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The influence of the trunk cross section zone on the emission of VOC, chemical composition and structural parameters of fir (*Abies alba* Mill.)

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Abstract: The level of volatile organic compounds emission from the heartwood zone and the sapwood zone of fir was determined. Tests were carried out by the chamber method based on the requirements of ISO 16000 standards. The samples of air from the chamber were taken after 3, 7, 14 and 28 days. The content of particular chemical components in the both parts of the trunk cross section was determined as well. It was determined that the sample of heartwood originated from the typical juvenile wood zone and the sapwood sample from the mature wood zone. The border between these zones was defined based on the changeability of the tracheid length. Throughout the whole testing period the heartwood sample emitted more volatile organic compounds compared to the sapwood sample; however, the volumes of these emissions were the lowest compared to other previously studied softwood species.

Keywords: fir, emission of volatile organic compounds (VOC), chemical composition of wood, juvenile wood, mature wood,

INTRODUCTION

The diversity of wood properties determines the possibilities of its use as both a raw material and finished products. In this aspect it is important that one learns not only the interspecies, but also the intraspecies changeability of wood properties. Hence, in recent years more and more wood studies have been devoted to identification of the changeability of wood qualities within a given species. This changeability stems from the diversity of wood structure and chemical composition on the cross section and along the tree height. The radial changeability of some wood qualities depends on the width of the heartwood zone and the sapwood zone. On the one hand, heartwood is the part of a tree that increases wood durability (Bergström 2003), and on the other hand, the zone that for most softwood species demonstrates higher VOC emission than the sapwood zone. In the case of softwood species balsamic resin is the main source of VOC emission. This resin is a solution of solid resin acids in a mixture of terpenes (Augustin et al. 1982, Fenegel and Wegener 1989); however it is not present in all the species. One of such species is fir, which additionally and distinct from most softwood species has so-called non-pigmented heartwood (Hejnowicz 2006). Many literature reports indicate that the size of the heartwood zone and the sapwood zone has no influence on the increase in wood durability from the core towards the circumference observed for softwood species (Taylor et. al. 2002). Such characteristic of mechanical properties is a result of the radial changes in wood density determined by the structure of annual rings, the cell length or the ultrastructure of cell walls. Changes in these properties are connected with distinguishing of the juvenile wood zone and the mature wood zone on the cross section. These zones also differ by the chemical composition. Therefore, change of some wood properties is determined by the process of heartwood creation; whilst other wood properties depend on the age of cambium from which the wood tissue is created, for young cambium produces juvenile wood and mature wood is created from the cambium cells which already reached their maximum size.

In the light of the above observations the authors carried out studies aimed at determination of VOC emission from fir heartwood zone and sapwood zone, as well as determination of the chemical composition of wood originating from these zones. Due to the fact that chemical composition of wood demonstrates diversity in the juvenile zone and the mature zone, the authors decided to define the widths of these zones in order to verify the position of tested samples within them.

MATERIALS

Material for testing was taken from an 85-year-old European fir (*Picea abies* Mill.), cut down in Sucha Forest Division in the Beskid Wysoki province in the Carpathian forest and nature region. 3 discs of the thickness of 5 cm cut out from the diameter breast high of the tree were taken for testing. Macrostructural parameters were measured on a test strip of wood cut out along the tree diameter. The length of tracheids was determined for the 3rd, 6th, 9th, 12th, 15th, and 20th ring and further for every 10th to the tree circumference. To this end the wood was subjected to maceration in a mixture of acetic acid and oxygenated water of the concentration of 30% in the proportion of 1:1. 30 tracheids of early wood and 30 tracheids of late wood from each studied ring were measured. Macro- and microstructural measurements were taken using a computer image analyser. Next two discs were intended for testing of VOC emission and wood chemical composition. Immediately after the tree was cut down the zones of heartwood and sapwood were determined on the cross section of each disc. The samples for volatile organic compounds emission testing were cut out from both zones. The dimensions of the test samples were so selected that the total surface of the planes exposed in the test chamber was 0.025 m^2 (test chamber load 1 m^2/m^3). The emission of volatile organic compounds was tested from the cross section of the samples, and the surfaces of the tangent section and the radial section were covered with aluminium tape.

Chemical analyses were carried out separately for the heartwood zone and the sapwood zone. 0.5-1.0 mm particle fraction was used in the tests.

RESULTS

The average width of annual rings calculated for total radius of the tree was 3.1 mm, and the share of late wood 32%. The dynamics of changes in the annual ring width and of the late wood share within the annual rings in 5-year ring zones is presented in fig. 1.

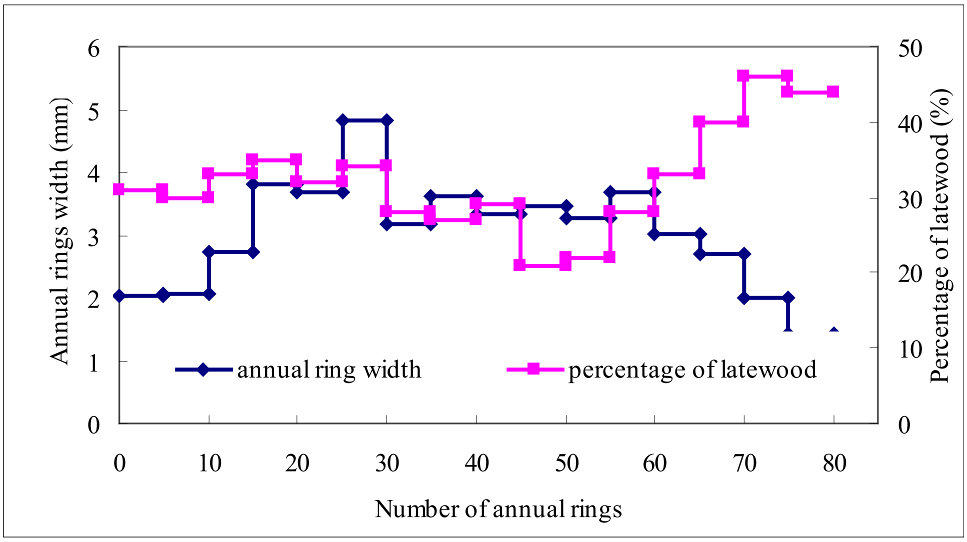

Fig. 1. The width of annual rings and the share of late wood in 5-year ring zones of fir (*Abies alba* Mill.)

The development of macrostructural parameters depends on the tree growth dynamics. According to Niedzielska (1995) the structure of tested fir indicates that this tree may be classified as belonging to the group of trees with narrow annual rings in the core zone, which slowly grow in width over successive years of the tree growth, and then gradually decrease.

Due to the diverse dynamics of the growth of tested fir tree the macrostructural qualities proved to have been insufficient for determination of the zone in which the juvenile tissue formed. These zones were distinguished by determination of the changeability of the tracheid length along the radius of tested fir tree. In every studied ring the lengths of the late wood tracheids were longer compared to the early wood tracheids. This difference did not exceed 10%. Over the length of total tree radius the tracheid length increased twice-fold. The highest tracheid length growth dynamics was observed in the first close-to-core rings. In the initial period of the tree growth the length of tracheids in both the early wood zone and the late wood zone increased by 60%. The successive annual rings demonstrated weaker or stronger fluctuations of the measured parameter. In order to determine the border between juvenile wood and mature wood, so-called sectional linear regression was carried out (Draper and Smith 1975) for the average tracheid length in the whole ring and the cambial age of the rings. The sectional linear regression showed that this border ran between the 30th and the 40th annual ring, which proves that tested heartwood sample originated from the typical juvenile wood zone and the sapwood sample from the mature wood zone (fig. 2).

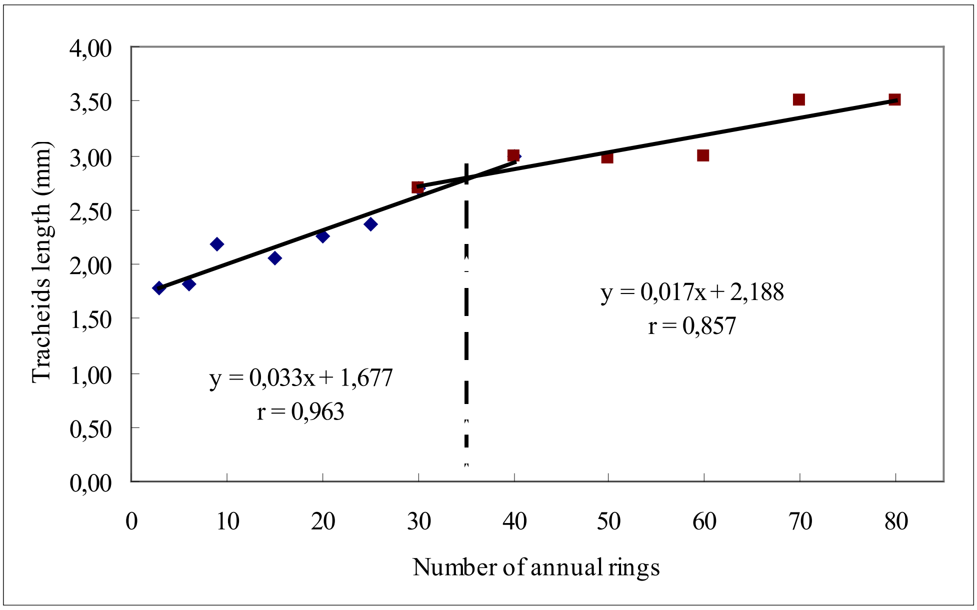

Fig. 2. Radial changeability of the average tracheid length in analysed annual rings of fir (*Abies alba* Mill.)

The sums of concentration of all volatile organic compounds (TVOC) emitted after 3, 7, 14, and 28 days of exposure of the fir heartwood sample and the fir sapwood sample in the chamber are given in fig. 3. The obtained results indicate that the volumes of VOC emission from tested fir differ for particular parts of the cross section. After the 3rd day the sample cut out from fir heartwood emitted approximately four-fold higher amounts of volatile organic compounds (TVOC 519 $\mu g/m^3$) compared to the sample obtained from fir sapwood (TVOC 126 $\mu g/m^3$). After 28 days of exposure in the chamber the levels of VOC emission from both test samples fixed at the level of 90 $\mu g/m^3$ in the case of heartwood and 68 $\mu g/m^3$ in the case of sapwood. Compared to other softwood species studied in previous years (pine, spruce, and larch), fir emitted the least volatile organic compounds, especially terpenes. This results from the specific anatomy of fir characterised by the lack of resin canals. The fact that terpenes were identified in the quality and quantity composition of air sampled from the chamber may prove that tested wood contained traumatic resin canals, which occur as a result of wood tissue damage caused by, for instance, the action of strong winds from one direction.

Fig. 3. The effect of the exposure time on the sum of concentrations of volatile organic compounds (TVOC) from the cross section of fir heartwood and sapwood

As mentioned above, extraction substances are the main source of VOC emission from softwood species. Chemical analyses which were carried out showed higher content of these substances in the fir heartwood sample compared to the fir sapwood sample (this concerns primarily substances extracted by cold water) – table 1. It follows from the data presented in literature that free fatty acids present in wood may oxidize formulating aldehydes (Roffael 2006a and 2006b). This was confirmed by the results of VOC emission from tested fir. Higher concentrations of aldehydes (compounds with carbonyl group) were emitted by the heartwood sample than by the sapwood sample. pH reaction was also determined and it was 5.4 for the sapwood sample, and 5.7 for the heartwood sample. Usually the pH values for softwood species are in the range pH 4-5, but in the case of fir this reaction is higher due to the high content of fatty acids.

Table 1 Chemical composition of the fir heartwood and sapwood samples

Determined component	Heartwood (juvenile wood)	Sapwood (mature wood)
	[%]	
Cellulose	46.91	45.96
Lignin	30.90	32.02
Pentosans:		
-furfural	5.35	5.17
- pentosans	9.15	8.84
- pentoses	10.40	10.05
Substances soluble in:		
- cold water	0.39	0.13
- hot water	1.68	1.70
- ethanol	1.25	0.75
- 1% NaOH	9.90	12.02
Ash content	0.38	0.26

CONCLUSIONS

1. Compared to other softwood species fir emitted the least volatile organic compounds. In the case of the heartwood sample a higher dynamics of VOC concentration drop was observed after the 3rd and the 7th day of exposure. After 28 days TVOC from heartwood and sapwood fixed at similar low levels.
2. The conducted studies of the chemical composition of the samples originating from fir heartwood and sapwood zones did not revealed significant differences in the content of cellulose, lignin, and hemicelluloses.
3. Changeability of macrostructural parameters on the trunk cross section was insufficient for determination of the juvenile wood zone and the mature wood zone.
4. The border between these zones was defined based on the changeability of the length of tracheids, which in the rings of the juvenile wood were approximately 60% shorter than the tracheids in the mature wood rings. The division of the cross section allowed the observation that analysed samples of heartwood and sapwood did not originate from the transient wood zones, but were located in the typical juvenile wood zone and the mature wood zone, respectively.

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Streszczenie: *Wpływ strefy przekroju poprzecznego pnia na emisję VOC, skład chemiczny i parametry strukturalne drewna jodły (Abies alba Mill.)*

Zbadano poziom emisji lotnych związków organicznych z części twardzielowej i bielastej drewna jodły. Badania wykonano metodą komorową opierając się na wymaganiach norm ISO 16000. Próbki powietrza z komory pobierano po 3, 7, 14 i 28 dobie. Określono także zawartość poszczególnych składników chemicznych w obydwu części przekroju poprzecznego pnia. Ustalono, że próbka twardzieli pochodziła ze strefy drewna typowo młodocianego a bieli ze strefy drewna dojrzałego. Granicę między tymi strefami wyznaczono na podstawie zmienności długości cewek. W trakcie całego okresu badawczego próbka twardzieli emitowała więcej lotnych związków organicznych w porównaniu z próbką bielu.

W 3 dobie ekspozycji w komorze, suma stężeń lotnych lotnych związków organicznych (TVOC) wyemitowanych z twardzieli jodły wyniosła 519 μg/m^3, a z bielu 126 μg/m^3. Po 28 dobach wartości TVOC dla obydwu prób badawczych ustaliły się na poziomie 90 μg/m^3 (próbka twardzieli) i 68 μg/m^3 (próbka bielu). Wielkości tych emisji były jednak najniższe w porównaniu do innych wcześniej zbadanych gatunków drewna iglastego. Wynikało to m.in. z niskiej emisji terpenów spowodowanej brakiem przewodów żywicznych w budowie anatomicznejdrewna jodły.

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