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SHORT NOTE

STIFFNESS MODULI OF VARIOUS EXTRANEOUS SPECIES DETERMINED WITH ULTRASOUND

Erik Baradit
Universidad Del Bio-Bio, Physics Department
Concepcion, Chile

Daniel Keunecke, Thomas Schnider, Peter Niemz
Eth Zürich Institute for Building Materials, Wood Physics Group
Zürich, Switzerland

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ABSTRACT

Comprehensive datasets of the elastic constants are available for only a few European wood Species, especially spruce. The goal of this study, therefore, was to provide Young's and shear moduli for the principal directions and planes for further selected extraneous species to extend the currently existing datasets. For this purpose, a dynamic technique was chosen: The moduli were estimated on the basis of sound velocity and density measurements. The collected data may be helpful for specialists in the relevant research and practical fields, particularly when stresses and strains of structural elements have to be calculated using modeling approaches.

KEYWORDS: Elastic constants, shear modulus, ultrasound, stiffness modulus.

INTRODUCTION

Information on the elastic constants of wood in the three principal directions and the three principal planes is still rather scarce. One of the few exceptions is provided by the former German standard DIN 68364 (1979), where such material properties, determined with a variety of mechanical tests, were compiled for selected wood species. The most detailed knowledge is available for the softwood species spruce (Neuhaus (1981), Požgaj et al. (1997), Keunecke et al. (2007, 2008), Wagenführ and Scholz (2008)). For the majority of the commercially relevant wood species, however, comprehensive and comparable datasets obtained from specimens with similar geometry and dimensions by applying uniform testing procedures are lacking, not to mention information on the influence of the grain angle or the growth ring angle on the elastic properties.

To calculate stresses and strains of structural elements in civil engineering made of wood or wood composites with modeling approaches, information on the elastic material properties in the principal directions has become increasingly important. For a comprehensive description of the elastic behavior of wood, three Young's moduli, three shear moduli and six Poisson's ratios are required. Besides static tests (e.g. tension, compression, shear), these properties can also be determined dynamically: on the basis of the velocities of ultrasonic waves, Young's and shear moduli can be estimated (Bucur, 1995) but one has to take into account that these dynamically determined elastic properties are 10 to 20 percent (or even more – depending on the frequency of ultrasonic waves) increased compared to statically determined values. Therefore, a direct comparison between several species tested with the same methodology clearly increases the informative value of the results.

The aim of this study was to extend the presently available datasets of elastic properties for selected extraneous wood species by estimating the three Young's and shear moduli on the basis of ultrasound velocity measurements. The focus was laid on collecting and providing data for specialists in the relevant research and practical fields.

MATERIAL AND METHODS

The tests were carried out on different extraneous species (see Tab. 1). For mechanical tests from elastic constants we mostly results only in longitudinal direction for bending test. The values are around 20 % or more lower in relation to results tested with ultrasound (see Tab. 1 and 3). The specimens were cubic with an edge length of 10 mm in the longitudinal, radial and tangential direction. They were stored at standard climatic conditions (20°C, 65 % relative humidity) until they reached their equilibrium moisture content and thus their air-dry density. Ten specimens per wood species were tested.

Tab. 1: Tested species and selected properties (Wagenführ 2007).

Species	Botanical Name	Bot. Family	Density (kg.m^{-3})	E-Modulus (N.mm^{-2})
Canalete	*Cordia* sp.	Boraginaceae	520…670	kA
Danta	*Nesogordonia papaverifera* (A. Chev.) R. Capuron	Sterculiaceae	680…760…830	8000…11000...13500
Doussie	*Afzelia* sp.	Caesalpiniaceae	750…950	12500…17700
Merbau	*Intsia* sp.	Caesalpiniaceae	830…900	13000…15400…16500
Wenge	*Milettia laurentii* De Wild.	Papilionaceae	810…860…950	16800…18200
Zebrano	*Microberlinia* sp.	Caesalpiniaceae	650…730	10000…15400

kA: not results available

The sound velocity was calculated using the ultrasonic flaw detector EPOCH XT (OLYMPUS). The Young's moduli were determined by means of longitudinal waves generated with an OLYMPUS A133S transducer (2.25 MHz), and the shear moduli by transversal waves generated with a STAVALEY S0104 transducer (1 MHz). For the coupling between transducer and sample, "Ultraschallgel II" (CONTROLTECH, Switzerland) was used. A constant contact pressure was guaranteed by the clamping apparatus. The system was calibrated with aluminum disks by adjusting it to the sound velocity of aluminium.

For longitudinal waves (to determine c_{LL}, c_{RR}, and c_{TT}) $i=j$ is given (equation (1)). To calculate Young's moduli, the terms of the stiffness matrix must be determined, such as $Sij^{-1} = Cij$, and the Young's moduli are then deduced as $E^* = S_{11}^{-1}$ etc. (Bucur 1995).

Such measurements, however, are not reported in this article, and thus the stiffness moduli determined with longitudinal waves and the specimen density are denoted as E^* instead of the common notation E in equation (1) (which is usually valid for long slender samples) and in the further paragraphs. E^* can be seen as a rough approximation of the Young's moduli when neglecting the influence of Poisson's ratios.

On the basis of the propagation velocity of the ultrasonic waves c_{ij} and of the normal density ρ of the specimens, the Young's moduli E_{ii} and shear moduli G_{ij} were calculated (Krautkrämer and Krautkrämer (1986)) according to equations (1) and (2).

$$E^*_{ii} = c_{ii}^2 \cdot \rho \tag{1}$$

$$G_{ij} = c_{ij}^2 \cdot \rho \tag{2}$$

where: i is the direction of wave propagation and j the direction of oscillation. For longitudinal waves $i=j$ is given, for transversal waves $i \neq j$. The methodological procedure and the theoretical background was described in more detail by Keunecke et al. (2007).

RESULTS AND DISCUSSION

Sound velocity

In general, the results confirm the well known differences between the sound velocities along the principal directions ($c_{LL} >> c_{RR} > c_{TT}$, Tab. 2). The velocities of longitudinal waves are also significantly higher than velocities of transversal ultrasonic waves. Also, a partly clear differentiation was found between the species.

Tab. 2: Tested sound velocity for longitudinal and transversal waves in the main directions.

Species		Longitudinal waves ($m.s^{-1}$)			Transversal waves ($m.s^{-1}$)					
		c_L	c_R	c_T	c_{LR}	c_{LT}	c_{RT}	c_{RL}	c_{TL}	c_{TR}
Canalete	x	5508	2440	2059	1470	1280	1014	1555	1376	1013
	s	37	64	65	73	52	34	282	162	49
Danta	x	5066	2214	1941	1387	1337	902	1434	1195	942
	s	125	30	48	158	92	63	157	41	36
Doussié	x	5910	2222	1928	1470	1376	887	1533	1439	884
	s	155	48	71	43	48	84	181	58	78
Merbau	x	6090	2063	1780	1586	1415	842	1581	1440	851
	s	51	49	10	171	156	52	94	149	51
Wenge	x	6015	2950	2376	1525	1294	929	1677	1317	882
	s	327	98	88	104	101	92	209	77	95
Zebrano	x	5568	2565	2079	1583	1370	884	1420	1288	918
	s	46	44	19	24	55	99	23	77	59

x-mean value, s-standard deviation

Modulus of elasticity (stiffness)

Tab. 3 shows the Young's and shear moduli calculated according to equations (1) and (2). An expected differentiation between the species was found.

Tab. 3: Stiffness Moduli E and shear moduli of various softwood and hardwood species determined on the basis of raw density and ultrasound velocities.*

Species	n	Density	Modulus of elasticity				Modulus of shear			
				Mean value	Standard deviation	Coefficient of variation		Mean value	Standard deviation	Coefficient of variation
		($kg.m^{-3}$)		($N.mm^{-2}$)	($N.mm^{-2}$)	(%)		($N.mm^{-2}$)	($N.mm^{-2}$)	(%)
Canalete	10	830	E_L	25177	964	4	G_{LR}/G_{RL}	1933	340	12
			E_R	4945	367	7	G_{LT}/G_{TL}	1477	208	14
			E_T	3524	300	9	G_{RT}/G_{TR}	854	58	7
Danta	10	746	E_L	19155	993	5	G_{LR}/G_{RL}	1504	243	16
			E_R	3657	106	3	G_{LT}/G_{TL}	1203	113	9
			E_T	2812	145	5	G_{RT}/G_{TR}	636	45	7
Doussié	10	848	E_L	29630	1567	5	G_{LR}/G_{RL}	1932	294	15
			E_R	4184	89	2	G_{LT}/G_{TL}	1686	148	9
			E_T	3151	168	5	G_{RT}/G_{TR}	669	80	12
Merbau	8	923	E_L	34240	1137	3	G_{LR}/G_{RL}	2330	74	12
			E_R	3928	133	3	G_{LT}/G_{TL}	1912	344	18
			E_T	2925	34	1	G_{RT}/G_{TR}	664	57	9
Wenge	10	781	E_L	28330	3262	12	G_{LR}/G_{RL}	2027	335	17
			E_R	6804	480	7	G_{LT}/G_{TL}	1337	163	12
			E_T	4415	324	7	G_{RT}/G_{TR}	647	76	12
Zebrano	10	683	E_L	21186	424	2	G_{LR}/G_{RL}	1546	29	2
			E_R	4499	164	4	G_{LT}/G_{TL}	1211	88	7
			E_T	2955	49	2	G_{RT}/G_{TR}	560	76	14

The crystal theory for solid orthotropic materials shows that the following relationship for transversal waves is valid: $c_{LR}=c_{RL}$; $c_{LT}=c_{TL}$; $c_{TR}=c_{RT}$. This, in the case of wood is not exactly the same because wood is an organic body and has a more complex structure, however the results of this work show a relativity good symmetry for shear waves (Tab. 2). Therefore the shear moduli are usually calculated on the basis of the arithmetic mean of the pairwise linked sound velocities. On other side, the variation in values for moduli determination can be explained by normal experimental measurements due to complex ultrasound signals. These is partially because for small samples there are too many reflections on the wood walls and the transversal signals are not clear and are complemented with longitudinal signals.

However as expected, the Young's moduli were in some cases clearly higher than those determined in static tests (such as documented e.g. in the German standard DIN 68364 (1979)). Low shear moduli G_{RT} of spruce are conspicuous. A low G_{RT} can cause rolling shear failure, e.g. in layered materials such as plywood and cross-laminated panels.

REFERENCES

1. Bucur, V., 1995: Acoustics of wood. Boca Raton, CRC Press, 284 pp.
2. DIN 68364, 1979: Characteristic values for wood species, strength, elasticity, resistance.
3. Keunecke, D., Hering, S., Niemz, P., 2008: Three-dimensional elastic behaviour of common yew and Norway spruce. Wood Science and Technology 42(8): 633-647.
4. Keunecke, D., Sonderegger, W., Pereteanu, K., Lüthi, T., Niemz, P., 2007: Determination of Young's and shear moduli of common yew and Norway spruce by means of ultrasonic waves. Wood Science and Technology 41(4): 309-327.
5. Krautkrämer, J., Krautkrämer, H., 1986: Werkstoffprüfung mit Ultraschall. Berlin, Springer, 708 pp.
6. Neuhaus, F.H., 1981: Elastizitätszahlen von Fichtenholz in Abhängigkeit von der Holzfeuchtigkeit. Dissertation, Ruhr Universität Bochum, 162 pp.
7. Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M., 1997: Wood structure and properties. (Štruktúra a vlastnosti dreva). Príroda, Bratislava, 485 pp. (in Slovak).
8. Wagenführ, A., Scholz, F., 2008: Taschenbuch der Holztechnik. Fachbuchverlag, Leipzig im Hanser Verlag, Leipzig, München, 568 pp.
9. Wagenführ, R., 2007: Holzatlas. Fachbuchverlag im Hanser Verlag Leipzig, München, 816 pp.

Erik Baradit
Universidad del Bio Bio
Physics Department
Avda. Collao 1202
Casilla 5 Correo
Concepcion
Chile

Daniel Keunecke, Thomas Schnider, Peter Niemz
Eth Zürich
Institute for Building Materials
Wood Physics Group
Schafmattstrasse 6
Ch 8093 Zürich
Switzerland
Corresponding author: niemzp@ethz.ch