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DETERMINATION OF FIBRE SATURATION POINT OF SELECTED TROPICAL WOOD SPECIES USING DIFFERENT METHODS

The main objective of this research was to determine the fibre saturation point of tropical wood. Two different methods were used to achieve this aim: the logarithm of strength properties versus moisture content and volumetric shrinkage-moisture content plot to zero shrinkage. The test included selected wood species from Africa: Opepe, Iroko, African padouk, and Wenge, and South America: American mahogony and Ipe. For comparison, selected domestic wood species of a similar structure – European beech (Fagus sylvatica L.) – were also tested. Determination of the fibre saturation point of the selected wood species using two methods delivered similar results (the small differences were not significant). The results showed that, generally, the fibre saturation point of the tropical wood species was lower than in the case of the European wood species. The lowest values of the fibre saturation point were shown by the African padouk and Ipe (approx. 17 %). Moreover, it was found that in the case of the tropical wood, the basic density had a significant influence on the sorption properties of the tested wood species.

Keywords: tropical wood, European beech, fibre saturation point, compressive strength, volumetric shrinkage

Introduction

The demand for tropical wood products has led to increased trade on markets, as well as further knowledge of the characteristics of exotic wood, such as its physical, mechanical and technological properties. Knowledge in this field is still incomplete and often limited to a presentation of the names and appearance of the wood. For an evaluation of the sorption behaviour of domestic wood species the sorption properties of fir are usually used [Popper et al. 2007, 2009; Adampoulos and Voulgarridis 2012]. Due to differences in wood structure and chemical composition, it seems clear that differences in the sorption behaviour will appear [Popper et al. 2009]. A determination of the fibre saturation point, as

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well as the physical and mechanical behaviour of the wood as a hygroscopic material are very useful in the drying, conversion and utilization of timber [Hamami et al. 1998].

The term fibre saturation point (FSP) was introduced by Tiemann [1906] early in the 20th century, in connection with his work on strength-moisture relations. Since then, the fibre saturation point has been the subject of numerous investigations. In spite of this fact, discussion concerning how it should be defined and measured is ongoing [Babiak and Kudela 1995]. The concept of FSP is defined in terms of the theoretical condition of the wood when its cell cavities are completely devoid of water, while at the same time the cell walls are saturated with water.

This value can be determined using many methods. Some of them require extrapolation, e.g.: moisture content adsorption isotherms to unit relative vapour pressure, the differential heat of wetting (moisture content plot to zero heat evolved), volumetric shrinkage-moisture content plot to zero shrinkage or shrinkage involved, determining the ratio of the total volumetric shrinkage to the green volume specific gravity and a correction for the average density of the absorbed water. Two methods are involved in determining the transition point using the relationship: determination of the logarithm of electrical conductivity versus the moisture content, and determination of the logarithm of the strength properties versus the moisture content [Stamm 1964]. The described methods of determining the fibre saturation point of wood are characterized by some limitations. Therefore, it is advisable to determine the fibre saturation point using more than one method. The sorption behaviour of wood has been described in detail in the literature [Themelni 1998; Popper et al. 2006, 2007]. However, knowledge in this area is still incomplete due to the number of new wood species on the European market [Popper et al. 2009; Adampoulos and Voulgarridis 2012].

Determining the properties of the tropical wood commercially available on the European market is important and the results of research should be taken into account during the stage of wooden product design. A knowledge in this area would help manufacturers avoid many problems during the exploitation of wooden products such as floors. The main objective of this research was to determine the fibre saturation point in wood of various morphologies and to improve the knowledge of the sorptive properties of tropical wood. Sorption tests were combined with measurements of the physical and mechanical properties providing to obtain the value of the fibre saturation point of the wood species selected for the tests. This group included tropical wood from Africa and South America.

Materials and methods

The wood species used in this study are summarized in table 1.

Table 1. The material tested

Trade name according to PN-EN 13356:2005	Latin name	Plant family	Origin	Special features
African padouk	*Pterocarpus soyauxii* Toub.	*Fabaceae*	West Central Africa	axial parenchyma in narrow bands
American mahagony	*Swietenia macrophylla* King.	*Meliaceae*	South America	irregular fibres arrangement, axial parenchyma in narrow bands
European beech	*Fagus sylvatica* L.	*Fagaceae*	Europe (Poland)	wide wooden rays
Ipe	*Tabebuia* sp.	*Bignoniaceae*	South America	irregular fibres arrangement
Iroko	*Milicia excelsa* (Welw.) C.C.Berg	*Moraceae*	West Central Africa	irregular fibres arrangement, axial parenchyma in bands
Opepe	*Nauclea diderrichii* Merrill.	*Rubiaceae*		irregular fibres arrangement
Wenge	*Millettia laurentii* De Wild.	*Fabaceae*		axial parenchyma in wide bands

Samples of each wood species were collected from one board to obtain "identical samples". Thanks to this, the samples were similar and the structure was preserved in order to avoid differences in the tested properties caused by differences in wood anatomy. The samples, each measuring 30 mm (T) × 30 mm (R) × 5 mm (L), were prepared in order to find the dimensional changes at different levels of relative humidity. Furthermore, samples measuring 20 mm (T) × 20 mm (R) × 30 mm (L) were prepared in order to determine the compressive strength along the fibres at different levels of relative humidity. The specimens were exposed to a moisture sorption test (adsorption), as follows: oven-drying, conditioning at five different levels of relative humidity ranging from 9 to 97%, and water wetting. As soon as each point of sorption was reached, the mass of specimens was measured to the nearest 0.001 g and their dimensions were taken to the nearest 0.01 mm. The conditioning of the specimens to an appropriate moisture content was possible with the use of sealed enclosures in which prescribed saturated salt solutions were placed at a temperature close to 20°C. The relative humidity was monitored and recorded using a hygrometer. The salt solutions used to create various levels of the relative humidity of air at 20 ±2°C are listed in table 2. A criterion for equilibrium was established as three successive identical mass readings at 24 hour intervals.

The FPS was obtained at the intersection of the extrapolated sets of data - the results of testing the strength of the wood at different levels of moisture content (R_{mc}) and after wetting (R_w) in water, and in the second method, the results of determining partial wood shrinkage (S_{mc}) and total wood shrinkage (S_v). The procedure was described by Stamm [1971], and details of how the FSP was determined are shown figure 1.

Table 2. Relative humidity of air at a constant temperature 20 ±2°C obtained in sealed enclosures with the use of saturated salt solutions

Saturated salt solution	Relative humidity in [%] at 20 ±2°C
Potassium hydroxide KOH	9
Magnesium chloride MgCl	37
Sodium bromide NaBr	55
Sodium chloride NaCl	70
Potassium sulphate K_2SO_4	97

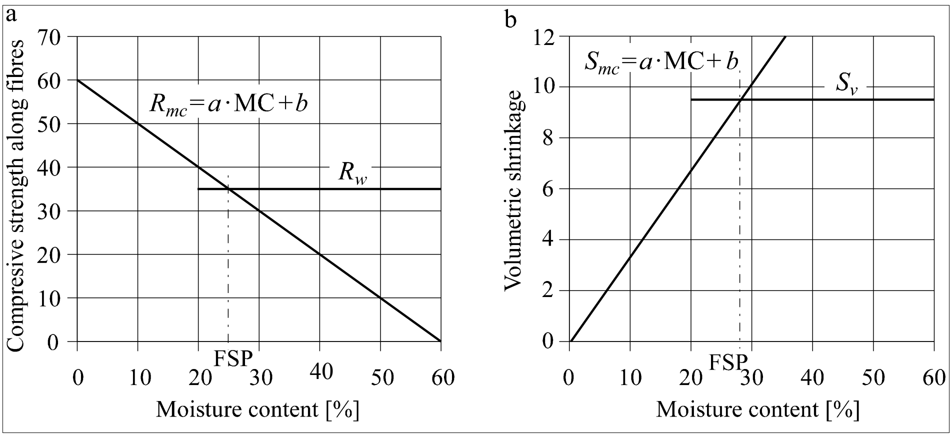

Fig. 1. Scheme of determination FSP: a – using volumetric shrinkage (S_{mc} – volumetric shrinkage at different levels of moisture content, S_v – total volumetric shrinkage), b – using compressive strength along fibres (R_{mc} – compressive strength at different levels of moisture content, R_w – compressive strength after water wetting)

The equilibrium moisture content of the samples was determined according to the standards PN-D-04100:1977 and ISO 3130:1975. The wood density of the samples was determined according to PN-D-04101:1977 and ISO 3131:1975. The volumetric shrinkage of the wood was determined according PN-D-04111:1982 and ISO 4858:1982, while determination of the compressive strength along the fibres was made based on PN-D-04102:1979 and ISO 3787:1976.

Results and discussion

The average values of the measured equilibrium moisture content for adsorption at 20°C are shown in table 3. For each wood species, 10 samples were used. In the case of every wood species tested, the equilibrium moisture content at different levels of humidity was diverse. The largest differences in the moisture content (MC) were visible when the air humidity was highest (approx. 97%).

Table 3. Equilibrium moisture content of selected tropical wood species and beech wood

Wood species	Equilibrium moisture content at relative humidity				
	9%	37%	55%	70%	97%
African padouk	2.10	7.32	9.17	10.35	14.47
American mahagony	3.28	10.14	12.72	13.98	23.26
European beech	3.00	7.51	11.80	12.87	24.02
Ipe	2.11	7.71	10.50	11.60	17.05
Iroko	2.25	7.17	8.55	10.15	18.61
Opepe	3.01	8.67	10.55	12.79	20.73
Wenge	2.75	8.41	10.15	11.90	15.66

The effects of the determination of the FSP of the selected wood species using two different methods are given in table 4 and table 5. It may be said that irrespective of the wood tested, the results of FSP determination were almost identical and the small differences were not significant (falling within the margin of error). The results show that, generally, the fibre saturation point of the tropical wood species was lower than in the case of the European beech. The highest value of the FSP was observed for the beech wood. The lowest values of the fibre saturation point were shown by the African padouk and Ipe (approx. 17%).

Furthermore, the results showed that the basic density of the tropical wood had a significant influence on the sorption properties of the tested wood species (the European beech wood was not included in this analysis). The same conclusion was reached by Hernandez [2006] following research on nine tropical hardwoods from Peru and sugar maple wood from Quebec. According to Babiak and Kúdela [1995], it is not only wood density but also wood structure that can play an important role. The wood species tested revealed a similar structure. All of the species constituted diffuse-porous wood. In some cases, expanded axial parenchyma were observed (Wenge, Iroko), while in others they were absent.

Table 4. Parameters describing relationship between volumetric shrinkage of wood and relative humidity of air

Wood species	Approximation of linear function in hygroscopic interval		Total volumetric shrinkage	Computed value of fibre saturation point
	equal	r	[%]	[%]
African padouk	S_v=0.4232·MC	0.998	7.45	17.7
American mahagony	S_v=0.4520·MC	0.997	11.00	22.9
European beech	S_v=0.6751·MC	0.996	21.56	31.0
Ipe	S_v=0.6688·MC	1.000	12.53	18.7
Iroko	S_v=0.3965·MC	0.998	9.00	23.2
Opepe	S_v=0.5799·MC	1.000	13.34	23.0
Wenge	S_v=0.8099·MC	0.998	16.73	21.1

S_v – total volumetric shrinkage, MC – moisture content of wood, r – coefficient of correlation.

Table 5. Parameters describing relationship between compressive strength along fibres of wood and relative humidity of air

Wood species	Approximation of linear function in hygroscopic interval		Compressive strength along the fibres after soaking wood in water
	equal	r	[MPa]
African padouk	R_c=145.6 – 4.182·MC	-0.994	71.6
American mahagony	R_c=75.5 – 1.953·MC	-0.997	33.6
European beech	R_c=122.2 – 3.480·MC	-0.989	22.9
Ipe	R_c=183.3 – 5.229·MC	-0.996	97.3
Iroko	R_c=88.3 – 2.519·MC	-0.994	31.9
Opepe	R_c=115.8 – 2.670·MC	-0.996	52.6
Wenge	R_c=153.4 – 3.077·MC	-0.994	84.6

R_c – compressive strength along fibres at different moisture content, MC – moisture content of wood, r – coefficient of correlation

The difference between the fibre saturation point of the European beech wood and the tropical wood was probably caused by the number of extractives in the wood structure which may act hydrophobically. This supposition finds confirmation in the literature [Popper et al. 2009; Adampoulos and Voulgarridis 2012]. Previous research has indicated the influence of extractives on the sorptive properties of wood. However, studies in this area are incomplete and knowledge in this field of expertise should be expanded. European beech is a non-heartwood species and the other tested wood was derived from the heartwood zone. The differences between the FSP of the European beech and tropical wood seem obvious, but differences between tropical wood species require verification.

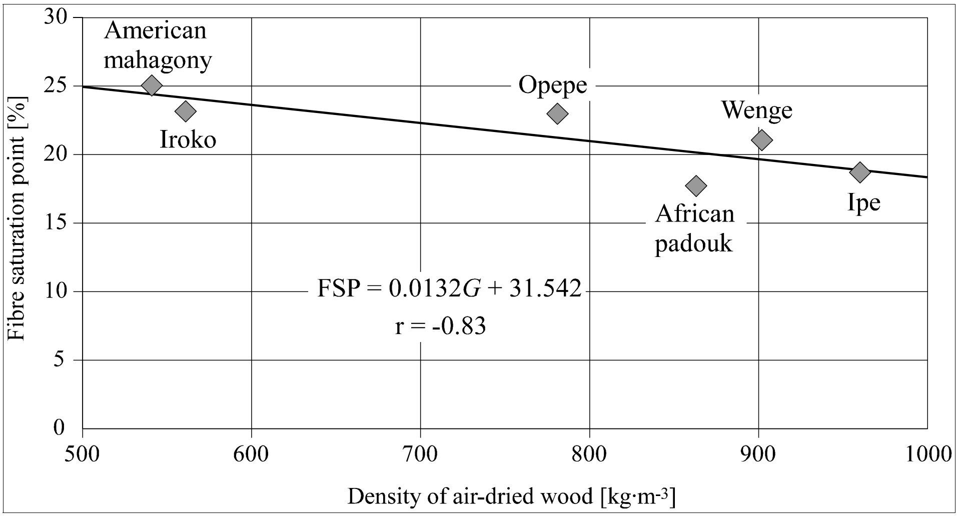

Fig. 2. Relationship between fibre saturation point and density of tested tropical wood species

Analysis of the obtained results is reason enough to consider further calculation of the FSP according to the formula given by Vorreiter [1949], Trendelenburg and Mayer-Wegelin [1955] and Krzysik [1957]:

$$FSP = S_v \cdot G_{H_2O}/G_0,$$

where S_v – total volumetric shrinkage, G_{H_2O} – density of water and G_0 – density of absolutely dry wood. According to our calculation, this equation should not be used in the case of tropical wood. Only in the case of the European beech were the results similar. In the case of all the tested tropical wood species using the presented formula, the values of FSP were lower and the differences were significant, eg. in the case of the African padouk, the FSP value was 11.86%. For this reason it may be said that information concerning the sorptive properties of wood should not be generalized and the knowledge in this area needs to be extended.

Conclusions

During the test it was confirmed that two methods of determining the fibre saturation point - the logarithm of the strength properties versus the moisture content and the volumetric shrinkage – moisture content plot to zero shrinkage delivered similar results. The findings showed that, generally, the fibre saturation point of tropical wood species (heartwood zone) was lower than in the case of European wood species. The lowest values of the fibre saturation point were shown by the African padouk and Ipe (approx. 17%).

It was also found that in the case of the tropical wood, the basic density had a significant influence on the sorption properties of the tested wood species. The fibre saturation point of the tropical wood species was negatively correlated with the wood density.

The influence of extractives on sorptive properties will be considered in future research.

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ISO 3131:1975. Wood – Determination of density for physical and mechanical tests

ISO 3787:1976. Wood – Test methods – Determination of ultimate stress in compression parallel to grain.
ISO 4858:1982. Wood – Determination of volumetric shrinkage
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PN-D-04111:1982. Drewno – Oznaczanie skurczu i spęcznienia (Wood – Determination of shrinkage and swelling)
PN-EN 13556:2005. Drewno okrągłe i tarcica – Terminologia stosowana w handlu drewnem w Europie (Round and sawn timber – Nomenclature of timbers used in Europe)

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