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SELECTED ASPECTS OF THE REACTION BEECH WOOD

Jarmila Geffertová – Anton Geffert – Tatiana Vilkovská – Ivan Klement – Ondrej Vacek

ABSTRACT

The specifics of reaction beech wood in terms of basic chemical properties, colouration and dimensional properties of the wood fibres are presented in the paper. The samples of reaction and opposite beech wood were evaluated using standard chemical analyses by means of measuring the colour coordinates L^*, a^* and b^* and determining the dimensional properties of the wood fibres using Fiber Tester. A well-known fact that reaction wood has a higher proportion of cellulose and a lower proportion of lignin than opposite wood is confirmed by the chemical analyses. The content of extractives in both samples was very similar (from 2.97 to 3.53%). The lightness (L^*) of reaction wood is higher than the lightness of opposite wood, both in wet and dried wood. After the drying process, the lightness of wood increased slightly. The biggest colour differences were noticed between the wet reaction and opposite wood (ΔE^*=18.6). Except one sample, all observed values of the total colour difference were ΔE^*>3. Knowledge about well-recognized colour changes in wet reaction wood could also be applied in the early identification of reaction wood in the industrial practice. Based on the fibre length distribution, the fact that reaction wood contains fewer parenchyma cells alongside with the higher representation of fibre cells and the lower representation of vessels can be concluded.

Key words: beech, reaction wood, colouration, dimensional properties of fibres.

INTRODUCTION

The issue of beech wood quality, especially the early detection of reaction wood, is becoming more important in relation to future forecasts of long-term forestry planning where an increase in the representation of beech to 35.9% (KÚDELA and ČUNDERLÍK 2012) compared to 33.5% in 2016 is forecasted (Green Report 2017).

Beech wood quality is a very variable parameter, which has caused and still causes many processing problems. The method of using beech wood depends on its quality, which is determined by the structure and properties of wood, as well as the frequency of defects in this material. Their detailed knowledge, as well as knowledge of a number of factors influencing these properties (humidity, temperature, etc.), can help to minimize processing problems (KAČÍK and KUBOVSKÝ 2011, KÚDELA and ČUNDERLÍK 2012).

Beech wood has a high frequency of defects (red false heartwood, reaction wood, necrosis, rot, etc.), which markedly affect its quality. Some defects are difficult to identify during the processing of beech logs and can be detected only after the cutting or due to

negative effects during the further processing (KÚDELA and ČUNDERLÍK 2012, MARČOK *et al.* 1996, Vilkovska *et al.* 2018).

One of the frequent defects in the beech wood structure is also reaction wood (tension wood) that forms in the part of the log and branches during the growth as a response to different external factors. Its presence in the cuttings is undesirable because reaction wood behaves very differently in humidified thermal stress than normal wood (ČUNDERLÍK *et al*. 1992, 1995, KÚDELA 1993, 2002). Reaction wood represents 14 to 21% of the total wood volume of beech raw material (ČUNDERLÍK and KÚDELA 1992).

Regarding the chemical composition of reaction beech wood, several literary sources indicate a higher amount of cellulose and a lower amount of lignin, in comparison to normal wood. Cellulose is a polysaccharide that is most strongly involved in these changes. Reaction wood has a higher proportion of crystalline cellulose and contains more hexoses and fewer pentosans (PANSHIN and DE ZEEUW 1980, BLAHO *et al.* 1993, VOZÁR *et al.* 1994, KAČÍKOVÁ 1997, VILKOVSKÁ *et al*. 2018).

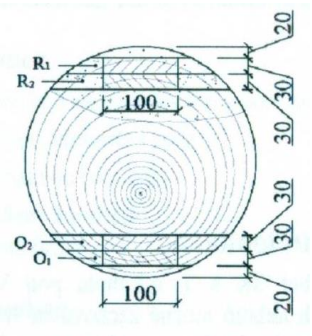
The chemical wood composition is correlated with the colour of the wood surface. The wood surface colour is important for the identification of wood and also serves as a benchmark for wood quality assessment (BABIAK *et al.* 2004, HRČKA 2008).

Reaction wood (tension wood) in hardwood spieces has the function of transmitting greater tensile stresses, which is reflected in an increased proportion of mechanical tissues (a higher proportion of fibre cells at the expense of a lower vessel proportion) and also its higher density. The fibre cells are modified to form thick-walled wood fibres with a thin S_2-layer and with a thick G-layer containing non-lignified high-crystalline cellulose (ČUNDERLÍK 2009).

The aim of the paper was to complete already acquired knowledge on tension wood of beech in term of its colouration and dimensional properties of wood fibres. Tension beech wood turned out to be without any significant differences in wood density and moisture content, only having small differences in some chemical properties.

MATERIAL AND METHODS

Samples of beech wood (*Fagus sylvatica* L.) containing the reaction zone came from Kronotimber Ltd. (Lehota pod Vtáčnikom, Slovakia). The visual detection of tension wood was based on the determination of the shiny appereance in logs. Using this method, it is neccesary to select and brush the surface of discs (thickness 10 cm) from logs and dry them under laboratory conditions (103°C per 4 hours). Then tension wood is more visible on the surface of these discs . Based on this visual detection of the reaction zone, the samples containing reaction wood (R_1, R_2) and the samples containing opposite wood (O_1, O_2) were cut out off the place of occurrence. Opposite wood was located on the opposite side of the log from the reaction zone. The quality of reaction wood was not detected in material.



Sample dimensions after cutting:
length 400 mm
width 100 mm
thickness 30 mm

Fig. 1 Sawing method of the samples.

Experimental measurements were only performed on two samples from each group used for monitoring the selected physical and chemical properties in work of VILKOVSKÁ *et al.* (2018) due to lack of experimental material.

Selected chemical properties were measured in the disintegrated samples of reaction and opposite beech wood (0.5-1.0 mm fraction):

Ethanol-toluene solubility	ASTM D 1107-96
Cellulose	Kürschner-Hoffer method (KAČÍK and SOLÁR 2000)
Lignin	ASTM D 1106-96

The measurement of the colour coordinates L^*, a^*, b^* was made using the Color Reader CR-10 colorimeter. All measurements were made in the conditions of standard illuminant D65 and Specular Component Included (SCI) and a Xenon lamp light source including a lit area of 8mm. Only for the purpose of colouration measuring reaction wood was divided into a reaction and a pre-reaction part (the part of transition from normal to reaction wood). The colour coordinates were measured at 10 uniformly distributed points. Determined values of these coordinates were assessed and compared for wet samples and oven-dried samples and they expressed the influence of moisture on the colour of reaction and non-reaction wood.

The moisture content of the samples was determined by the gravimetric method. The monitored samples were dried to a constant weight in the oven at 104±1°C (KAČÍK and SOLÁR 2000).

The total colour difference ΔE^* between the individual parts and samples was calculated with:

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + \left(b_2^* - b_1^*\right)^2} \qquad (1)$$

(L_2^*- L_1^*) change in the value of the black-white coordinates (specific lightness)
(a_2^*- a_1^*) change in the value of the green-red coordinate
(b_2^*- b_1^*) change in the value of the blue-yellow coordinate.

The suspension of wood fibres of concentration 0.05 g in 100 cm^3 was prepared in order to determine the dimensional properties of the fibres from studied wood. The wood of a match shape boiled under the reverse cooler for 3 hours in the concentrate solution of CH_3COOH and 30% H_2O_2 in ratio of 1:1 (BEREŠOVÁ and ČUNDERLÍK 1999).

After aspirating, washing and diluting, the suspension was used to measure the dimensional properties of the wood fibres on the Fiber Tester, which measures the length and width for at least 20,000 wood fibres in one measurement (KARLSSON 2006).

RESULTS AND DISCUSION

Table 1 shows the average values of the absolute moisture content (w_a) and selected chemical properties of reaction and opposite beech wood samples (content of extractives, cellulose and lignin).

Tab. 1 Chemical composition of beech wood samples.

Beech wood	**Sample No.1**		**Sample No.2**	
	Reaction R_1	**Opposite O_1**	**Reaction R_2**	**Opposite O_2**
Moisture content -w_a (%)	**67.8**	60.3	**65.7**	58.6
Content of extractives (%)	3.53	3.17	2.97	3.07
Cellulose content (%)	42.56	41.79	45.91	40.57
Lignin content (%)	19.71	21.44	18.31	21.40

Measured values of the moisture content (w_a) showed that moisture of reaction wood was higher in both samples (sample No.1 by 7.5% and sample No.2 by 7.1%) and moisture of sample No.1 was higher than moisture of sample No.2 (reaction wood by 2.1% and opposite wood by 1.7%).

The content of extractives in both samples was very similar, while in sample No.1 more extractives were found in reaction wood (by 0.36%) and in the sample No.2 more extractives were found in opposite wood (by 0.10%).

Reaction wood of both samples contained more cellulose (sample No.1 by 0.77% and sample No.2 by 5.34%) and less lignin (sample No.1 by 1.73% and sample No.2 by 3.09%) than wood opposite, which is consistent with the literary sources mentioned above.

The visual observation of both beech wood samples showed a lighter colour of reaction wood (Figure 2). As also shown by KLEMENT *et al.* (2018) the lightness of reaction wood plays a key role in its visual detection.

Fig. 2 Light and curved part of reaction beech wood after drying.

Table 2 shows the colour coordinates L^*, a^*, b^* of samples No.1 and 2 of beech wood determined in its reaction and opposite parts.

Tab. 2 Average values of the colour coordinates.

Beech wood		Reaction part (R)				Opposite part (O)			
		wet	STDEV	oven-dried	STDEV	wet	STDEV	oven-dried	STDEV
Sample No.1	L^*	71.5	1.2	72.1	1.0	69.4	0.9	69.7	0.6
	a^*	7.5	0.7	6.9	0.4	9.2	0.8	7.5	0.2
	b^*	25.5	1.2	20.8	0.3	32.7	1.1	22.6	0.5
Sample No.2	L^*	78.3	2.3	78.0	0.4	71.1	0.4	72.4	0.4
	a^*	3.5	1.0	3.7	0.1	8.6	0.3	7.1	0.3
	b^*	14.9	1.3	15.8	0.3	31.3	1.0	22.1	0.7

Based on the above results it can be stated that lightness (L^*) of wet and dried reaction wood is higher than that of opposite wood in both wood samples. While the difference in the lightness between wet reaction and opposite wood for sample No.1 is $\Delta L^*=2.1$, the difference for sample No.2 up to 7.2. Having dried this wood, this difference slightly increased to 2.4 for sample No.1 and dropped to 5.6 for sample No.2 and the lightness value slightly increased in both samples (except R_2).

The change of the green-red coordinate a^* between reaction and opposite wood was again greater for sample No.2 than for sample No.1. There was a shift to the green area $\Delta a^*=5.1$ in the wet sample (R_2–O_2) and (R_2–O_2) $a^*=3.4$ in the case of dried wood.

There was a more significant change of sample No.2 in comparison to sample No.1 in the blue-yellow coordinate b^* between reaction and opposite wood. This difference was up to $\Delta b^*=16.4$ in wet wood and $\Delta b^*=6.3$ in dried wood.

The values of the total colour difference (ΔE^*) summarize all the colour coordinates and are listed in Table 3. These values show the colour changes of both samples in the combinations of reaction and opposite wood and wet and dried wood (o. d.).

Tab. 3 Average values of the total colour difference (ΔE^*).

Beech wood		ΔE^*	
		Sample No.1	Sample No.2
wet - oven-dried	reaction	4.8	1.0
	opposite	10.2	9.4
reaction - opposite	wet	7.7	18.6
	oven-dried	3.1	9.1

The most significant colour changes on beech wood were recorded on sample No.2 between wet reaction and opposite wood (ΔE^*=18.6). According to ALLEGRETTI *et al.* (2009), colour changes 6<ΔE^*<12 can be evaluated as large colour differences and colour changes ΔE^*>12 already as different colours. In addition to ΔE^* for reaction wet and dried wood of sample No.2, all observed values of the total colour difference were ΔE^*>3.

The samples of beech wood No.1 and 2 were divided into these following parts: reaction wood, pre-reaction wood and opposite wood of wet (w) and dried (o. d.) for better monitoring of the changes of the colour coordinates (L^*, a^* and b^*). Figures 3 to 6 show the changes of values of the given coordinates.

Comparing Figures 3 and 4 for sample No. 1 between individual zones, there is clearly notice a more abrupt change in the values of the colour coordinates in wet wood than in dried wood. Wet reaction wood shows that there is a more pronounced shift of the lightness to the white area, coordinate a^* to the green area and coordinates b^* to the blue area, which subsequently resulted in the lighter part of reaction wood compared to the opposite and pre-reaction part.

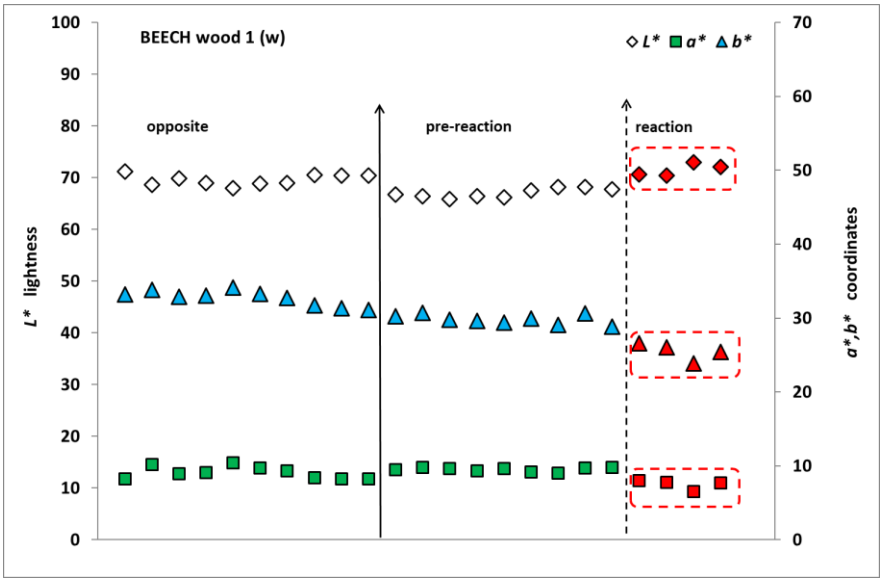


Fig. 3 Changes of the colour space coordinates for wet sample No. 1.

The changes in colour coordinate values were measured for sample 2, as shown in Figures 5 and 6.

More pronounced changes of sample No.2 of L^*, a^*, b^* were observed again in the wet sample compared to dried sample. Even in wet pre-reaction wood, a slight shift in the colour coordinates was recorded in the white, blue and green areas. The shift in the pre-reaction portion decreased in the dried wood sample.

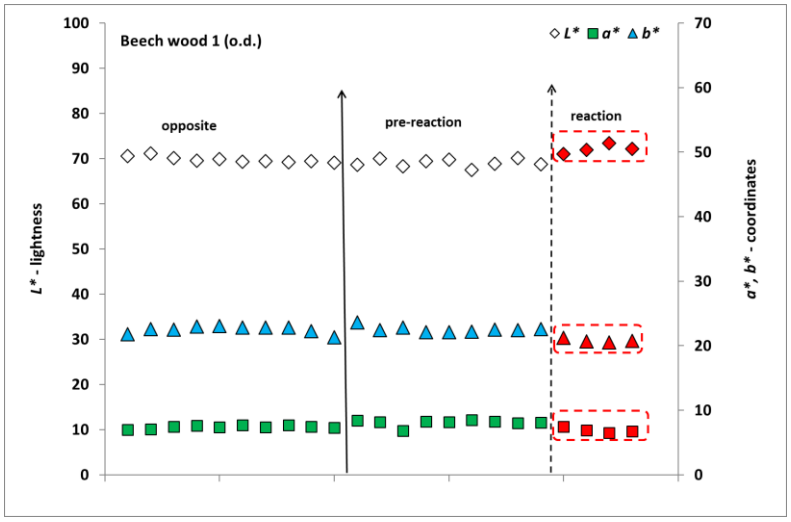


Fig. 4 Changes of the colour space coordinates for oven-dried sample No.1.

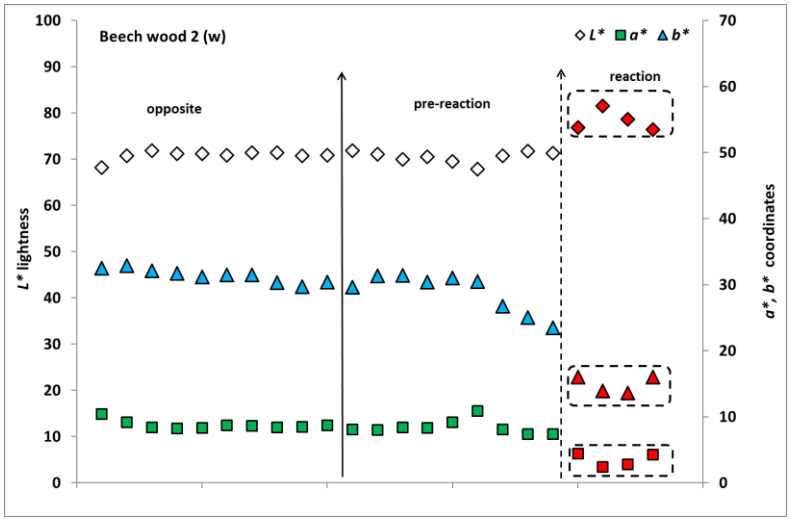


Fig. 5 Changes of the colour space coordinates for wet sample No.2.

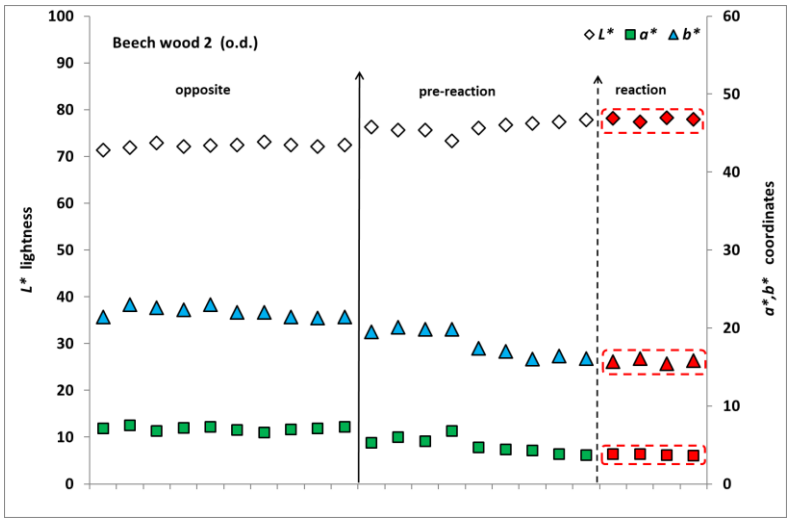


Fig. 6 Changes of the colour space coordinates for oven-dried sample No.2.

The results obtained from the measurement of the colour parameters are in compliance with findings of KLEMENT *et al.* (2018).

Since tension wood is richer in cellulose and a fibre content, the dimensional properties of beech reaction and opposite wood were followed in the next part of the work.

The distribution of the length and width of the wood fibres and the content of fines were determined by the instrument called Fiber Tester. The number of all measured fibres was higher than 20,000 in one measurement.

The distribution of the length clearly showed two sets (Fig. 7).

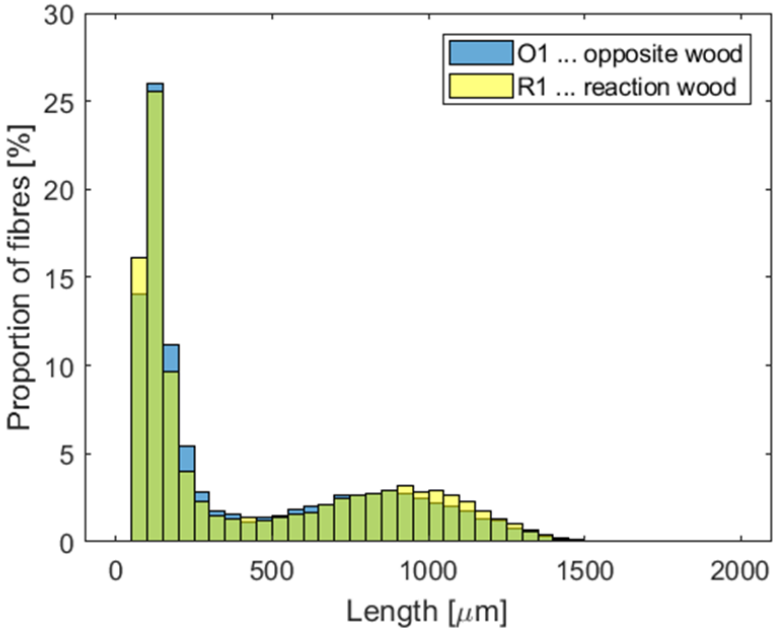


Fig. 7 Ditribution of fibre length – sample No.1.

The first set of lengths of up to 0.5 mm consists mainly of a fine fraction up to 0.2 mm but also of the vascular cells whose length in beech reaches only 0.4 to 0.5 mm (Požgaj *et al.* 1993). Therefore in order to compare the dimensional properties of the fibres of reaction and opposite wood beech, only a set of lengths over 0.5 mm was considered (Table 4).

Tab. 4 Corrected average values of dimensional properties of fibres

Sample		Number of fibres (filtered)	Mean length (mm)	Mean width (μm)
No.1	reaction wood	7458	0.926	22.02
	opposite wood	7019	0.910	21.97
No.2	reaction wood	7458	1.008	21.64
	opposite wood	7019	0.927	21.32

A greater proportion of the longer fibres was determined in both samples of reaction wood. Average fibre length of the reaction wood (0.926 and 1.008 mm) is higher than opposite wood (0.910 and 0.927 mm).

In parallel to the length of the fibres, their width was also determined. In both samples, reaction wood had a slightly higher fibre width than opposite wood.

The modified portions of the average length and width fibres of reaction and opposite wood were tested by MatLab program and are shown in Figures 8 and 9:

Reaction vs. opposite wood		F	Probability
Sample No. 1	Length	14.38	0.000
	Width	0.81	0.368
Sample No. 2	Length	397.43	0.000
	Width	35.07	0.000

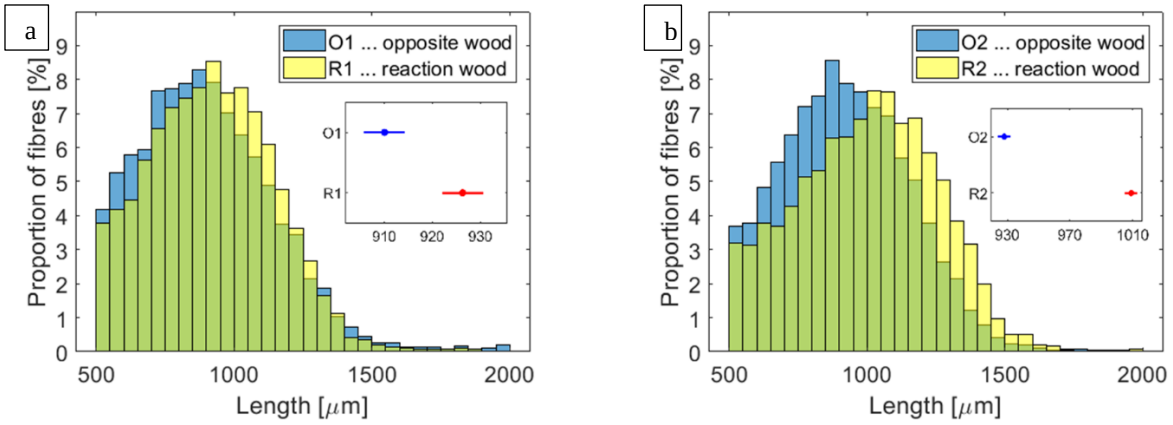


Fig. 8 Corrected proportion of fibres by length (a - sample No.1, b - sample No. 2).

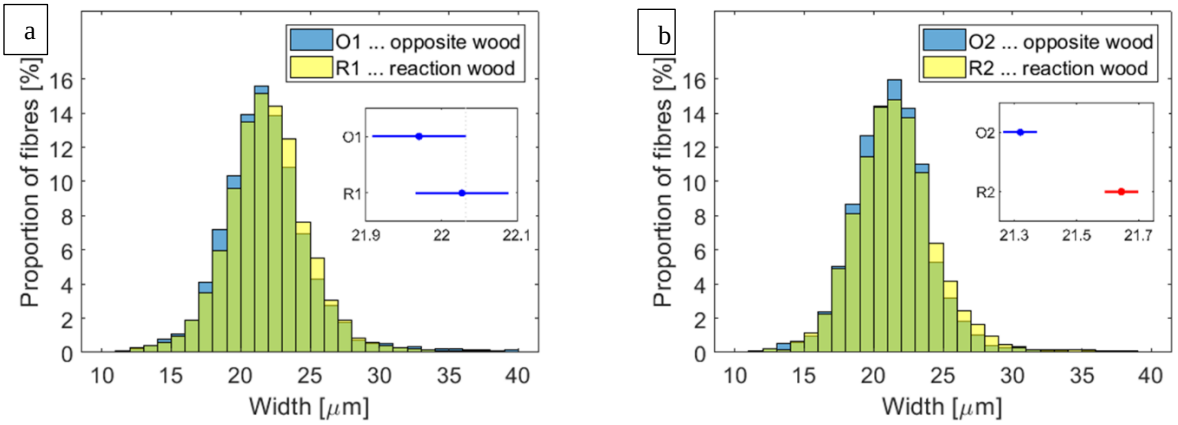


Fig. 9 Corrected proportion of fibres by width (a - sample No.1, b - sample No. 2).

The means of groups in reaction and opposite wood are significantly different for length of samples No.1 and 2 (Figure 8a,b).

The means of groups in reaction and opposite wood are also significantly different for width of samples No.2 (Figure 9b). Means are not significantly different from reaction and opposite wood of sample No.1 (Figure 9a).

Tab. 4 Content of fines (fraction up to 0.2 mm).

Beech wood	Content of fines (%)			
	Sample No.1		Sample No.2	
	reaction	opposite	reaction	opposite
0.0–0.1 mm	3.2	3.1	0	3.2
0.1–0.2 mm	11.0	13.2	8.5	11.5

A higher proportion of fine fraction to 0.2 mm in opposite wood was determined in both samples (No.1 and 2), with several times higher values representative of the fine fibres in the length range of 0.1 to 0.2 mm. It can be concluded that in addition to the higher representation of the fibre cells and the lower representation of the vessels in reaction wood, reaction wood contains fewer parenchyma cells (in the pulp and paper practice they tend to say "zero fibres").

CONCLUSION

The achieved results confirmed the well-known fact that reaction wood contains more cellulose and less lignin than opposite wood. The content of extractives determined in both samples was very similar. A higher moisture content in reaction wood than opposite wood was proved in both samples.

On the basis of the results of colouration, it can be stated that the lightness (L^*) of reaction wood is higher than of opposite wood for both wood samples, both in wet and dried wood. Having dried this wood, the lightness slightly increased.

The largest colour changes of beech wood were recorded on sample No.2 between wet reaction and opposite wood (ΔE^*=18.6). Except for ΔE^* for reaction wet and dried wood, all observed values of the total colour difference were ΔE^*>3.

The colour changes are better recognizable in wet reaction wood than in dried wood and instrumentally they can be quickly quantified. This knowledge could also find its application in the early identification of reaction wood in the industrial practice.

The average length of the wood fibres in both samples was higher in reaction than in opposite wood. Regarding the width of the fibres, there were very small differences between reaction and opposite wood. A higher portion of the fine fraction of 0.2 mm was determined in opposite wood, with several times higher values representative of the fine fibres in the length range of 0.1 to 0.2 mm.

On the basis of the fibre length distribution it can be concluded that beside the higher representation of the fibre cells and the lower representation of the vessels in reaction wood, reaction wood contains fewer parenchyma cells. Therein lies the advantage of the processing of reaction wood for pulp.

REFERENCES

ALLEGRETTI O., TRAVAN L., CIVIDINI R. 2009. Drying Techniques to obtain White Beech. In Quality control for wood and wood products, EDG Wood Drying Seminar, Bled, 2009, 7–12.

ASTM Standard D 1106 – 96: 1998. Standard Test Method for Acid Insoluble Lignin in Wood. (TAPPI T T-13m-54).

ASTM Standard D 1107–96, Re-approved: 2001. Standard Test Method for Ethanol-Toluene Solubility of Wood. (TAPPI T 204 os-76).

BABIAK, M., KUBOVSKÝ, I., MAMOŇOVÁ, M. 2004. Colour space of selected domestic woods (Farebný priestor vybraných domácich drevín), In: Interaction of wood with various form of energy. Technical University in Zvolen, 2004, 113–117, ISNB 80-228-1429-6.

BEREŠOVÁ, K., ČUNDERLÍK, I. 1999. Morfológia vláknitých buniek smreka s rôznym stupňom imisného poškodenia. In Drevo, štruktúra a vlastnosti, Zvolen : TU vo Zvolene, 17–22. ISBN 80-228-0887-3

BLAHO, J., VOZÁR, M., ŠINDLER, J. 1993. Niektoré vlastnosti reakčného a normálneho dreva buka (*Fagus sylvatica* L.). In Zborník vedeckých prác Drevárskej fakulty TU vo Zvolene, Bratislava : ALFA, 1993, 297–306.
ČUNDERLÍK, I. 2009. Štruktúra dreva. 1.vyd. Zvolen : TU vo Zvolene, 2009. 135p. ISBN 978-80-228-2061-5.
ČUNDERLÍK, I., KÚDELA, J.1992. Štruktúra a vlastnosti reakčného dreva buka. Zvolen : VŠLD (TU) vo Zvolene, 22 p.
ČUNDERLÍK, I., KÚDELA, J., BLUSKOVA, G. 1995. Relaxation of stresses in steamed beech tension wood. In Lesotechničesko obrazovanie v Blgarija, Sofia : TOM II. Visš lesotechničeski institut, 1995, 199–205.
ČUNDERLÍK, I., KÚDELA, J., MOLIŃSKI, W. 1992. Reaction beech wood in drying process. In 3rd IUFRO International Wood Drying Conference. Vienna : Universität für Bodenkultur, 1992, 350–353.
HRČKA, R., 2008. Identification of discoloration of beech wood in CIELAB space, In Wood Research, 2008, 53(1): 119–124, ISSN 1336-4561.
KAČÍK, F., KUBOVSKÝ, I. 2011. Chemical changes of beech wood due to CO_2 laser irradiation. In Journal of Photochemistry and Photobiology A: Chemistry, 2011, 222: 105–110, ISSN 1010-6030.
KAČÍK, F., SOLÁR, R. 2000. Analytická chémia dreva [Analytical Chemistry of Wood]. Zvolen : Technical University in Zvolen, 2000. 369 p. ISBN 80-228-0882-0.
KAČÍKOVÁ, D. 1997. Charakteristika bukového reakčného dreva z hľadiska sulfátového spôsobu výroby buničín. Zvolen : Technická univerzita vo Zvolene, 1997. 55 p. ISBN 80-228-0609-9.
KARLSSON, H. 2006. Fibre Guid. Fibre analysis and process applications in the pulp and paper industry. Elanders Tofters, Sweden, 2006. 120 p. ISBN 91-631-7899-0.
KLEMENT, I., VILKOVSKA, T., BARANSKI, J., KONOPKA, A. 2018. The impact of drying and steaming processes on surface color changes of tension and normal beech wood, In Drying Technology, 2018, DOI: 10.1080/07373937.2018.1509219.
KÚDELA, J. 1993. Determination of deformation of beech prisms, containing reaction wood. In Drevársky výskum, 1993, 38(2): 19–28.
KÚDELA, J. 2002. Analýza príčin defektov v bukovom dreve počas jeho hydrotermickej plastifikácie. In Vybrané procesy pri spracovaní dreva. Bystrá : TU vo Zvolene, 2002, 1–5.
KÚDELA, J., ČUNDERLÍK, I. 2012. Bukové drevo: štruktúra, vlastnosti, použitie. 1.vyd. Zvolen : TU vo Zvolene, 2012.152 p. ISBN 978-80-228-2318-0.
MARČOK, M., KÚDELA, J., ČUNDERLÍK, I. 1996. Possibilities of using X-ray computed tomography for identification of reaction wood. In Zborník vedeckých prác Drevárskej fakulty TU vo Zvolene, Zvolen : TU vo Zvolene, 1996, 49–58.
PANSHIN, A.J., DE ZEEUW, C. 1980. Textbook of wood technology. New York : McGraw Hill, 1980, 722 p.
POŽGAJ, A., CHOVANEC, D., KURJATKO, S., BABIAK, M., 1993. Štruktúra a vlastnosti dreva. 1.vyd. Bratislava : Príroda, 1993. 486 s. ISBN 80-07-00600-1.
VILKOVSKA, T., KLEMENT, I., VÝBOHOVA, E. 2018. The effect of tension wood on the selected physical properties and chemical composition of beech wood (*Fagus Sylvatica* L.). In Acta Facultatis Xylologiae Zvolen, 2018, 60(1): 31–40, ISSN 1336-3824.
VOZÁR, M., ČUNDERLÍK, I., KAČÍK, F. 1994. Some chemical properties of tension and oppsite beech wood. In Drevársky výskum, 1994, 39(4): 23–33.
ZELENÁ SPRÁVA 2017: Správa o lesnom hospodárstve v Slovenskej republike za rok 2016. 1. vyd. Bratislava: Ministerstvo pôdohospodárstva a rozvoja vidieka SR, Národné lesnícke centrum, 2017. 68p. ISBN 978-80-8093-235-0.

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AUTHORS ADDRESS

doc. Ing. Jarmila Geffertová, PhD.
prof. Ing. Anton Geffert, CSc.
Ing. Tatiana Vilkovská, PhD.
doc. Ing. Ivan Klement, CSc.
RNDr. Ondrej Vacek, PhD.
Technical University in Zvolen
Faculty of Wood Sciences and Technology
T. G. Masaryka 24
960 01 Zvolen
Slovakia
geffertova@tuzvo.sk
geffert@tuzvo.sk
tatiana.vilkovska@tuzvo.sk
klement@tuzvo.sk
ondrej.vacek@tuzvo.sk