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The role of parenchyma content in dimensional stability of wood

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Abstract: *The role of parenchyma content in dimensional stability of wood*. The objective of this study was to investigate the role of axial and rays parenchyma in dimensional stability of wood. To achieve this goal the multiple regression analysis was used. The selected tropical and subtropicalwood of eight species were chosen to the research as well as European beech. It was found that the higher the content of axial parenchyma, the lower shrinkage is, which was a result of the fact that wood extractives are mostly found in the parenchyma. In tested wood species no significant role of parenchyma tissue in wooden rays was established. Moreover, the knowledge about the anatomical structure of exotic wood was supplemented.

Keywords: parenchyma content, rays proportion, dimensional stability, exotic wood.

INTRODUCTION

Hygroscopicity is one of the most important property of wood. Differences in hygroscopicity between many species of wood affect the variability of wood properties, such as eg equilibrium moisture, swelling and shrinkage, as well as fiber saturation point.. Shrinkage is a phenomenon that determines the use of wood and is the result of the interaction of several features of its structure at the ultra-, micro- or macroscopic level as well as the chemical composition.. This complexity hinders the scientists in their efforts to study the parameters involved in dimensional variations, so that shrinkage has been the subject of research for several decades [Kawamura 1984, Watanabe et al. 1998].

It is known how far dimensional stability depends on wood density, proportion of wooden rays and ultrastructure such as microfibril angle in the S2 layer of the secondary cell wall [Harris and Meylan 1965, Kawamura 1984, Schulgasser and Witztum 2015]. Tangential shrinkage is greater than radial shrinkage due to the ultra-, micro- and macrostructure of wood. A simplistic explanation of the density–shrinkage relationship is often provided - thicker walls shrink more than the thin ones [Derome et al. 2011, Cavalheiro et al. 2016]. It is known, that the chemical composition of wood also has an influence on the physical properties. A number of tests have shown that the extractives influence the dimensional changes of wood [Choong and Achmadi 1991]. These substances exhibit hygroscopic, hydrophobic, or neutral behaviours.

So far, only wood parenchyma in form of wooden rays were analysed in context of influence on dimensional changes of wood [Kawamura 1984]. Axial parenchyma content has not been considered as a factor. Probably due to the fact that mainly coniferous wood species were tested or deciduous wood from moderate climate zone and those wood species showed rather scanty proportion of axial parenchyma. But there was no much research and investigation including tropical wood. Thus, the aim of this study was to determine role of parenchyma content in dimensional stability of wood, especially tropical.

MATERIALS AND METHODS

The following wood species were used in this study: African paduk (*Pterocarpus soyauxii* Taub.), courbaril (*Hymenaea courbaril* L.), afzelia (*Afzelia* sp.), European beech (*Fagus sylvatica* L.), ipe (*Tabebuia* sp.), light red meranti (*Shorea* sp.), merbau (*Intsia* sp.), tatajuba (*Bagassa guianensis*Aubl.) and teak (*Tectona grandis* L.). These species were selected in order to have a representative sample of hardwood, with a wide range of density, the share of parenchyma cells and different anatomical structures. European beech wood was used as a reference. All test materials were heartwood because it is more important commercially than sapwood. Wood from each wood species was acquired from company DLH Poland (Warsaw, Poland). Material was identified in the laboratory using macroscopic and microscopic techniques.

Samples of each wood species were collected from one log; thus, differences in tested properties caused by differences in wood anatomy were avoided. Each part was quarter-sawn to produce planks of approx. 40mm thickness. Then they were conditioned to air-dry in a room with relative humidity close to 50 % and temperature of 21 °C for six months prior to testing. The defect-free planks were sawn and sized to samples for moisture sorption and dimensional stability testing. Each sample had dimensions of 30 mm (tangential) × 30 mm (radial) × 5 mm (longitudinal). For each species 30 samples were tested.

Swelling and density determination

The wood basic density of samples was determined according to PN-D-04101:1977 and ISO 3131:1975. The volumetric shrinkage of wood was also determined according to PN-D-04111:1982 and ISO 4858:1982.

Determination of proportion of anatomical parameters

Before the microscopic measurements were performed, the wood specimens had been soaked for three months in a mixture of water, glycerol, and 96% ethanol to soften the wooden tissue (volume ratio 1:1:1). A sledge microtome (Reichert) was used to cut samples in slices of 10- to 30-μm thickness each. Microscopic preparations were stained with 5% safranin solution in ethyl alcohol (96%). Anatomical parameters were measured using an image transverse and tangential cross-section. Images of the wood were captured using an Olympus BX40 light microscope (Olympus Corporation). The ratio of axial parenchyma and rays were measured by the image processing software WinCELL (Regent Instrument Inc., version 2016a).

Statistical procedure and modelling of data

Statistical analysis of the test results was carried out using Statistica v. 10 software (StatSoft, Inc.). Data were analysed and provided as the mean ± standard deviation, the median, scatter plot of results around the median, and minimum and maximum values. Multiple regression analyses were used to evaluate relations.To indicate the most important anatomy element for wood dimensional stability, the model of regressiondepending wood shrinkage on share of axial parenchyma and share of parenchyma present in rays were done.

For established regression coefficient of determination (R^2), the level of statistical significance (p) and value of F statistic were calculated. To define importance of each included independent variable, the beta coefficients were determined. These coefficients were calculated for each regression model and they cannot be compared.

RESULTS AND DISCUSSION

Wood species chosen to the research exhibited high variability in dimensional stability (Tab. 1). The highest value of total volume shrinkage showed European beech (16.7%), while the lowest value was observed for teak wood (7.2 %). Based on obtained results it can be stated that there was high variation in anatomical characteristics among tested wood species. In case axial parenchyma content the variation was significant. Percentage proportion of axial parenchyma ranged from 3.5 % in ipe to 23.6% in afzelia (axial parenchyma present in wide bands). Proportion of parenchyma in rays showed much less variability and it ranged from 9.5 % (in case of African paduk) to 19.8 % (in case of teak wood).

Table 1. Density, dimensional changes and anatomical parameters of selected tropical wood species and European beech

Wood name	Wood density D	Shrinkage			Share of parenchyma	
		radial S_r	tangential S_t	volumetric S_v	axial P	rays R
	$kg \cdot m^{-3}$	%				
African paduk	590	3.3	5.3	7.8	21.2	9.5
Courbaril	910	4.4	8.6	12.0	15.8	11.7
Afzelia	720	3.1	4.6	8.7	23.6	16.1
European beech	670	6.0	14.1	16.7	5.2	10.9
Ipe	900	5.3	6.7	12.7	3.5	9.8
Light red meranti	500	3.9	8.9	13.5	4.6	16.0
Merbau	825	4.1	6.1	11.0	22.2	13.7
Tatajuba	890	3.8	5.5	10.9	14.8	17.6
Teak	750	2.5	5.7	7.2	21.9	19.8

Table 2. Correlation coefficients between wood properties and anatomical parameters

Variables	D	S_r	S_t	S_v	P	R	PR
D	1.00	ns	ns	ns	ns	ns	ns
S_r	0.20	1.00	*	*	*	ns	*
S_t	-0.22	0.77	1.00	*	ns	ns	ns
S_v	-0.11	0.88	0.95	1.00	*	ns	*
P	0.06	-0.82	-0.64	-0.75	1.00	ns	*
R	0.06	-0.65	-0.39	-0.41	0.49	1.00	*
PR	0.07	-0.86	-0.64	-0.74	0.96	0.70	1.00

Note: D – wood density, S_r – total radial shrinkage, S_t – total tangential shrinkage, S_v – total volumetric shrinkage, P - proportion of axial parenchyma on transverse surface, R - proportion of rays area on tangential surface, PR – sum of P and R; * - statistical significant value at p level <0.05; ns - not significant at 0.05 level.

Table 3. Multiple regression equation models of the relations between wood shrinkage and share of axial parenchyma and parenchyma in rays

Multiple regression equation model	R^2	p	F
$S_v = 18.136^* - 0.330P^* - 0.074R$ (-0.73) (-0.16)	0.75	0.011	4.0052
$S_r = 6.518^* - 0.070P^* - 0.097R$ (-0.65) (-0.35)	0.76	0.015	9.0769
$S_t = 11.1512^* - 0.172P^* - 0.081R$ (-0.63) (-0.11)	0.64	0.201	3.1187

P - percentage share of axial parenchyma on transverse surface, R – percentage share of rays area on tangential surface; in parentheses beta coefficient of regression is given; * - statistical significant value at p level <0.05; F – value of test Fisher, p – level of significance.

The standardized regression coefficient (Tab. 2) were applied to verification the anatomical factors determining tested properties. The larger absolute values of the standardized regression coefficient, the greater its influence on the dependent variables. This allowed to indicate a significant role of axial parenchyma both in radial and volumetric shrinkage. The relations are negative. It means that the higher content of axial parenchyma, the lower dimensional changes of wood.

The multiple regression equations describing the relations between wood shrinkage and wood anatomy parameters explained dependence on level 64% to 75% (Tab.3). The low level of statistical significant values ($p<0.05$) for S_v and S_r suggests that obtained equations can be used for prediction (e.g. during macroscopic observations unidentified wood species to predict its properties). According to the results, the axial parenchyma content is more important factor that wooden rays. The most probably reason o the role of axial parenchyma is the fact that mostly wood extractives are found largely in the parenchyma [Hillis 1971]. And as is generally known, a number of studies proved that the extractives influence the dimensional changes of wood.

CONCLUSION

The role of axial parenchyma in dimensional stability of wood was determined. It was found that the higher the content of axial parenchyma, the lower shrinkage is, which was a result of the fact that wood extractives are mostly found in the parenchyma cells. In tested wood species no significant role of parenchyma tissue in wooden rays was established.

Based on the obtained results it was concluded that multiple regressions analysis can be useful in understanding wood properties as the results of the complex structure of wood.

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Streszczenie: *Rola miękiszu drzewnego w stabilności wymiarowej drewna.* Celem badań była próba określenia roli, jaką odgrywa miękisz drzewny (osiowy oraz promieni łykodrzewnych) w stabilności wymiarowej drewna. W analizie wykorzystano regresję wieloraką. Do badań użyto wybranych gatunków drewna ze strefy tropikalnej i subtropikalnej, jak również drewno buka zwyczajnego. Ustalono, że im wyższa zawartość miękiszu osiowego tym niższy skurcz, co najprawdopodobniej wynika z faktu, że w miękiszu znajduje się większość substancji ekstrakcyjnych. Ponadto, uzupełniono wiedzę z zakresu budowy drewna o informacje związane z udziałem miękiszu drzewnego w objętości drewna.

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