 5.64 mm was forced into the depth of 5.64 mm, which created an indented area of 1 cm². The force necessary for indenting of the ball directly provides the hardness per 1 cm², which was converted to MPa. As we assumed the material will be more fragile, we only forced the ball into the half depth – 2.82 mm (Matovič 1993).

Results

Dendrochronology

All samples were dendrochronologically processed. Some of them were well synchronizable, therefore 4 average tree-ring curves were created (Tab. 1). The average tree-ring curve from Strážnice was dated using Moravian oak standard chronology. The reliability of the dating has been confirmed by statistical indicators (Tab. 2) as well as optical comparison of curves (Fig. 1). The average tree-ring curve of samples from Majdalena was reliably dated using Czech oak standard chronology (Tab. 3, Fig. 2). The remaining two average tree-ring curves (Tovačov 01 and Tovačov 02) and the tree-ring curve from Kostomlátky were sent out to be dated by the radiocarbon method.

Table 1: Dating of average tree-ring curves

average annual ring curves	number of annual rings	dendrochronological dating	standard chronology	radiocarbon dating
Tovačov 01	182	–	–	2675–2275 BC
Tovačov 02	204	–	–	265–50 BC
Kostomlátky	132	–	–	165 BC–241 AD
Strážnice 01	112	1322	morges	–
Majdalena 01	80	1519	czges	–

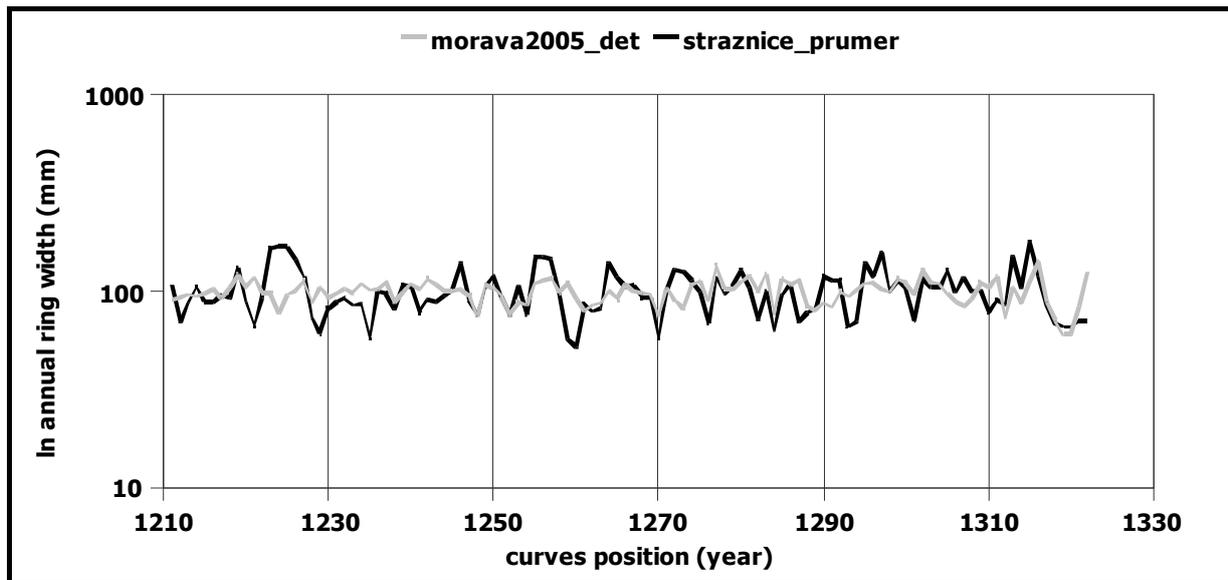


Figure 1: Synchronization of the average tree-ring curve from Strážnice (black) with the Moravian oak standard chronology morges 2005 (grey)

Table 2: Results of correlation of the average tree-ring curve from Strážnice with the Moravian oak standard chronology morges 2005

standard chronology	TBP	THO	GI	Overlap	EndYear
czges2005_det	6.72	7.53	73.8	80	1519

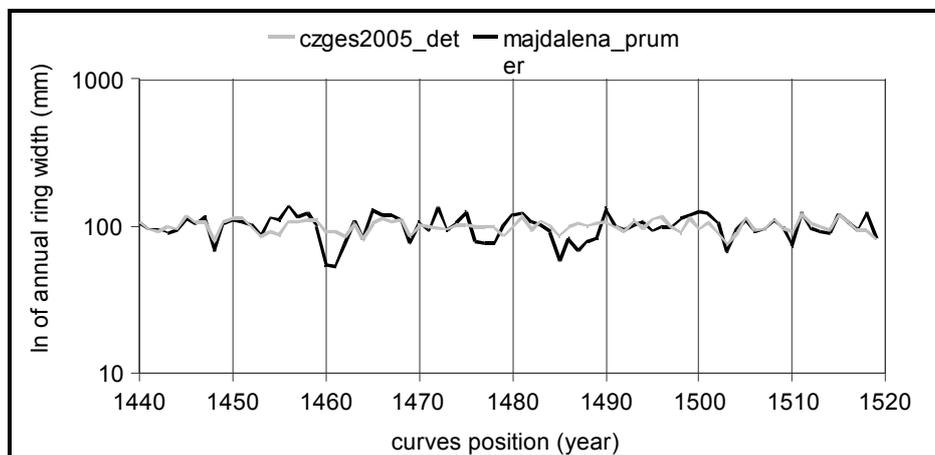


Figure 2: Synchronization of the average tree-ring curve from Majdalena (black) with Czech oak standard chronology czges 2005 (šedě)

Table 3: Results of correlation of the average tree-ring curve from Majdalena with Czech oak standard chronology czges 2005

standard chronology	TBP	THO	GI	Overlap	EndYear
czges2005_det	4.92	5.28	62.9	112	1322

Physical properties

Wood density

Table 4 shows the results of subfossil wood density from individual locations. The samples from Osek nad Bečvou correspond to the density of recent wood. However, there is a considerable difference in the samples from Tovačov, where the density is about 100 kg.m^{-3} lower and it decreases with age. On the contrary, the density of the sample from Kostomlátky achieves quite high values.

Dimensional changes

Table 4 shows the values obtained in measuring the shrinkage of subfossil oak. It is obvious that the percentages of shrinking are quite high and the differences between location are not very significant. Generally, we can conclude that the values correspond to the values presented in professional literature. Compared with recent wood, the values of subfossil wood are approximately twofold. As far as the swelling of subfossil wood is concerned, we can see the conclusion is the same as in case of shrinking. The values of swelling are similar to the values of shrinking.

Table 4: Values of physical properties of subfossil oak

properties	location / source	Tovačov (no.6)	Tovačov (no.19)	Osek nad Bečvou	Kostomlátky	Govorčín, Sinković (1995)	Vavrčik et al. (2008)	Tsoumis (1991)
	age of wood	2490–2190 BC	265–50 BC	945–405 BC	165 BC–241 AD	cca 2050 BC	recent	recent
wood density (kg.m ⁻³)	moisture 0 %	529.0	575.0	669.0	746.0	735.0	618.2	690.0
shrinkage (%)	longitudinal	0.88	0.42	0.46	0.91	1.09	–	0.40
	radial	7.43	6.53	8.36	10.36	9.37	4.70	4.00
	tangencial	15.89	11.78	15.32	14.41	17.22	8.40	7.80
	volumetric	22.83	17.85	22.74	23.97	25.79	13.00	12.20
swelling (%)	longitudinal	0.67	0.45	0.86	1.28	–	–	–
	radial	5.95	6.63	8.46	11.93	–	–	–
	tangencial	11.23	13.70	14.93	17.08	–	–	–
	volumetric	18.64	21.79	25.72	32.71	–	–	–

Mechanical properties

Compression strength parallel to the grain

Table 5 presents average values of the compression strength parallel to the grain of subfossil oak wood from the examined locations. The strength does not exceed the limit of 40 MPa and the modulus of elasticity does not exceed the limit of 9500 MPa.

Static hardness

The resulting average values of the static hardness of subfossil oak in all directions are presented in table 5. The hardness in the longitudinal direction exceeds 40 MPa, whereas the hardness in the transversal directions is about half of the value. Furthermore, it is slightly higher in the radial direction than in the tangential direction. The range of values of hardness in the transversal directions is quite wide in dependence on the density and the age of the wood – between approximately 19 MPa and 34 MPa.

Table 5: Values of compression strength parallel to the grain and static hardness of subfossil oak

properties (moisture 12 %)	location / source	Tovačov (vz.19)	Osek nad Bečvou	Tovačov (vz.6)	Kostomlátky	Wagenführ (2000)	Ugolev (1975)
	age of wood	265–50 BC	945–405 BC	2490–2190 BC	165 BC–241 AD	subfossil	recent
wood density (kg.m ⁻³)	moisture 0 %	575.0	669.0	529.0	746.0	630.0	650.0
compression parallel to the grain (Mpa)		32.63	39.95	29.40	39.19	38.00	57.50
Modulus of elasticity (MPa)		4634	9384	4846	7640	–	14600
hardness (Mpa)	longitudinal	42.8	–	41.6	52.4	44.0	67.5
	radial	27.3	–	22.3	33.5	23.0	56.0
	tangencial	20.6	–	19.1	27.2	–	49.0

Conclusion

The aim of the study was dendrochronological or radiocarbon dating and the examination of selected physical and mechanical properties of subfossil oak wood, and the comparison of the obtained results with the data presented in literature on subfossil and recent oak.

All samples were dendrochronologically processed and 4 average tree-ring curves were created. It was possible to date the curve from Strážnice (1322 AD) (Fig. 1, Tab. 2) and from Majdalena (1519 AD) (Fig. 2, Tab. 3) using oak standard chronologies for the Czech Republic. The radiocarbon method dated the average tree-ring curves of Tovačov 01 back to 2675–2275 BC, and Tovačov 02 to 265–50 BC and Kostomlátky to 165 BC–241 AD (Tab. 1).

Besides the basic indicator of density, the selected physical properties include the dimensional changes of wood, i.e. shrinking and swelling. Regarding mechanical properties, the attention focused on the compression strength parallel to the grain and the hardness of wood examined in all the three anatomical directions.

The results of wood density presented in table 4 show that there are considerable differences between individual locations. While the density of the sample from Osek nad Bečvou approximates the values of recent wood, the density of the sample from Kostomlátky, the youngest of the explored samples, significantly exceeds 700 kg.m^{-3} . In contrast, in the samples from gravel pit Tovačov the density is about 100 up to 200 kg.m^{-3} lower than presented in professional literature.

The average values of shrinking and swelling of samples from Osek nad Bečvou, Tovačov and Kostomlátky (Tab. 4) do not differ much, even with respect to their significantly differing age. Therefore, we can conclude that shrinking and swelling of subfossil oak does not change with time. When compared with the data presented in literature (Tab. 4), our results show that the dimensional changes are twice as high as those of recent oak wood. In contrast to the values of shrinking, the results of wood swelling in some cases vary to a great extent, especially in samples from Tovačov and in volumetric dimensional changes of samples from Kostomlátky. Because the values of subfossil wood swelling are not available in literature, they could not be compared.

The compression strength parallel to the grain is presented in literature to range between 70 and 80 % of the strength of recent oak. The resulting values of strength of the samples from Osek nad Bečvou 39.58 MPa and Kostomlátky 39.19 MPa (Tab. 5) confirm the theory. The values are comparable with results of subfossil oak presented by e.g. Wagenführ 2000 (Tab. 5). On the other hand, the strength of the Tovačov samples is considerably lower (30.33 MPa and 29.30 MPa), reaching about 55 % of the strength of recent oak. The lower strength of these samples is to a considerable extent affected by their lower density.

Wood hardness was tested using Janka method. Two samples of a different age from Tovačov and a sample from Kostomlátky were used to test the hardness. The averages of the resulting values of Tovačov samples are around 42 MPa in the longitudinal direction, 22–27 MPa in the radial direction and around 20 MPa in the tangential direction (Tab. 5). On the other hand, the Kostomlátky sample achieves much higher values even with respect to its higher density. The hardness of wood is 52.4 MPa in the longitudinal direction, 33.5 MPa in the radial direction and 27.2 MPa in the tangential direction. The lower hardness in the tangential direction in comparison with the radial direction can be explained by the orientation of pith rays in the wood. The results show that the hardness is lower in comparison with recent wood (Tab. 5), but also that there is a greater difference between the hardness in the longitudinal and the transversal directions. The hardness in transversal directions of subfossil wood amounts to about 45–65 % of the hardness in the longitudinal direction, whereas the hardness in transversal directions of recent wood amounts to about 70–80 % of the hardness in the longitudinal direction.

The outcome of the research is that the properties of subfossil oak wood in comparison with recent wood are quite different. The density is highly variable, the dimensional changes are considerably higher and mechanical properties are approximately 20–30 % lower. There are more possible explanations for the changes of properties. One of the theories is a biological degradation of wood which causes the decomposition of wood structure, and thus the change of properties (Klaassen

2008). Another theory can be based on the difference of the compositions of subfossil and recent oak wood.

It is hard to assess the influence of age on the properties of the samples as the samples from Tovačov are considerably different from all the others in all their parameters. However, if we consider the samples from Tovačov separately from the samples from Kostomlátky and Osek nad Bečvou, it is possible to use the data in table 4 and state that with the increasing age the wood density decreases. The same dependence is valid for the other examined properties because all of them are considerably affected by the density. However, to confirm or reject this theory it will be necessary to analyse many other samples from various locations.

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