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EVALUATION OF THE CLEAN SOFTWOOD COMPONENTS' LONGITUDINAL YOUNG'S MODULI BY MEANS OF OVERALL MEASUREMENTS

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ABSTRACT

The paper aims to determine the longitudinal Young's modulus of early- and latewood, by conducting global measurements for the entire wood specimen. In order to accomplish this least squares method is used as mathematical instrument, together with a global elasticity modulus investigation experimental method – where, according to the authors, there are two methods which can successfully be used in order to solve the problem: one using a tensile-compression testing machine, foreseen with the very expensive video-extensometers, and the other using Video Image Correlation method on a classical tensile-compression testing machine without any supplementary devices.

KEYWORDS: Softwood, early-wood, latewood, longitudinal Young's moduli, last squares method, global compression test.

INTRODUCTION

The test carries out to determine the mechanical properties of materials are using homogenous materials, or considered to be homogenous or uniform on average. The majority of materials are treated as being homogenous and isotropic, or transversal-isotropic ones. In this last category is including the wood-based ones, too.

Thus, the properties of the materials (between others: The composites, respectively the clean woods ones) considered isotropic or transversal isotropic in average, are determined. Yet, some applications are requiring the exact data regarding the materials' constitutive phases properties, in such a way as in the end, the material behaviour based on the component materials proportion, can be determined.

In the case of the composite materials mechanics, several methods for obtaining the overall properties of a composite are studied, considering the component elements properties, their emplacement, dimension, concentration, etc. Hence, formulas for basic engineering parameters, such as the longitudinal elasticity modulus, bulk modulus, Poisson coefficients, shear modulus, etc. are obtained (Cristescu et al. 2003).

Due to the fact that the materials are bonded together inside the same resultant material, the direct measurement of properties for a single constituent phase is not possible. The specimens manufactured according to mechanical testing standards, will contain, all the phases, in the amounts required by the manufacturer. This leads to the necessity of using a method which allows determining the properties of the constitutive phases, from the global properties measured for the composite.

In the papers published by Teodorescu-Drăghicescu et al. 2011, Vlase et al. 2011, 2012 are presented classical measurement methods for a homogenous, isotropic material Young's modulus determination.

In the case of the clean wood, as it is well known, the experimental investigations are focused mainly on the global mechanical behaviour; only a few numbers of experimental investigations were focusing on the individual components elastic properties.

Through a carefully and critical evaluation of this field (mechanical properties of the wood measurement) one can make some remarks not on their suitability, but mainly on their limitations.

1. The Ultrasonic Wave Technique is suitable for determining the elastic moduli; however, non-diagonal terms of the stiffness matrix must be considered when calculating the Young's moduli (Ożyhar et al. 2013). Nevertheless its eligibility to measure the Poisson's ratios remains uncertain.

2. Eder et al. 2013 mentioned that the single fibre test presents several difficulties both in fixing of these small specimens and in obtaining real values, respectively the nano-indentation takes into consideration among others the different moisture content of the small specimen and the initial wood-part, as well as the different mechanical response of a single fibre compared with the subassembly, constituted form several co-working/co-acting fibres.

3. Jernkvist and Thuvander 2001 mentioned that there are differences between the macro-scale tests' results and micro-scale ones, which are mainly based on the loading condition's lower accuracy with respect to the ideal case (the load in these global tests /at macro-scale tests/ is not fully aligned to the principal orthotropic axes of the material).

4. Keunecke and Niemz (2008) demonstrated possibilities of micro-mechanics but also reveal several difficulties and ultimately conclude that it is too time-consuming for standardized application; plenty of specimens had to be sorted out since the specimen quality did not meet the requirements.

5. When one applies some micro-scale or nano-scale tests, there will be obtained indeed high-accuracy mechanical parameters, but their generalization on the macro-scale specimens, or what is still worse, on the real wood member behaviours, will be far from the reality, mainly due to the fact that the individual fibres present totally different behaviours as compared with those when they are working together in a macro-scale specimen or in a real wood member (Bodig and Jayne 1982).

6. In the macro-scale tests, even if there are involved in experiments some very expensive Video Extensometers, the obtained results will be only global, without any information on the components behaviours.

MATERIAL AND METHODS

The authors' innovative proposal consists of keeping the wood specimen intact and to evaluate the individual elastic properties of early and late rings (Gálfi and Száva 2009) under these conditions. This proposal was study thoroughly in (Gálfi 2011). Softwood specimens (Norway spruce-*Picea abies*) with dimensions of 20 x 20 x 50 mm (R*T*L) were tested under compression, these specimens containing at least five annual rings in their cross-sections.

The elastic properties of the specimen are determined by the elastic properties of the different rings. In a softwood specimen having a tangential-radial (T-R) cross-section, the early-, and late annual rings (the corresponding early, and late-wood segment/section/region, respectively) are parallel-connected (Fig. 1).

Starting from this fact, it became useful to establish their individual elastic properties for a more accurate and easier Finite Element modelling.

Each specimen are worked-out identically and made of the same wood-item; the number of the specimens was large enough for a further statistical evaluation (here: 15 specimens).

The specimens were compressed in a longitudinal direction by mean of a progressive load F^j. Based on the results measured $F-\Delta\ell$ force-displacement curves we developed and then used a simple analytical procedure (described below) to obtain the individual properties of the early-, and late segments/regions.

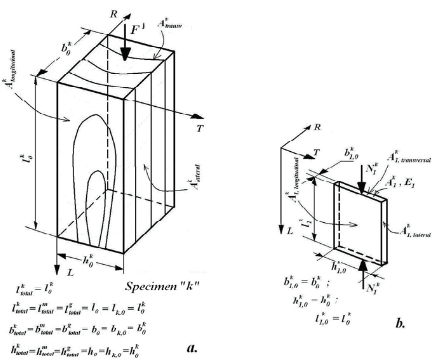

Fig. 1: Geometrical parameters for the tested soft-wood specimen a) and one of the representative elements (here: 1 - early-wood) b) (Gálfi and Száva 2009), (Gálfi 2011).

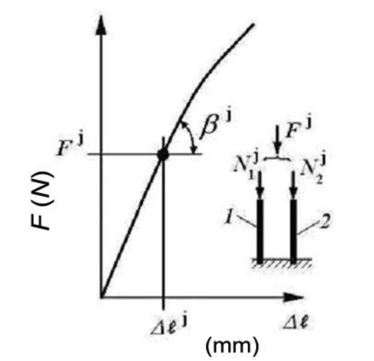

Fig. 2: Calculus schema for parallel-connected elements (Gálfi and Száva 2009), (Gálfi 2011).

In the authors opinion, the softwood specimen ***k*** (Fig. 1a), can be considered as a unit of two parallel-connected elements: 1 - early-wood, 2 - late-wood, each having different cross-sectional area.

They will work together and for a given cross-section, they will offer a nominal, global mechanical behaviour. If we change only their cross section's ratio, consequently we will obtain, of course, other global mechanical behaviours.

For a given mechanical system (Fig. 2), regarding on the tested specimen ***k***, one can use the static equilibrium equation and the Bernoulli hypothesis to obtain the corresponding load-ratios $N_{k,1}^{j}$, $N_{k,2}^{j}$ (from the applied load $F_k^j = F^j$) for these characteristic elements (***1*** and ***2***):

$$\begin{cases} F_k^j = N_{k,1}^j + N_{k,2}^j ; \\ \Delta\ell_{k,1}^j = \Delta\ell_{k,2}^j = \Delta\ell_k^j ; \end{cases} \text{or} \quad \begin{cases} F_k^j = N_{k,1}^j + N_{k,2}^j ; \\ \varepsilon_{k,1}^j = \varepsilon_{k,2}^j = \varepsilon_k^j \; . \end{cases} \tag{1}$$

The shortening of these two characteristic elements are:

$$\begin{cases} \frac{N_{k,1}^{j}\ \ell_{k,0}}{E_1\ A_{k,1}} = \Delta\ell_{k,1}^{j}; \\ \frac{N_{k,2}^{j}\ \ell_{k,0}}{E_2\ A_{k,2}} = \Delta\ell_{k,2}^{j}, \end{cases} \tag{2}$$

from where we get the loads that belong to these elements:

$$\begin{cases} N_{k,1}^{j} = \frac{\Delta\ell_{k,1}^{j}}{\ell_{k,0}} E_1\ A_{k,1} = \varepsilon_{k,1}^{j}\ E_1\ A_{k,1} = \varepsilon_{k}^{j}\ E_1\ A_{k,1}; \\ N_{k,2}^{j} = \frac{\Delta\ell_{k,2}^{j}}{\ell_{k,0}} E_2\ A_{k,2} = \varepsilon_{k,2}^{j}\ E_2\ A_{k,2} = \varepsilon_{k}^{j}\ E_2\ A_{k,2}. \end{cases} \tag{3}$$

By substituting them into the static equilibrium equation, finally we obtain a relationship between the measured values (where we have among others: the real cross-sectional areas and the global strains of the tested specimens, respectively the global longitudinal direction's E_k Young's modulus) and the Young-moduli E_1, E_2 which belong to these two characteristic elements.

For a given specimen, noted by k, is obtained:

$$A_{k,1}\ E_1 + A_{k,2}\ E_2 = F_k^{j} / \varepsilon_k^{j}, \tag{4}$$

For a second specimen, noted by m one will obtain:

$$A_{m,1}\ E_1 + A_{m,2}\ E_2 = F_m^{j} / \varepsilon_m^{j}. \tag{5}$$

After solving this system (4)-(5) we have the unknown Young moduli E_1, E_2 for the early-, and late wood parts, respectively.

Even in order to establishing these two unknown (E_1, E_2), there are necessary two equations, for obtaining a better accuracy, the authors propose involving the Least Squares method, where the number of the tested specimen (worked out and tested in identical conditions) was large enough (n = 15) also from the point of view of the statistical evaluation, too.

In the following is presented this approach, based on the above-mentioned theoretical background.

For a given specimen, noted by ***k***, let be $\eta_{k,2} = \frac{A_k}{A_{k,2}}$ the latewood percentage of the wood specimen and $\eta_{k,1} = \frac{A_k}{A_{k,1}}$ the percentage of the early-wood.

Between them, one has the relation:

$$\eta_{k,1} + \eta_{k,2} = 1. \tag{6}$$

Let us consider a set of n = 15 specimens of wood that have identical cross-sections and dimensions, subjected to compression along their longitudinal direction, parallel to fibres direction.

In Tab. 1 are offered their early-, and latewood areas, from the same 20 x 20 mm cross-sectional area.

Tab. 1: The tested specimens' parameters.

k =	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
$A_{k,1}$ (mm^2)	364.89	364.760	364.725	364.920	364.910	364.880	364.860	364.800
$A_{k,2}$ (mm^2)	35.110	35.240	35.275	35.080	35.090	35.120	35.140	35.200

k =	*9*	*10*	*11*	*12*	*13*	*14*	*15*	
$A_{k,1}$ (mm^2)	364.88	364.87	364.82	364.898	364.907	364.910	364.870	
$A_{k,2}$ (mm^2)	35.12	35.13	35.18	35.102	35.093	35.090	35.130	

Based on these values, are obtained: The average values of the constitutive elements ($A_{1,average}$ = 35.140 mm^2 ; $A_{2,average}$ = 364.860 mm^2), respectively the corresponding standard deviation (σ = 0.131694).

Due to the fact that from each specimen were monitored the same load magnitudes ($F_k^j = F^j$), in the following one has to be noted by $F_j \equiv F_k^j = F^j$. Similarly, for the undertaken load percentages, respectively for the global Young's moduli of each specimen ***k*** will be used the simplified notations of $N_{k,1}^j \equiv N_{1,j}$; $N_{k,2}^j \equiv N_{2,j}$, respectively E_k .

Based on these hypotheses, respectively the above-mentioned theoretical background, one can obtain step-by-step the following relations:

$$\begin{cases} F_j = N_{1,j} + N_{2,j}; \\ \varepsilon_{1,j} = \varepsilon_{2,j} = \varepsilon_j \ ; \end{cases} \quad k = \overline{1,n} \tag{7}$$

The shortening of these two characteristic elements are:

$$\begin{cases} \dfrac{N_{1,j} l_0}{E_1 A_{k,1}} = \Delta l_{1,j}; \\ \dfrac{N_{2,j} l_0}{E_2 A_{k,2}} = \Delta l_{2,j}; \end{cases} \quad k = \overline{1,n} \tag{8}$$

from which one can determine the loads corresponding to each kind of material:

$$\begin{cases} N_{1,j} = \dfrac{\Delta l_{1,j}}{l_0} E_1 A_1 = \varepsilon_{1,j} E_1 A_{k,1} = \varepsilon_j E_1 A_{k,1}; \\ N_{2,j} = \dfrac{\Delta l_{2,j}}{l_0} E_2 A_2 = \varepsilon_{2,j} E_2 A_{k,2} = \varepsilon_j E_2 A_{k,2}; \end{cases} \quad k = \overline{1,n} \tag{9}$$

By substituting them into the static equilibrium equation (2), one can obtain a correlation between the determined (by measurement) global value of Young's modulus E_k and the Young's moduli and E_1, E_2 which belong to the two constituents.

We also have:

$$F_j = N_{1,j} + N_{2,j} = \varepsilon_j \left(E_1 A_{k,1} + E_2 A_{k,2} \right) \ ; \quad k = \overline{1,n} \tag{10}$$

where: $A_k = A_{k,1} + A_{k,2}$

For the global compression of the specimen, based on the Hooke's law, we have:

$$F_j = \frac{\Delta l_j}{l_0} E_k A_k = \varepsilon_j E_k A_k \, . \quad k = \overline{1,n} \tag{11}$$

Taking into the consideration the areas percentages ($\eta_{k,1}$, $\eta_{k,2}$), finally we obtain

$$E_k = \eta_{k,1} E_1 + \eta_{k,2} E_2 \qquad k = \overline{1,n} \tag{12}$$

which represents the well-known law of mixtures from the composite material's mechanics (Eder et al. 2013).

If *n* measurements are considered, *n* relation of this kind can be written. For each measurement the percentages of latewood and early-wood ($\eta_{k,1}$, $\eta_{k,2}$) can be determined using an optical identification method, presented briefly bellow.

Based on each measurement (for specimen $\boldsymbol{k}$, $k=\overline{1,n}$), can be drawn-up both the force-displacement ($F-\Delta\ell$) and the corresponding stress-strain ($\sigma-\varepsilon$) curves.

Taking into the consideration the stress-strain curve easily can be obtained the corresponding global Young's modulus E_k (of course, only for the linear zone of the $\sigma-\varepsilon$ curves).

In this sense, we will consider, starting from approximately 1500 *N*, small loading intervals of $([F_j;\ (F_j+50\,N)]=\Delta F_{50\,N}$, where we have the corresponding shortenings $\Delta\ell''=\Delta\ell_j-\Delta\ell_{j+50\,N}$.

Based on the well-known relation of $tg\beta^j=\frac{\Delta\ell''}{\Delta F_{50\,N}}=E_{k,j}$, one can obtain, for the mentioned loading interval the corresponding $E_{k,j}$ Young's modulus.

Taking into the consideration the whole loading interval (starting from approximately 1500 *N* up to the maximal load, corresponding to the linear-elastic zone), finally we will obtain the probable value of E_k.

The suggested/mentioned minimal loading value of the approximately 1500 *N* is based on the observation of the authors, that for lower loads, practically the all $F-\Delta\ell$ curves (for all $k=\overline{1,n}$ specimens) will be the same and the below-mentioned calculus, respectively the system (4)-(5) cannot offer the expected solutions (the systems became undetermined).

In order to involve the Least Squares method for the all $k=\overline{1,n}$ tested specimen, one has to be considered the *S* objective function:

$$S=\sum_{k=1}^{n}\left(E_k-\eta_{k,1}E_1-\eta_{k,2}E_2\right)^2 \tag{13}$$

and we are looking for E_1 and E_2 values, which are guaranteeing the minimum of this expression.

The minimum conditions for *S* are leading to:

$$\frac{\partial S}{\partial E_1}=0 \quad ; \quad \frac{\partial S}{\partial E_2}=0 \tag{14}$$

or:

$$\begin{aligned}&-2\sum_{k=1}^{n}E_k\eta_{k,1}+2E_1\sum_{k=1}^{n}\eta_{k,1}^2+2E_2\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}=0\\&-2\sum_{k=1}^{n}E_k\eta_{k,2}+2E_1\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}+2E_2\sum_{k=1}^{n}\eta_{k,2}^2=0\end{aligned} \tag{15}$$

These two conditions will lead to a linear system:

$$\begin{aligned}&E_1\sum_{k=1}^{n}\eta_{k,1}^2+E_2\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}=\sum_{k=1}^{n}E_k\eta_{k,1}\ ;\\&E_1\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}+E_2\sum_{k=1}^{n}\eta_{k,2}^2=\sum_{k=1}^{n}E_k\eta_{k,2}\ ,\end{aligned} \tag{16}$$

having the solution:

$$\begin{Bmatrix}E_1\\E_2\end{Bmatrix}=\frac{1}{\Delta}\begin{bmatrix}\sum_{k=1}^{n}\eta_{k,2}^2 & -\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}\\-\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2} & \sum_{k=1}^{n}\eta_{k,1}^2\end{bmatrix}\begin{Bmatrix}\sum_{k=1}^{n}E_k\eta_{k,1}\\\sum_{k=1}^{n}E_k\eta_{k,2}\end{Bmatrix} \tag{17}$$

with

$$\Delta = \left(\sum_{k=1}^{n}\eta_{k,1}^{2}\right)\left(\sum_{k=1}^{n}\eta_{k,2}^{2}\right) - \left(\sum_{k=1}^{n}\eta_{k,1}\eta_{k,2}\right)^{2} \quad (18)$$

The percentage of the components'/constituent phases'/ ratio and the measured E_k equivalent global values of the Young's modulus will be influencing the solution.

In conclusion, the advantage of the proposed method is that it uses all the obtained information by measurements, thus a greater number of measurements leads to a more precise system solution.

RESULTS AND DISCUSSION

Determining the percentages of the component phases (constituents)

In order to determine the specimens component parts' areas ratio, a photo capture of the transversal cross sections (at the both ends of each specimen) have been taken (Fig. 3), and then, with the aid of specific calculus programs, the percentages of the components have been determined.

The image was analysed in IMTOOL (Matlab) and with the aid of Measure Distance tool has been counted the pixel number along a 250 mm distance.

With the aid of a 5-steps image processing program, written in Matlab by the authors, the area of the constituitev elements (early-, and late wood parts) has been determined, as follows.

The first step of the mentioned process is cropping and reading it in Matlab (Fig. 4); then, the working area of the cropped image is marked, by inserting the coordinates of the specimen base 4 corners.

This is necessary due to the fact that the wood specimens have not been placed along the perpendicular direction to the lens, during the photo shot, and the cutting has only rectangular shape. The total area is computed by counting the number of pixels. (Step 2); Next, is performed a colour probe sampling in order to highlight the latewood fibres.

The sampling can be done from one up to a maximum of 5 times, until the highlighting of the different materials areas was enough. (Step 3) (Gálfi and Száva 2009).

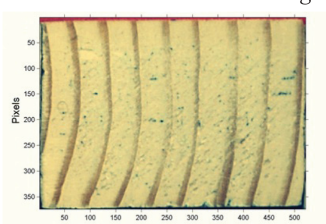

Fig. 3: Photo of a cross-section.

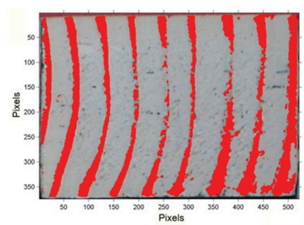

Fig. 4: Filtered image for determining the number of pixels .

Step 4 consists of filtering the image in order to correct the colouring of areas with different nuances. The last step, Step 5, defines the number of pixels corresponding to $A_{k,1}$ early-wood-, and $A_{k,2}$ late-wood-, and A_k, global area, as well as determining their pixel ratios. Consequently one has also the $\eta_{k,1}$, $\eta_{k,2}$ percentages, too (Fig. 4) (Száva and Gálfi 2013).

Experimental methods for measuring the global elasticity modulus

The investigation method (**V**ideo **I**mage **C**orrelation, VIC-3D) is a full-field non-contact one and its 3D version practically eliminates all disadvantages or limitations of the most widely used other experimental methods.

In principle, the system consists of two high-resolution video cameras, mounted on a very rigid tripod by means of a high-precision and also very rigid connecting rod (Fig. 5).

The system allows measurements in normal working conditions, due to the fact, that one can eliminate the rigid body movements from the displacements field (VIC-3D, 2010).

The method of Video Image Correlation seems to satisfy very well all the requirements of the non-destructive testing of the composite materials, where, the wood-based ones occupy an important place.

The tested object will be sprayed in advance with a water-soluble paint, in order to obtain a non-uniform dotted surface. The sizes of the dots are dependent on the surface sizes. In this way it is possible to guarantee different grey-intensities for each pixel of the analyzed surface (Száva and Gálfi 2013).

Fig. 5: The VIC-3D setup (VIC-3D, 2010).

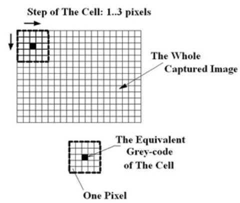

Fig. 6: The measuring principle based on the scanning procedure (VIC-3D, 2010).

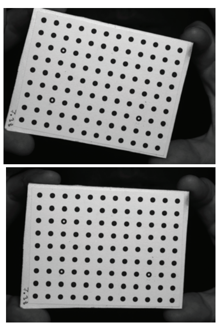

Fig. 7: Different stages of the calibration process.

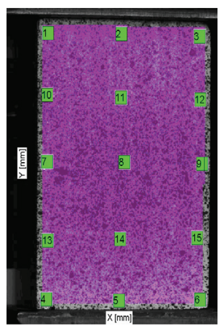

Fig. 8: Selected set of points.

One other important step consists in performing a calibration, using a special calibration target (Fig. 7), which is chosen depending on the investigated surface magnitude, optical set-up, respectively the requested accuracy.

In the first step of the foreseen test, one has to perform an image-pair capture (by the 2 cameras) of the unloaded (or preloaded) object) in static condition (in its initial stage).

After than, during the concrete test (here: Compression test) the system will perform image-pairs capturing with a preselected frequency (e.g.: 100 images/s, or more, depending on the testing conditions). All of the captured image-pairs are stored by software.

The measuring principle consists in analyzing the captured image-pairs, based on the followings: the captured images (by the left and right cameras) of the initial stage of the object, consisting of an [n × m] matrix of pixels, will be analyzed by means of a so-called Sub-set, or simply: Cell (Fig. 6), having a software-recommended size (e.g. 5 × 5 = 25 *pixels*), respectively an optimal step-magnitude.

For this Cell, the software will establish, corresponding to its median pixel, an unique grey-code, together with an unique, high-accuracy 3D positioning (x, y, z coordinates). By translating this Cell from left to right, respectively from upper part to lower of the image, with the foreseen step, for each new position of the Cell, we will obtain a new unique grey-code, respectively an unique 3D positioning.

Consequently, the captured image (left, respectively right image), consisting initially from this [n × m] matrix of pixels, will be substituted by means of a well-defined number of representative points, easily recognized by software during the image deformation (produced by the loading process).

A similar analysis will be performed for the captured left-, and right images throughout the whole loading stage. The software will compare the 3D displacements at the representative median pixels with those belonging to the initial stage and then it will draw-up the corresponding displacements vectors. Consequently, it becomes possible to follow, in 3D, not only the displacements, but also the corresponding strains at the significant points in the Area of Interest.

In order to perform the requested evaluation, the software requires selecting the area of interest, using a special tool. Based on the selected Area of Interest, the software will suggest the accuracy for the displacements evaluation, respectively one has to identify only one point in the left and right images. The accuracy of VIC-3D is lower than 1 μm for the common optical set-up.

After this evaluation, only on has to select a number of points (which presents interest for us), similarly with those shown in Fig. 8; for these points, the software will offer even in colour graphs, even in Excel-format the requested displacement's components, the corresponding strains, or the main strains, too.

Regarding on the points' selection from Fig. 8, one has to mention/underline the fact, that for this experiment only the pairs of points located in the median part of the specimens were accepted, by excluding those, who are located near the loading plates, I mean: 1; 2; 3; 4; 5; 6. Also, the points, disposed at the margin/edge (e.g.: 10; 7; 13; 12; 9, respectively 15), where excluded/eliminated.

The evaluation process for the above-mentioned strategy is very easy: for each significant loading step (F_j) were monitored both the precise magnitude/value of the load and for 2…3 median-disposed pairs of points (in vertical direction) the corresponding shortenings.

So, became possible to establish (to drawn up) the probable $F - \Delta\ell_k$ force-displacement curves, respectively the $\sigma - \varepsilon_k$ stress-strain curves. Based on these data, using the mentioned relation of $tg\beta^j = \dfrac{\Delta\ell''}{\Delta F_{50N}} = E_{k,j}$, we will obtain step-by-step the requested E_k global Young's modulus, corresponding to the specimen #***k***.

Finally, by means of the mentioned original approach, were established/calculated the early-, and late-wood components' Young's moduli (Fig. 9):

$E_{1,average}$ = 2858.59 *MPa;* $E_{2,average}$ = 14 486.36 *MPa*

One can observe that up to the mentioned load limit (F = 1500N) the calculus presents several uncertainties, due to the fact that up to this limit the $F - \Delta\ell$ curves practically are superposed and consequently the linear system (16) became inconsistent.

This can represent a limitation of the strategy, but usually, the normal loading forces are much higher than this value (e.g.: Here we had approximately F = 8000N).

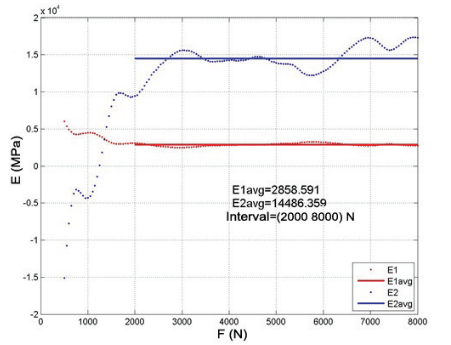

Fig. 9: The calculus of the Young's moduli for the soft-wood's constituents using the proposed approach.

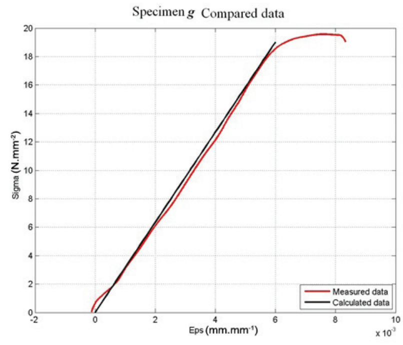

Fig. 10: The predicted ("calculated") and the real ("measured") curves in the linear zone.

Validation of the presented method

The validation of the above-presented theory was performed by means of a supplementary test, which will be described in the following.

Based on the described analytical approach, became possible to predict for an untested specimen (of course, worked out from the same sort of wood-species) its global Young's modulus. In this sense one has to evaluate in advance only the early-, and late-wood η_1, η_2 percentages.

Let consider this new, untested specimen, noted by g. Supposing the same cross-section, but with a different ratio between the early and late rings' area ($\eta_{g,1}, \eta_{g,2}$), one can determine its global Young's modulus, using the mentioned relation (12) of the mixture-law:

$$E_g = \eta_{g,1} E_1 + \eta_{g,2} E_2 \tag{12a}$$

By using this global Young modulus E_g, it becomes possible to draw (to predict) the linear zone of the stress-strain curve $\sigma - \varepsilon$, and to compare it to the real, experimentally-obtained, stress-strain curve (Fig. 10).

In this sense, for the new specimen, noted by g, were determined: A_g = *400 mm²*;
$A_{g,1}$ = *352.37 mm²*; $A_{g,2}$ = *52.63 mm²*; $\eta_{g,1} = 0.880925$; respectively $\eta_{g,2} = 0.131575$.

With the above-mentioned averages $E_{1,average}$ = 2858.59 *MPa*; $E_{2,average}$ = 14 486.36 *MPa*; equation (12a) yielded E_g = 4369.62 *MPa*. It was compared with the measured value of 4413.23 N.mm^{-2}, finding an acceptable fitting.

The most interesting and useful aspect (Fig. 10) consists of in a very good fitting in the linear zone of the theoretical ("calculated") linear behaviour, based on the relation (12a), with the real ones ("measured", I means: Based on the real experimental determination of the $\sigma - \varepsilon$ curve).

Usefulness of the proposed approach

The authors thus conclude that the proposed method requiring only the effective cross-sectional areas of the early-wood and late-wood parts offers a good accuracy in the linear zone of the $\sigma - \varepsilon$ curve for new specimens.

This method can be applied not only in the case of some small specimens, but also in industrial environments: having an adequate data base of several soft-wood species, taking into the consideration not only the areas percentages, but also the humidity's influence, became possible to predict for an unknown wood member its mechanical behaviour in linear zone of the solicitation.

CONCLUSIONS

The authors have developed a new and simple method, in order to evaluating the constitutive parts' (early-, and late-wood parts) Young's moduli, only by simply global tensile or compression tests.

This method applies for materials which allow as calculus method the mixtures law, being applied to the longitudinal elasticity modulus calculus in soft-wood species.

To determine the Young's moduli of the early-wood and late-wood components, a set of measurements on several, identical worked-out, specimens are required.

The main advantage of this new method is that it provides a better approach to determining the elastic properties of the individual rings, which can also be included in a more accurate FEM model.

Using the measurement strategies presented, it is possible to determine the elastic constants of the early-, and late-wood and various types of softwood material with excellent accuracy from only previously measured area ratios of the early-, and late-wood zones from the tested specimen. These values can then be used to predict the real load-bearing capacity of the structure. However, the specimen must be tested to a force greater than 2000 N, because otherwise the linear system (16) becomes inconsistent.

The least squares method has been used as calculus method. The main advantage of this method consists of in the fast and good accuracy solution, using only laboratory measurements of global values.

The feasibility of the method is demonstrated by its application to the longitudinal elasticity modulus for early-wood and late-wood, which are comprised in a softwood sample.

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