WOOD RESEARCH
57 (4): 2012
573-580

ANALYSIS OF THE ANNUAL RING STRUCTURE AND WOOD DENSITY RELATIONS IN ENGLISH OAK AND SESSILE OAK

Hanuš Vavrčík, Vladimír Gryc
Mendel University in Brno, Faculty of Forestry and Wood Technology
Brno, Czech Republic

(Received February 2012)

This study was presented at the Dendrosymposium in Otočec, Slovenia (April 16-19, 2009).

ABSTRACT

The analysis of wood density variability of English oak (*Quercus robur* L.) and Sessile oak (*Quercus petraea* (Matt.) Liebl.) was carried out. English oaks were taken from testing area in floodplain forest of South Moravia (Czech Republic) and Sessile oaks were from highland. Sample logs were taken at height 1.3 m from the ground (log length 1 m) from 10 tree stems, i.e. 5 from each testing area. Both intra-species and inter-species variabilities along the stem radius were analysed. Also relation between wood density, annual ring width and portion of late wood were studied. The average oven-dry wood density of English oak and Sessile oak was 584.3 kg.m^{-3} and 672.7 kg.m^{-3} respectively.

KEYWORDS: Wood density, annual ring, *Quercus robur, Quercus petraea*.

INTRODUCTION

Oak trees cover 173 047 ha, i. e. 6.7 % of forest stands of the Czech republic. It is the second most important hardwood of the country (Report on the state of forest and forestry in the Czech republic 2007). There are three indigenous oak species in the Czech republic territory: English oak (*Quercus robur* L.), Sessile oak (*Quercus petraea* (Matt.) Liebl.) and Downy oak (*Quercus pubescens* L.). The most important for forest and wood industry are English oak and Sessile oak (Pikula et al. 2003).

Wood density is one of the most important properties since it correlates well to many other physical and mechanical properties (Tsoumis 1991, Knapic et al. 2007). Thus wood density is a good feature for estimation of all other material properties. Wood density (or specific gravity) depends upon (1) the size of the cells, (2) the thickness of the cell walls, and the interrelationship between the number of cells of various kinds in terms of (1) and (2) (Panshin and de Zeeuw 1980). Wood density is not distributed evenly along the stem radius. Its distribution is related to the annual ring structure. Each annual ring consists of lighter earlywood and darker latewood. Latewood is made of cells which have thicker walls and smaller lumina in comparison to earlywood. This results in a higher density of latewood (Fromm et al. 2001) and explains why the density of wood increases with increasing proportion of latewood (Panshin and de Zeeuw 1980, Tsoumis 1991). Oak belongs to ring-porous hardwoods (Jane 1956, Schweingruber 1990) where an increase of annual ring width is associated with an increase of latewood proportion thus density also increases (Tsoumis 1991). According to decreasing ring width with an age of a tree it is obvious that higher density should be in the central part of a tree stem of ring-porous species.

The average value of oven-dry wood density by Kollman (1951) is 650 kg.m^{-3} both for *Q. robur* and *Q. petraea*. Vichrov (1954) studied wood density of oaks at different locations. For flood plain forest he measured 589 kg.m^{-3} and for downs 654 kg.m^{-3}.

As already as in 1973 Taylor et al. mentioned that variations in wood density are very important for wood industry. These data can be used to estimate intra-species and inter-species variation of the wood density and indicate variations available for selection in tree improvement programs. Finally, knowledge of wood density profile is likely to improve the accuracy of estimates of stem biomass.

Guilley et al. (1999) investigated wood density variation in *Q. petraea* and they proved that regional, site quality and silvicultural effects explained a very few part of the total variation of wood density. The consequence was that the relationship between wood density and radial growth did not change according to the sampled regions and according to the three sampled site qualities (Guilley 2000).

The hypothesis was stated that there was the same relationship between density and latewood proportion for two species of oak growing at their origin areas. This paper is focused on testing of this hypothesis.

MATERIAL AND METHODS

Sampling material was taken from two locations in the Czech republic, Europe. First location (1) was a floodplain forest stand of English oak (*Quercus robur* L.) near Lednice at altitude 161 m a. s. l. and (2) lowland forest stand of Sessile oak (*Quercus petraea* (Matt.) Liebl.) in Útěchov near Brno city, at altitude 440 m a. s. l. (Fig. 1).

Fig. 1: Sampling plots (arrows) in the Czech republic.

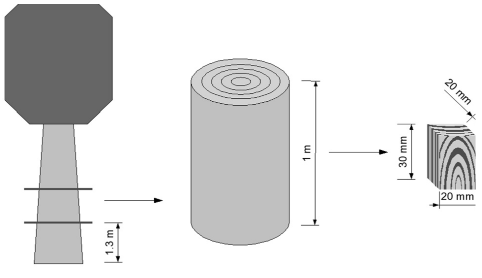

Fig. 2: Sampling: Tree – log – specimen.

Five trees from each location were cut. The diameter of trees at breast height for *Q. robur* and *Q. petraea* was ranging from 38.0 to 49.5 cm and from 32.0 to 36.0 cm, respectively. Specimens 20 × 20 × 30 mm for density testing were prepared according to Fig. 2. Specimens were dried at

103±2°C in a program oven.

Each oven-dried specimen was measured in three anatomical directions and specimens were weighed. Oven-dry wood density of specimens was calculated as:

$$\text{oven-dry density} = \frac{m_0}{V_0} \tag{1}$$

where: m_0 - the oven-dry weight (kg),
V_0 - oven-dry volume (m^3).

A set of 20 % of randomly selected specimens in corresponding sections was used for calculation of average ring width (*arw*) and average proportion of latewood (*apl*). These values were calculated for each specimen of the set as:

$$arw = \frac{\sum_{i=1}^{n} w_i}{n} \tag{2}$$

$$apl = \frac{\sum_{i=1}^{n} l_i}{\sum_{i=1}^{n} w_i} \cdot 100 \tag{3}$$

where: w_i - i^{th} annual ring width,
n - the number of rings on the specimen,
l_i - i^{th} annual ring width of the latewood.

RESULTS AND DISCUSSION

Q. robur showed a lower average oven-dry wood density (584.3 $kg.m^{-3}$) in comparison to *Q. petraea* (672.7 $kg.m^{-3}$), i.e. difference was 88.4 $kg.m^{-3}$. Variability of values was a little higher in *Q. robur* datas et (Tab. 1). t-test proved that there was a statistically significant difference in mean values ($\alpha = 0.05$).

Tab. 1: Oven dry wood density ($kg.m^{-3}$) of Q. robur and Q. petraea. Descriptive statistics.

	N	Average	Q1	Median	Q3	Min	Max	Std. dev.	CV (%)
Q. robur	1317	584.3	552.6	586.0	616.5	384.3	863.9	55.7	9.5
Q. petraea	822	672.7	642.4	673.1	705.2	488.2	832.9	52.5	7.8

As seen in Fig. 3 the wood density was distributed along the radius in very similar way in both species but values of *Q. petraea* were shifted higher. In both species the highest average value was detected in the central part of the stem diameter then average values decreased to the lowest one in the outer part of the stem. It is obvious that differences in wood density between centre and outer parts of the stem were lower in *Q. petraea*. Found out trends are in accordance with results of other authors (Vichrov 1954, Tsoumis 1991, Guilley et al. 1999).

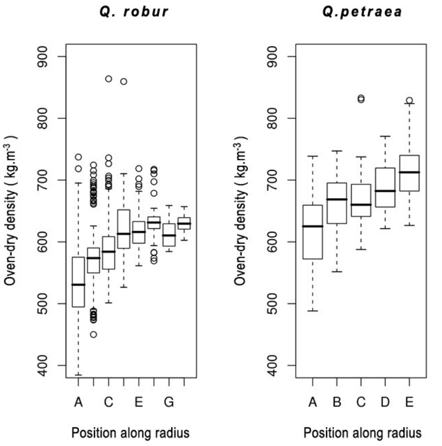

Fig. 3: Wood density distribution along the stem radius (A – close to bark, G – close to pith).

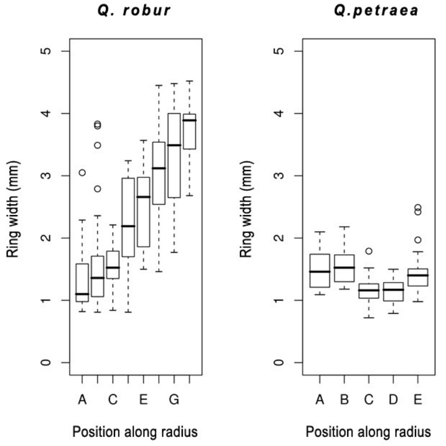

Fig. 4: Annual ring width distribution along the stem radius (A – close to bark, G – close to pith).

There were differences in average values and variability of annual ring width in relation to species. The higher ring width was shown by *Q. robur* (2.1 mm) in comparison to *Q. petraea* (1.4 mm). The noticeable difference was in variability of these two files – values of ring width in *Q. robur* were almost twice variable as these in *Q. petraea* (Tab. 2).

Tab. 2: Annual ring width (mm) of Q. robur and Q. petraea. Descriptive statistics.

	N	Average	Q1	Median	Q3	Min	Max	Std. dev.	CV (%)
Q. robur	289	2.1	1.3	1.8	2.8	0.8	4.5	0.9	45.0
Q. petraea	154	1.4	1.2	1.3	1.5	0.7	2.5	0.3	24.2

As seen in Fig. 4 average ring width decreased rapidly along the stem radius in direction from the pith to bark only in *Q. robur*. In *Q. petraea* files of ring width values for each radial zone were very similar along the radius. When compared to trends of density values (Fig. 3) there are differences especially in *Q. robur* part close to the pith and in *Q. petraea* it is a different trend along whole radius.

Distribution of late wood proportion in different zones along the stem radius is described in Fig. 5. Average values decreased along the stem radius in *Q. robur* but in *Q. petraea* values varied only a little. These trends along the radius are more similar to those for wood density.

Linear regression analysis of dependency between latewood portion and ring width showed that at the same ring width *Q. robur* produced lower proportion of latewood in comparison to *Q. petraea* (Fig. 6). Regression lines are quite parallel thus difference in theoretical values of latewood proportion is a constant. According to this it was supposed that it should resulted in lower wood density in *Q. robur* due to the rule that narrower rings have a lesser portion of latewood within a ring (Tsoumis 1991).

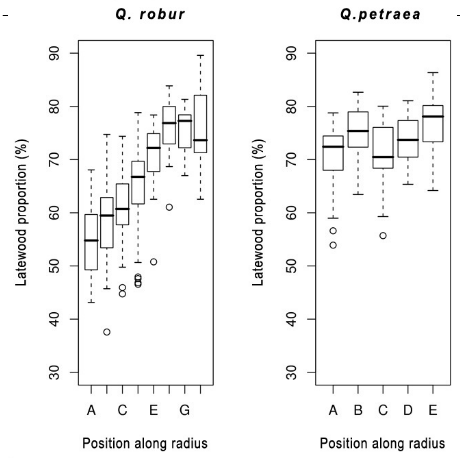

Fig. 5: Proportion of late wood distribution along the stem radius (A – close to bark, G – close to pith).

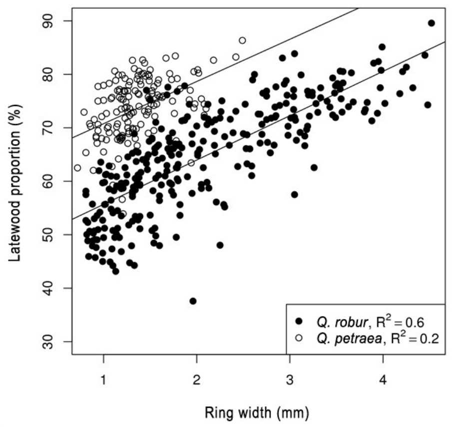

Fig. 6: Regression analysis of latewood portion and ring width.

The suggestion was confirmed (Fig. 7). As seen in the figure – predicted (theoretical) wood density is higher in *Q. petraea* at the same annual ring width.

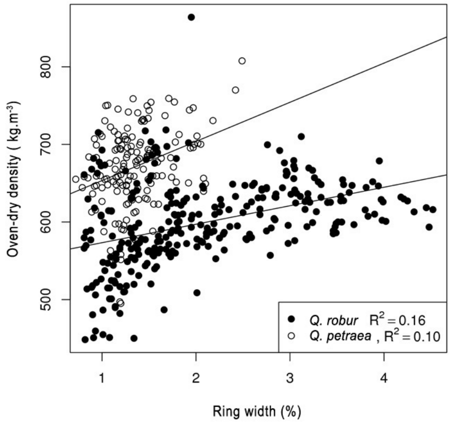

Fig. 7: Regression analysis of oven-dry density and ring width.

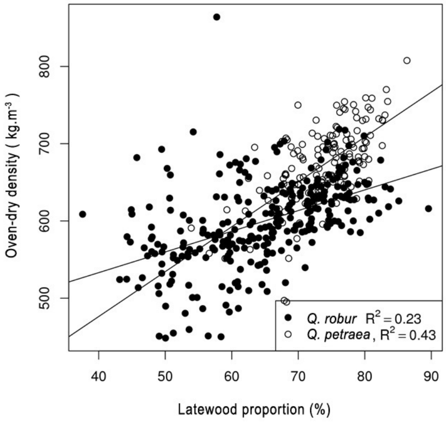

Fig. 8: Regression analysis of oven-dry density and latewood proportion.

As shown in Fig. 8 predicted values of wood density are higher in *Q. robur* until latewood proportion is smaller than 60 %. When it is greater than this value then predicted (theoretical) values of wood density are higher in *Q. petraea*.

CONCLUSIONS

It was proved that there were smaller differences in wood density between outer and inner part of the stem in *Quercus petraea* in comparison to *Quercus robur*. In other words difference between non-outlier range of min-max values in *Q. petraea* and *Q. robur* was 344.7 and 479.6, respectively.

In spite of wider annual ring width of *Q. robur* the higher wood density was found out in *Q. petraea*. Both species were growing at their native locations, i.e. *Q. petraea* in downs and *Q. robur* in floodplain forest in lowland.

It can be concluded that:

1) at the same ring width *Q. petraea* had a higher latewood proportion
2) at the same ring width *Q. petraea* had a higher wood density
3) at the same latewood proportion (> 60 %) *Q. petraea* had a higher wood density

It is suggested that wood density is dependant not only on annual ring width and latewood proportion but it also depends on "quality" of latewood.

ACKNOWLEDGMENT

This project was supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 6215648902. Special thanks to Forests of the Czech Republic, s.e.

REFERENCES

1. Fromm, J.H., Sautter, I., Matthies, D., Kremer, J., Schumacher, P., Ganter, C., 2001: Xylem water content and wood density in spruce and oak trees detected by high-resolution computed tomography. Plant Physiology 127(2): 416–425.
2. Guilley, E., 2000: Wood density in Sessile oak (*Quercus petraea* Liebl.): Modelling of the within- and between-tree variability; origin and non-destructive assessment of the «tree» effect; interpretation of the developed model with anatomical traits. PhD. thesis Sciences Forestières et sciences du bois, 206 pp.
3. Guilley, E., Hervé, J.C., Huber, F., Nepveu, G., 1999: Modelling variability of within-ring density components in *Quercus petraea* Liebl. with mixed-effect models and simulating the influence of contrasting silvicultures on wood density. Ann. For. Sci. 56(6): 449–458.
4. Jane, F.W., 1956: The structure of wood. London, A. & C. Black, 427 pp.
5. Knapic, S., Louzada, J.L., Leal, S., Pereira, H., 2007: Radial variation of wood density components and ring width in cork oak trees. Ann. For. Sci. 64(2): 211–218.
6. Kollmann, F., 1951: Technologie des Holzes und der Holzwerkstoffe. 2nd ed. Berlin: Springer-Verlag, 1050 pp.
7. Panshin, A.J., de Zeeuw, C., 1980: Textbook of wood technology: Structure, identification, properties, and uses of the commercial woods of the United States and Canada. New York: McGraw-Hill, 722 pp.
8. Pikula, J., Obdržálková, D., Zapletal, M., Beklová, M., Pikula, J.(Jr.)., 2003: Tree and bush forms of wooden species of forests and open landscape in Czech Republic. (Stromové a keřové dřeviny lesů a volné krajiny České republiky). Brno, CERM s.r.o., 226 pp (in Czech).
9. Report on the state of forest and forestry in the Czech republic (2007): Ministry of agriculture, Prague, 100 pp (in Czech).

10. Schweingruber, F.H., 1990: Anatomie europäischer Hölzer: Ein Atlas zur Bestimmung europäischer Baum-, Strauch- und Zwergstrauchhölzer. Bern, Verlag Paul Haupt, 799 pp.
11. Taylor, F.W., Wooten, T.E., 1973: Wood property variation of Mississippi delta hardwoods. Wood and Fiber Sci. 5(1): 2–13.
12. Tsoumis, G.T., 1991: Science and technology of wood: Structure, properties, utilization. New York: Chapman & Hall, 494 pp.
13. Vichrov, V.E., 1954: The structure, physical and mechanical properties of oak wood (Strojenije i fiziko-mechaničeskije svojstva drevjesiny duba). Moscow: Akademia nauk USSR, 264 pp (in Russian).

Hanuš Vavrčík, Vladimír Gryc
Mendel University in Brno
Faculty of Forestry and Wood Technology
Zemedelská 3
613 00 Brno
Czech Republic
E-mail: vavrcik@mendelu.cz