WOOD RESEARCH
64 (5): 2019
903-912

LONGITUDINAL CONTRACTION OF REACTION AND OPPOSITE WOOD DURING DRYING PROCESS

Tatiana Vilkovská, Ivan Klement, Igor Čunderlík
Technical University in Zvolen
Slovak Republic

(Received March 2019)

ABSTRACT

Reaction beech wood has different anatomical and also chemical characteristics than normal (opposite) wood. The difference in density is conditioned by percentage of G–layer. Fibers cells in reaction beech wood have a different cell wall structure and a different chemical composition, as well. Longitudinal contraction was noticeable in reaction (tension) samples, where it was several times higher, what could be expected considering the physical properties of reaction beech wood. Our measurements confirmed that drying time has remarkable effect on longitudinal contraction. Higher longitudinal contraction was measured in temperature 60°C and 120°C, which had almost identical drying time. The issue of variability initial moistures did not affect the drying process and samples reached approximately equal final moisture content. Reaction beech wood is a very serious problem in nowadays wood production.

KEYWORDS: Beech wood, tension wood, reaction beech wood, longitudinal contraction.

INTRODUCTION

European beech (*Fagus sylvatica* L.) is an important tree species with a rather large distribution in western and central Europe (Čunderlík et al. 2017).The reaction beech wood (tension wood) has different anatomical and also chemical characteristics from normal (opposite) wood. The reaction beech wood occurs largely in beech wood. Kúdela and Čunderlík (2012) stated 14% up to 21% ratio of reaction beech wood in beech raw material. Due to reaction beech wood occurrence, the consequences are shown in form of deformations, increased portion of waste, and decreased quality of final products (Vilkovská et al. 2016). Kúdela and Čunderlík (2012), Yamamoto et al. (2005) studied an influence of reaction wood on material. Authors stated that increased portion of cellulose in reaction wood, where by weaker bonding between G–layer and S_2 layer bigger swelling of other layers occurs and therefore, another sorption sites are created, as the main reason of its possible higher moisture content (MC). According to Tanaka et al. (2004), due to the composition of the cell wall and its micro and submicroscopic structure,

the cell wall can be established as a reinforced matrix, which is mainly composed of polymers and where micro fibrils angle gives needed stiffness to increased crystalline cellulose content. The difference in density is conditioned by percentage of G–layer. Fibers cells in reaction beech wood have different cell wall structure and different chemical composition as well. Based on the cited work Kačíková (1997) reported that a lower content of lignin in the wood results in a rapid delignification, reducing the time of the pulping and in a lower content of residual lignin in the obtained pulp. Hydrothermal treatment has considerable effect on morphological changes which occur in the cell wall of reaction beech wood. The stress relaxation shows as a dimension changes in longitudinal direction. Čunderlík et al. (1995) studied the effect of hydrothermal treatment on release the growth stress of reaction beech wood. The experiments proved that steaming time and temperature of hydrothermal treatment have considerable effect on reaction beech wood longitudinal contraction.

On the contrary, normal or opposite samples practically did not show any longitudinal contraction. It was proved, that longitudinal contraction of reaction beech wood increases proportionally with time and temperature. The steaming lasting more than 1h had not considerable effect on longitudinal contraction increase Čunderlík et al. (1995).

As also shown by Čunderlík et al. (1995) their measurements prove that highest longitudinal contraction occurred at temperatures above 100°C. Lower values of longitudinal contraction were observed at lower temperatures (Fig. 1).

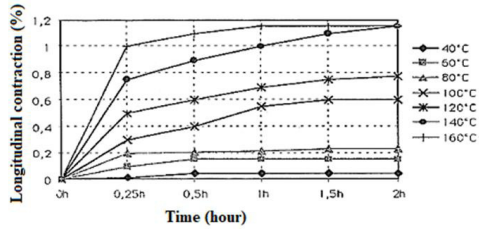

Fig. 1: Impact of temperature and time of steaming on the longitudinal contraction reaction beech wood (Čunderlík et al. 1995).

Using the hydrothermal treatment by steaming in case of submicroscopic structure, no cracks were observed in steamed wood, contrarily cracks formed considerably in cell wall of normal wood. Clair et al. (2001) studied the oak (*Querus serrata* M.) reaction wood. The experiment was done on small diameters, approximately 21 cm on the narrow end of logs. The hydrothermal treatment process took place in autoclaves at 120°C and 0.2 MPa. The longitudinal dimension change was monitored. Longitudinal contraction should be approximately 0.3% after the 1 h of hydrothermal treatment at 80°C. Sujan et al. (2015) observed higher longitudinal contraction after 1 h using the temperature 120°C, where the longitudinal contraction was 2.6%. Placet et al. (2002) and Tejada et al. (1998) explained the results of longitudinal contraction by qualitative changes of cell wall structure after the hydrothermal treatment application. Moreover, using high temperatures degrades noticeably more developed reaction wood what leads to increase in longitudinal contraction of material, what is in concordance with Čunderlík et al. (1995). Yamamoto et al. (2005) studied steaming of (Zelkovaserrata M.) and they pointed out that value of longitudinal contraction after the hydrothermal treatment was lower comparing to the non-treated samples of reaction wood. However, the experiment was noticeable only at higher G–layer content. That could be caused by softening of cell wall with G–layer content. Due to the work of

Sujan et al. (2015) G–layer is thought to be the most likely element responsible for the abnormal deformations in reaction wood. Longitudinal contraction is a very serious problem in production of solid wood panels assembled of beech lamellae joined alternatively breadth wise and longwise into large-sized blocks (Kúdela et al. 2014).

The aim of this paper is to identify sizes of longitudinal contraction between tension and opposite beech wood with using different drying modes.

MATERIALS AND METHODS

Beech wood (*Fagus sylvatica* L.) was used for the experimental measurements. Samples were chosen from four beech logs with a diameter of 48 cm and length of 150 cm. Beech logs were selected from forests called Michalková– Burzovo (550 m.a.s.l.) belonging to University Forest Enterprise of the Technical University in Zvolen, Slovakia. Logs were chosen without visible defects such as red false heartwood, rot and necrosis which can affect measurements. One of many factors, to evaluate content of the reaction beech wood in lumber is longitudinal warping, the woolly appearance of sawn surface, eccentric pith and shiny appearance of reaction beech wood in wood rings calling them "white rings were observed in the transverse plane. All mentioned methods were used for detection of reaction beech wood. In addition, for detailed observation we provided detection of reaction beech wood in timbers also by chemical reagent which was developed at our department.

Based on the identification of the reaction zone using the above methods, were prepared two groups of samples containing the reaction beech wood (R_1 and R_2) and the group containing the opposite wood (O_1 and O_2) (Fig. 1). The samples had final dimensions of thickness 30 mm, width 100 mm and length 300 mm.

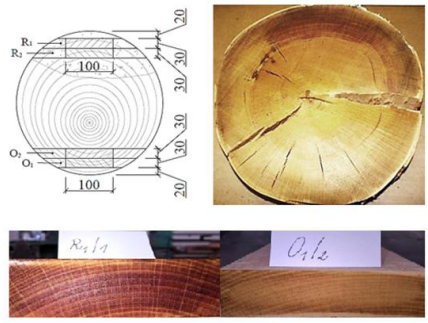

Fig. 2: Cutting scheme of different zones reaction (R) and opposite (O) wood and detection of reaction beech wood in timbers by chemical reagent.

The experiment was carried out in a Memmert HCP 108 laboratory dryer. The drying mode was divided into two phases restricted by the presence of free water and bound water in the dried wood.

When drying process was above fibre saturation point (FSP), psychrometric difference (Δt) was maintained at 2°C. After the MC was under the FSP, the psychrometric difference (Δt) was increased to 12°C at temperatures 60°C, 80°C a 90°C (Tab. 1). Drying mode 120°C had temperature of surrounding air 90°C and psychrometric difference was 2°C in first stage of

drying process. Second stage had increased temperature up to 120°C, without regulation (Δt). It was drying process in heated steam. FSP was determined by continuous MC measurement through samples from both groups. Specimens MC were measured every 24 hours. After reaching the average MC value at 28%, the drying parameters were changed. The drying rate between the reaction and the opposite samples were analysed at use of the different temperatures. The drying temperatures were 60°C, 80°C, 90°C and 120°C (Tab. 1)

Tab. 1: Parameters of drying modes.

Drying mode	Above fibre saturation point (FSP)			Under fibre saturation point (FSP)		
	Temperature of surrounding air (°C)	Δt (°C)	φ (%)	Temperature of surrounding air (°C)	Δt (°C)	φ (%)
60	60	2	91	60	12	52
80	80	2	93	80	12	65
90	90	2	94	90	12	60
120	90	2	94	120	-	-

The gravimetric method was used to determine the moisture content (MC) before (MC_i) and after (MC_f) drying process on the sixteen reactions and opposite samples, respectively. The moisture content was calculated using Eq. 1 according to the Slovak standard STN EN 49 0103:

$$MC = \frac{m_w - m_0}{m_0} \cdot 100 \ (\%) \tag{1}$$

where: m_w - mass of moisture sample (g) and m_0 - mass of oven-dry sample (g).

The oven-dried density was determined for every sample with reaction and opposite wood. The measurement was performed under laboratory conditions. The oven-dried density was calculated using Eq. 2 according to the Slovak standard EN 49 0108:

$$\rho_0 = \frac{m_0}{V_0} \ (\mathrm{kg \cdot m^{-3}}) \tag{2}$$

where: m_0 - mass of sample in oven dry-state (kg),
V_0 - volume of sample in oven dry-state (m^3).

The length dimension of the samples was measured before and during in different time of drying process to determine longitudinal contraction.

The measurement was carried out every 24 hours using a sliding scale, always at the same location on the cross section of the samples (Fig. 3). Subsequently, longitudinal contraction, were evaluated using Eq. 3 based on the quoted work Čunderlík et al. (1995):

$$\alpha_l = \frac{l_{before} - l_{after}}{l_{before}} .100 \ (\%) \tag{3}$$

where: l_{before} - length of sample before drying process (mm),
l_{after} - length of sample in different time of drying process (mm).

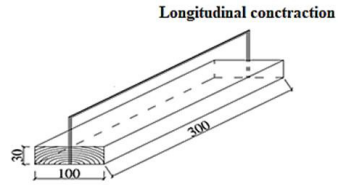

Fig. 3: Measurement of the longitudinal contraction.

RESULTS AND DISCUSSION

Moisture content was measured on the reaction and opposite samples before (MC_i) and after (MC_f) drying for each drying mode, respectively. These values of moisture content were higher in the reaction wood before drying process. Different values were measured at density in oven dry-state in the reaction samples, where the values were higher. The values of drying rates are shown in Tab. 2, divided into drying above and under FSP.

Tab. 2: Values of MCi, MCf, density and drying rate.

Samples	Drying mode	ø Moisture content (%)		ø Density ρ_0 ($kg \cdot m^{-3}$)	Drying rate (%·h^{-1})	
		MC_i	MC_f		Above FSP	Under FSP
Reaction	60	77.4	7.8	668	0.9	0.18
	80	86.7	9.2	674	0.91	0.34
	90	71.4	1.6	666	0.9	0.2
	120	80.3	2.7	659	0.31	1.39
Opposite	60	67.8	7.5	662	0.98	0.17
	80	78	8.7	652	1.02	0.41
	90	64.9	4.5	653	0.95	0.2
	120	76.7	2.8	649	0.32	1.24

Using inductive statistics (Fig. 4), we evaluated the dependence of moisture content based on the significance level ($p < 0.05$) between the comparison groups significant difference was found. Reaction beech wood had higher initial moisture content than opposite wood.

Based on the work of the Čunderlík et al. (1995) and Sujan et al. (2015), which confirmed that the reaction timber has a higher moisture content because is known that the reaction beech wood bounds more water. This finding can be explained by increasing the proportion of cellulose in reaction beech wood (Okuyama et al. 1994).

The analysis between reaction and opposite wood at density in oven dry-state confirmed statistically significant differences (Fig. 5). Based on the F-test and the p value, the significance level was 0.0356, not more than 0.05. Analysis confirmed fact that samples containing of reaction beech wood had a higher density value in the dry-state significantly.

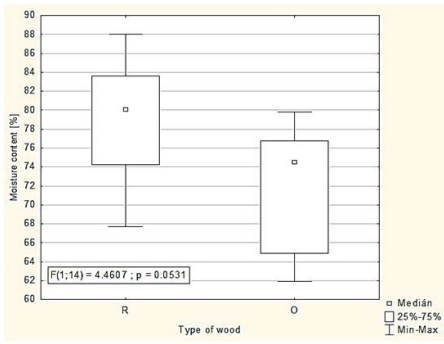

Fig. 4: Moisture content before drying process for reaction (R) and opposite (O) samples.

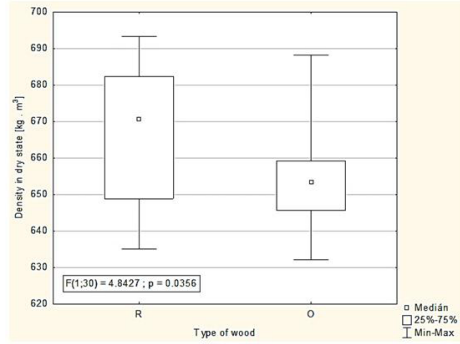

Fig. 5: Density in dry state for reaction (R) and opposite (O) beech wood.

Variability of density in dry state can be caused by different quantitative and qualitative representation of thick walls fibres with gelatinous layer. Based on the results Čunderlík et al. (1995) microscopicall and chemical structure of cell wall of reaction beech wood is responsible for differences of physical properties of opposite wood.

Longitudinal contraction was analysed every 24 hours of drying process, recorded data are presented in Tab. 3. Highlighted are values of samples reached a moisture content of about 28 % (FSP), also changing the drying parameters. Graphical representation of the longitudinal contraction reaction and opposite samples with use different drying modes 60, 80, 90, 120 are shown in Fig. 6.

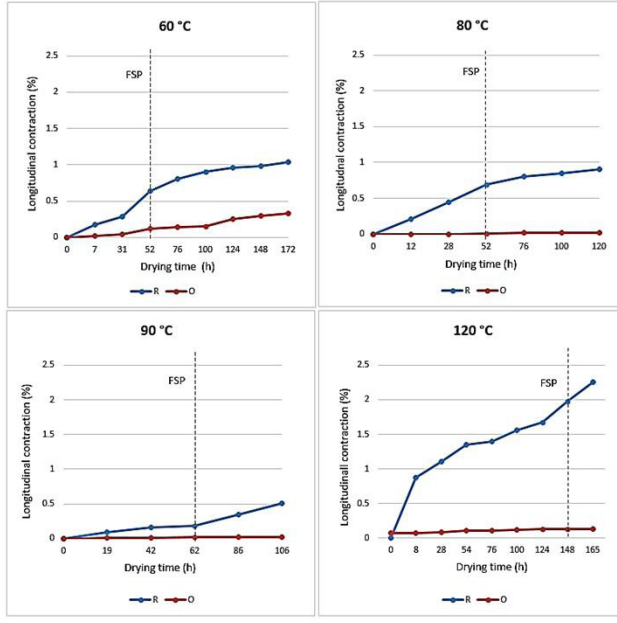

Fig. 6: Longitudinal contraction of reaction and opposite samples with use different drying mode.

Fig. 6 also shows drying time for each temperature respectively, course of longitudinal warping which was divided into two phases above and under FSP (boundary is marked by a dashed line). As is shown in Tab. 3 reaction beech wood had remarkable longitudinal contraction after achievement FSP (boundary is marked by a green line).

The final drying times were different at lower temperatures. Higher temperature modes showed smaller differences and drying times were almost the same for reaction and opposite samples after drying process (Tab. 3).

Tab. 3: Values of the longitudinal contraction and a drying time for the every drying mode.

Drying mode											
60			80			90			120		
Drying time (h)	Longitudinal contraction (%)		Drying time (h)	Longitudinal contraction (%)		Drying time (h)	Longitudinal contraction (%)		Drying time (h)	Longitudinal contraction (%)	
0	0	0	0	0	0	0	0	0	0	0	0.069
7	0.18	0.02	12	0.21	0	19	0.09	0.01	8	0.87	0.076
31	0.29	0.04	28	0.44	0	42	0.16	0.01	28	1.11	0.079
52	0.64	0.12	52	0.69	0.01	62	0.18	0.02	54	1.35	0.112
76	0.81	0.14	76	0.8	0.02	86	0.34	0.02	76	1.4	0.113
100	0.91	0.15	100	0.85	0.02	106	0.51	0.02	100	1.56	0.114
124	0.96	0.25	120	0.9	0.02				124	1.67	0.136
148	0.98	0.3							148	1.98	0.136
172	1.04	0.33							165	2.26	0.136

Remarkable changes in the longitudinal contraction occurred in reaction beech wood samples. Opposite samples longitudinal contraction had almost 0%. In case of used drying mode at 60, the contraction of opposite wood is 0.33%. Given measurement can be affected by the fact that reaction beech wood could be found in the opposite wood in small amount. Except samples treated at 60°C, where samples reached 0.33%.

At all used temperatures, it can be concluded that longitudinal contraction had remarkable findings in reaction samples. Longitudinal contraction was increasing with lowering moisture content and FSP can be defined as a boundary point. However, that does not apply at 120°C, where the increasing contraction can be observed already after 8 hours from the beginning of drying to about 1%.

The measurement can be explained by increased ambient temperature over 90°C, which intensified longitudinal contraction of reaction beech wood. Regulation drying time of drying mode 120 was very difficult above FSP. Drying rate was slowly as is shown in Tab. 2 in a both types of wood.

Longitudinal contraction was over 1% at temperatures 60°C and 120°C, and under 1% at 80°C and 90°C. Drying time can also be the cause while it was almost equal at 60°C and 120°C. Lower values of longitudinal contraction were observed at shorter drying time.

Many authors analysed definition of longitudinal contraction and its evaluation (Kúdela and Čunderlík 2012, Mellerowicz et al. 2008, Kopen (1989, 1991), Jourez 2001). The above mentioned authors deal with problematic of increased contraction of reaction beech wood, where they examined the differences at FSP values of reaction and normal beech wood. Shrinkage and swelling of reaction beech wood is more pronounced in longitudinal direction, what causes higher values of longitudinal warping.

Norberg and Meier (1966), Okuyana et al. (1994) studied increased shrinkage of reaction beech wood in longitudinal direction. They tried to find more pronounced difference in shrinkage not only in the G–layer. According to Clair et al. (2001) longitudinal shrinkage after 1 h should be approximately 0.3%.

More detailed explanation of reaction beech wood shrinkage in longitudinal direction is in article of Čunderlík et al. (1995), where they concluded that G–layer is characterized with high transversal shrinkage based on observation and analysis of the composition of individual layers. G–layer separation from S_2 layer occurs as a result of this shrinkage and weak bounds between the layers. This allows S_1 and S_2 layers to shrink in larger extent.

The analyses confirmed that the main cause of samples deformation with reaction beech wood content is 6 times higher longitudinal shrinkage of reaction beech wood compared to normal (opposite) wood and microscopic structure as well.

CONCLUSIONS

Based on our final assessment, we can conclude that reference samples were cut only from reaction and opposite zones.

- Reaction beech wood had a higher MC than opposite wood in all samples as well.
- Differences among oven dry-state densities were more remakeable in reaction beech wood.
- Measured data confirmed that variability of initial moistures did not affect the drying process and samples reached approximately equal final moisture.
- Longitudinal contraction was remakeable in reaction wood, where it was several times higher (FSP was found as boundary point in all measurements), what could be expected considering the physical properties of reaction beech wood.
- Measurements confirmed that drying time and temperature has a noticeable effect on the longitudinal contraction.
- Higher longitudinal contraction was measured in temperature 60°C and 120°C, which had almost identical drying time.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-17-0583 and APVV – SK - PL-18-0052.

REFERENCES

1. Clair, B., Thibaut, B., 2001: Shrinkage of the gelatinous layer of Poplar and Beech Tension wood. IAWA Journal 22: 121-131.
2. Čunderlík, I., Kúdela, J., Bluskova, G., 1995: Relaxation of stresses in streamed beech tension wood. In: Lesotechničesko obrazovanie v Bulgarija. Sofia: TOM II. Visš lesotechničeski institut, Pp. 199–205.
3. Čunderlík, I. Vilkovský, P. Račko, V., 2017: Shear strength and analysis of shear area on wood/bark interface on beech wood (*Fagus sylvatica* L.). Wood Research 62(5): 691-700.

4. Jourez, B., Riboux, A., Leclercq, A., 2001: Anatomical characteristics of tension wood and opposite wood in young inclined stems of poplar (*Populus euramericana* CV. "Ghoy"). IAWA Journal 22: 133-157.
5. Kačíková, D., 2001: Makromolekulové vlastnosti hlavných zložiek bukového dreva z hľadiska sulfátových buničín. (Macromolecular properties of the main components of beech wood in terms of kraft pulps. In Slovak). Zvolen: Technical University in Zvolen, 84p.
6. Kopen, S., Torrati, T., Kanerva, P., 1989: Modelling longitudinal elastic and shrinkage properties of wood. Wood Science and Technology 23: 55-63.
7. Kopen, S., Torrati, T., Kanerva, P., 1991: Modelling longitudinal elastic and shrinkage properties of wood. Wood Science and Technology 25: 25-32.
8. Kúdela, J., Čunderlík, I., 2012: Bukové drevo štruktúra, vlastnosti, použitie. (Beech wood structure, properties and utilization). Technical University in Zvolen,152 pp. ISBN 978-80-228-2318-0.
9. Kúdela, J., Gryc, V., Tóth., V., 2014: Deformation of beech wood – the sources and their identification before beech logs processing. Annals of Warsaw University of Life sciences 87:121-125.
10. Mellerowicz, E., J, Immerzeel, P., Hayashi, T., 2008: The molecular muscle of trees. Annals Botany 102: 659-665.
11. Norberg, P.H., Meier, H., 1966: Physical and chemical properties of the gelatinous layer in tension wood fibres of Aspen (*Populus tremula* L.). Holzforschung 20(6): 174-178.
12. Okuyama, T., Yamamoto, H., Yoshida, M., Hattori, Y., Archer, R., R., 1994: Growth stresses in tension wood: role of microfibrils and lignification. Annals Forests Science 51: 291-300.
13. Placet, V., Passard, J., Perre, P., 2007: Viscoelastic properties of green wood across the grain measured by harmonic tests: hardwood versus softwood and normal wood versus reaction beech wood. Holzforschung 61: 548-557.
14. Sujan, K.C., Yamamoto, H., Matsuo-Ueda, M., Yoshida, M., Kazuhiro, Naito, K., Shirai, T., 2015: Continuum contraction of tension wood fiber induced by repetitive hygrothermal treatment. Wood Science and Technology 49(6): 1157-1169.
15. Tanaka, M., Yamamoto, H., Kojima, M., Yoshida, M., Matsuo, M., Abubakar, M. L., Hongo, I., Arizono, T., 2014: The interrelation between microfibril angle (MFA) and hygrothermal recovery (HTR) in compression wood and normal wood of Sugi and Agathis. Holzforschung 68(7): 823-830.
16. Tejada, A., Okuyama, T., Yamamoto, H., Yoshida, M., Imai, T., Itoh, T., 1998: Studies on the softening point of wood powder as a basis for understanding the release of residual growth stress in logs. Forest Product Journal 48: 84-90.
17. Vilkovská, T., Klement, I, Konopka, A., Barański, J., 2016: High temperature drying of beech with content of tension wood. In Chip and chipless woodworking processes 2016. 10th international science conference, September 8-10, Technical University in Zvolen. Zvolen: 2016, Pp. 333-339, ISSN 1339-8350.
18. Yamamoto, H., Abe, K., Arakawa, Y., Okuyama, T., Gril, J., 2005: Role of the gelatinous layer (G-layer) on the origin of the physical properties of the reaction beech wood of *Acer sieboldianum*. Journal of Wood Science 51: 222-233.

STANDARDS

STN EN 49 0103, 1979: Determination of moisture content of the physical mechanical tests. Slovak Standards Institute, Bratislava, Slovakia.

STN 490 108, 1993: Wood. Determination of density. Slovak Standards Institute, Bratislava, Slovakia.

Tatiana Vilkovská*, Ivan Klement
Technical University in Zvolen
Department of Wood Technology
T.G. Masaryka 24
960 01 Zvolen
Slovakia
*Corresponding authors: tatiana.vilkovska@gmail.com and klement@tuzvo.sk

Igor Čunderlík
Technical University in Zvolen
T.G. Masaryka 24
960 01 Zvolen
Slovakia