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PRELIMINARY RESULTS OF AN IMAGE PROCESSING BASED PROCEDURE FOR WOOD STRUCTURE CHARACTERIZATION

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Abstract:
Establishing accurate mechanical characteristics of the materials used in different processes is a basic requirement for engineering calculations. In this sense, both anisotropic materials and orthotropic materials, due to their complex structure, raise supplementary problems as compared with isotropic ones. In this paper we have proposed the development of a strategy for determining the mechanical characteristics of orthotropic material, in this case – wood. During the investigation, maple specimens with a disc shape of 80 mm diameter were analyzed. The testing device was conceived and realized to evaluate the specimens subjected to the required compressive deformation. As investigation method, we used the technique of image processing and we developed our own computer program in the programming language C++. The program offers the possibility of determining the deformation in plain state (in 2D); the results are presented graphically as well.

Key words: *maple wood; image processing; displacement evaluation.*

INTRODUCTION

The correlation between normal and tangential stresses respectively of linear and angular deformations, for applications where elastic principal directions are required, are given by the generalized Hooke's law (Bodig and Jayne 1982).

Where deformations occur only in a plane, we speak about a plane strain state. Considering that this plan is in xy coordinate plan, in perpendicular direction named z we have: $\varepsilon_z = 0$, $\gamma_{yz} = \gamma_{zx} = 0$ and $\gamma_{yz} = \gamma_{zy} = 0$. In this case the Hooke's law is given by the relation (Timoshenko and Goodier 1979):

$$\{\sigma\} = \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \frac{E_x \cdot (1 - \mu_{yz} \cdot \mu_{zy})}{\delta} & \frac{E_x \cdot (\mu_{yx} + \mu_{zx} \cdot \mu_{yz})}{\delta} & 0 \\ \frac{E_y \cdot (\mu_{xy} + \mu_{xz} \cdot \mu_{zy})}{\delta} & \frac{E_y \cdot (1 - \mu_{xz} \cdot \mu_{zx})}{\delta} & 0 \\ 0 & 0 & G_{xy} \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = [E] \cdot \{\varepsilon\}, \tag{1}$$

completed by the relation that gives the nonzero stress in normal direction

$$\sigma_z = \frac{E_z}{\delta} \cdot \left[(\mu_{xz} + \mu_{xy} \cdot \mu_{yz}) \cdot \varepsilon_x + (\mu_{yz} + \mu_{xz} \cdot \mu_{yx}) \cdot \varepsilon_y \right] \cdot \tag{2}$$

Where stresses occur only in a plane, we name it plane stress state. Considering that this plan is in xy coordinate plan, in perpendicular direction the stresses are equal to 0, then we have: $\sigma_z = 0$, $\tau_{xz} = \tau_{zx} = 0$ and $\tau_{xy} = \tau_{yx} = 0$, then we have the relation (Timoshenko and Goodier 1979):

$$\{\sigma\} = \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \frac{E_x}{1 - \mu_{xy} \cdot \mu_{yx}} & \frac{\mu_{xy} \cdot E_y}{1 - \mu_{xy} \cdot \mu_{yx}} & 0 \\ \frac{\mu_{yx} \cdot E_x}{1 - \mu_{xy} \cdot \mu_{yx}} & \frac{E_y}{1 - \mu_{xy} \cdot \mu_{yx}} & 0 \\ 0 & 0 & G_{xy} \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = [E] \cdot \{\varepsilon\}. \tag{3}$$

In this case in normal direction we have a nonzero ε_z strain.

The two elasticity matrices $[E]$ are valid only if the directions of orthotropy coincide with the directions of the coordinate axes. Otherwise, the two arrays must be rotated. Thus, the transformation leads to a full matrix (Ahmed *et al.* 2005)

$$[E] = \begin{bmatrix} \overline{E}_{11} & \overline{E}_{12} & \overline{E}_{13} \\ \overline{E}_{21} & \overline{E}_{22} & \overline{E}_{23} \\ \overline{E}_{31} & \overline{E}_{32} & \overline{E}_{33} \end{bmatrix}, \tag{4}$$

the components of which are the following:

$$\begin{aligned}
\overline{E}_{11} &= E_{11} \cdot \cos^4\theta + E_{22} \cdot \sin^4\theta + (E_{12} + E_{21} + 4 \cdot E_{33}) \cdot \sin^2\theta \cdot \cos^2\theta, \\
\overline{E}_{12} &= E_{12} \cdot \cos^4\theta + E_{21} \cdot \sin^4\theta + (E_{11} + E_{22} - 4 \cdot E_{33}) \cdot \sin^2\theta \cdot \cos^2\theta, \\
\overline{E}_{13} &= (E_{11} - E_{12} - 2 \cdot E_{33}) \cdot \sin\theta \cdot \cos^3\theta + (E_{21} - E_{22} + 2 \cdot E_{33}) \cdot \sin^3\theta \cdot \cos\theta, \\
\overline{E}_{21} &= E_{12} \cdot \sin^4\theta + E_{21} \cdot \cos^4\theta + (E_{11} + E_{22} - 4 \cdot E_{33}) \cdot \sin^2\theta \cdot \cos^2\theta, \\
\overline{E}_{22} &= E_{11} \cdot \sin^4\theta + E_{22} \cdot \cos^4\theta + (E_{21} + E_{12} + 4 \cdot E_{33}) \cdot \sin^2\theta \cdot \cos^2\theta, \\
\overline{E}_{23} &= (E_{11} - E_{12} - 2 \cdot E_{33}) \cdot \sin^3\theta \cdot \cos\theta + (E_{21} - E_{22} + 2 \cdot E_{33}) \cdot \sin\theta \cdot \cos^3\theta, \\
\overline{E}_{31} &= (E_{11} - E_{21} - 2 \cdot E_{33}) \cdot \sin\theta \cdot \cos^3\theta + (E_{12} - E_{22} + 2 \cdot E_{33}) \cdot \sin^3\theta \cdot \cos\theta, \\
\overline{E}_{32} &= (E_{11} - E_{21} - 2 \cdot E_{33}) \cdot \sin^3\theta \cdot \cos\theta + (E_{12} - E_{22} + 2 \cdot E_{33}) \cdot \sin\theta \cdot \cos^3\theta, \\
\overline{E}_{33} &= (E_{11} - E_{12} - E_{21} + E_{22} - 2 \cdot E_{33}) \cdot \sin^2\theta \cdot \cos^2\theta + E_{33}(\sin^4\theta + \cos^4\theta),
\end{aligned} \tag{5}$$

where,

$$[E_{12}] = \begin{bmatrix} E_{11} & E_{12} & 0 \\ E_{21} & E_{22} & 0 \\ 0 & 0 & E_{33} \end{bmatrix} \tag{6}$$

is the matrix of elasticity in the directions of orthotropy (it has only three independent elements). Therefore, where the directions of orthotrophy do not coincide with the axes, the elasticity matrix contains nine nonzero elements and is symmetric.

OBJECTIVES

Knowing the elastic constants is the basic requirement to obtain usable results in engineering practice with the condition of solving basic equations of elasticity of the wood material, taking into account also its boundary conditions.

In this paper a non-destructive investigation method is proposed to determine the mechanical characteristics of the wood: the longitudinal modulus of elasticity on the applied load direction and Poisson coefficients for the two transverse directions.

The main objective was to achieve a test bed for obtaining specimens subjected to compressive deformation and creating an image processing program to measure these deformations. Based on digital image analysis the software offers not only the developed displacement fields, but also the fields of the corresponding strains.

METHOD, MATERIALS AND EQUIPMENT

For more accurate determination of mechanical characteristics at compressive required, the principle of choice shape and size specimens was that on the same sample can be made to multiple measurements. During the analysis the specimens are rotated with 15^0 so that the fibers direction and the coordinates axis to make 0^0-90^0 angels. So the measurement results do not depend on the factors influencing the elasticity of wood.

For sample preparation identical specimens of different species of wood were made. Samples were cut parallel to the wood fibres and cut into specimens having the shape of a disc with a diameter of 80 mm and a thickness of 10 mm (Fig.1).

A sufficient number of samples were taken from the same timber (same shape and size) to perform subsequent statistical processing of measurement data. The wooden materials were first air-dried down to 12%mc, then conditioned for 2 weeks at $20^0C \pm 2$ and 65%RH. The material used in this research was maple wood (*Acer campestre*).

The object analyzed was previously spray painted in white, over which black spots were applied in order to obtain size, shape and random distribution. These provide good contrast on the initial background colour of the body and permit an easy subsequent identification of the deformations.

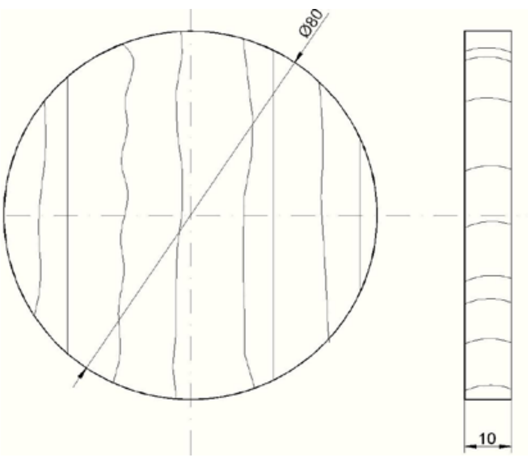

Fig. 1
Shape and dimensions of the wood samples used within the experiments.

Testing Device

The testing device from Fig. 2 was designed and realized in order to determine experimentally accurate mechanical characteristics of wood-based orthotropic materials. It was designed exclusively for specimens which require compressive deformation monitoring.

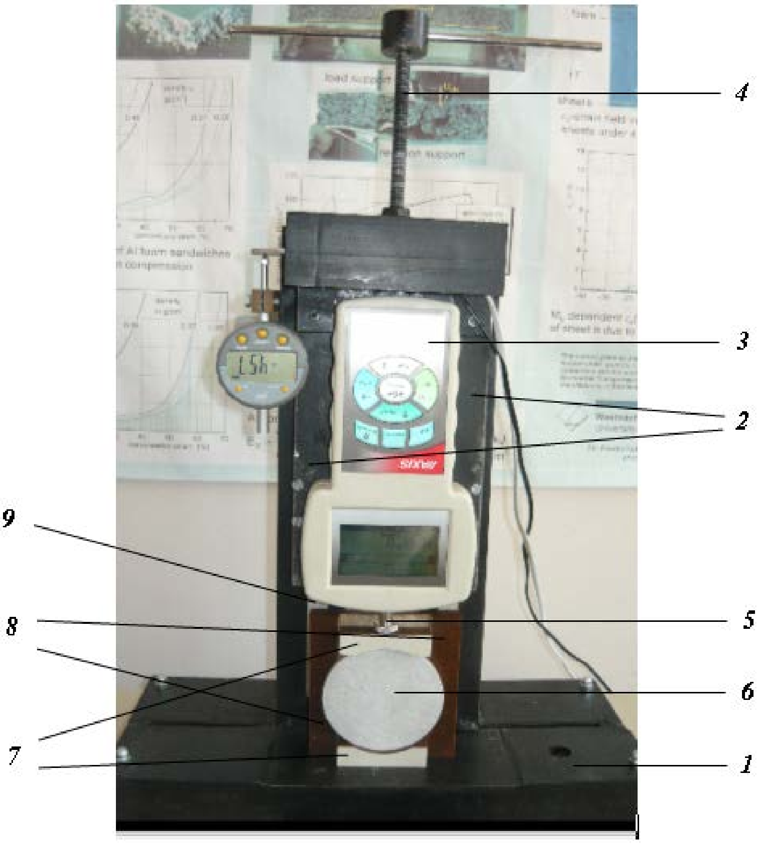

Fig. 2
Testing device.

The experimental installation consists of base plate ***1*** on which the columns of the device are mounted. On the steel columns ***2*** two guiding rails are attached with balls through a vertical mounting, on which two carts ***9*** are running. A plate is mounted on these carts, which moves in line with the columns of the device.

For accurate determination of compressive forces, a dynamometer ***3*** of 500 N is fixed on this plate. With threaded shaft ***4*** compressive forces F are exerted on the analyzed specimen.

The wood specimen ***6*** is placed between two jaws ***7***, following the form of the spherical specimen. These tanks themselves are fixed between two rails ***8***, which prevent their horizontal movement.

The dynamometer is in contact with the superior jaw by a high accuracy sensor ***5***, which measures the compressive forces. The values can be viewed on the dynamometer's display.

Image Processing

The deformation of the wood under pressure is studied using image processing technology. An image of the wood subjected to gradually increasing pressure is taken from lateral position, recording the corresponding compression value together with the image. Afterwards, a multi-stage image processing is performed:

1. Image enhancement consisting of the equalization of the average intensity of the pixels of the wooden object in all images.

2. A uniform grid is define in the initial image f_0, having 85x85 grid points, placing the centre of the grid in the centre of the round wooden object. The grid unit is 20 pixels, corresponding to 0.635 mm.

3. In each further image f_i we try to locate the best corresponding position for each grid point. This process involves non-integer coordinates. Bilinear interpolation is employed to approximate pixel intensities in non-integer coordinate positions. A two-level hierarchical approximation is performed. In the first step, the deformation is established with a resolution of 0.5 pixels, while in the second step, the resolution becomes

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finer to reach 0.02 pixels precision. Thus the deformation in any grid point is expressed in units of 0.635 μm. The estimated deformation at pixel (x, y) in the deformed image is given by the formula:

$$\arg\min_{(dx\ dy)} \sum_{p=-s}^{s} \sum_{q=-s}^{s} \left(F_0(x+p, y+q) - F_i(x+p+dx, y+q+dy)\right)^2, \tag{7}$$

with $|dx| < w$ and $|dy| < w$,

where,
F_0 and F_i represent the enhanced version of input image f_0 and f_i, respectively;
w is the maximum deformation, defined big enough to cover all actual deformations;
s stands for the window size considered around pixel (x, y), while searching for the best match.

The obtained estimated deformations are stored for each further grid point and each deformed image.

4. Reconstruction of the trajectory of certain grid points, to study the deformations caused by the gradually growing compression. Deformations are counted relatively to the position of the central grid point, which is considered to be unbiased throughout the whole study.

RESULTS

The specimen was subjected to compression perpendicular to the fibers direction, after that the disc has been rotated by 15^0 to each time compression is performed until 90^0. For each load was measured the deformations of wood specimens. We exemplify the image processing results for specimen rotated by 15^0.

On maple specimen surface used to illustrate the method, 81 points were marked in the program. Starting from the initial state, unsolicited, the compressive strength was increased by 50 N to 500 N. For each charge, after obtaining images, deformations of wood specimen were measured in the 81 points of interest. Measurement data could be acquired by the image processing method, from which the movements of points could be drawn according to the load, as shown in Fig. 3.

Analyzing the figure we can observe that the deformations direction of the points opposite to the y-axis is almost symmetric, the dissimilarity resulting from rotating the disc with 15^0 angles. The difference is in the amount of deformation, the upper part being greater than the bottom. This is due to the fact that considering the origin of the xy axis in the middle of grid (point no. 41) deformations of the points of interest are determined in relation to the origin point.

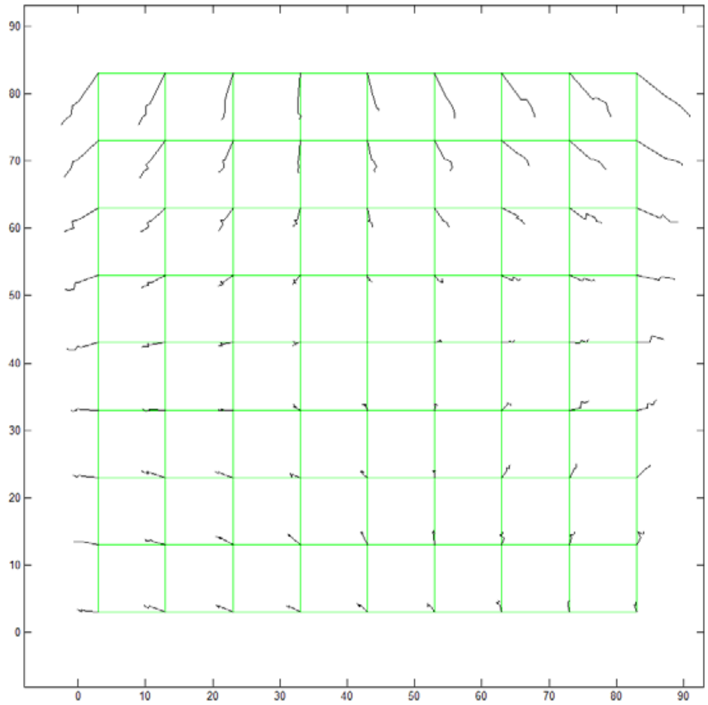

Fig. 3
Field of relative displacements.

Another facility of the method is the possibility of marking a distinct area which data may be also extracted for deformation. For each load, after receiving the imagines, in an area of 2.5cm^2 was evaluated field deformation of the specimen. In Fig. 4. are shown the displacements of the points a- by the x-axis and b- by the y-axis at a compressive force of 500N.

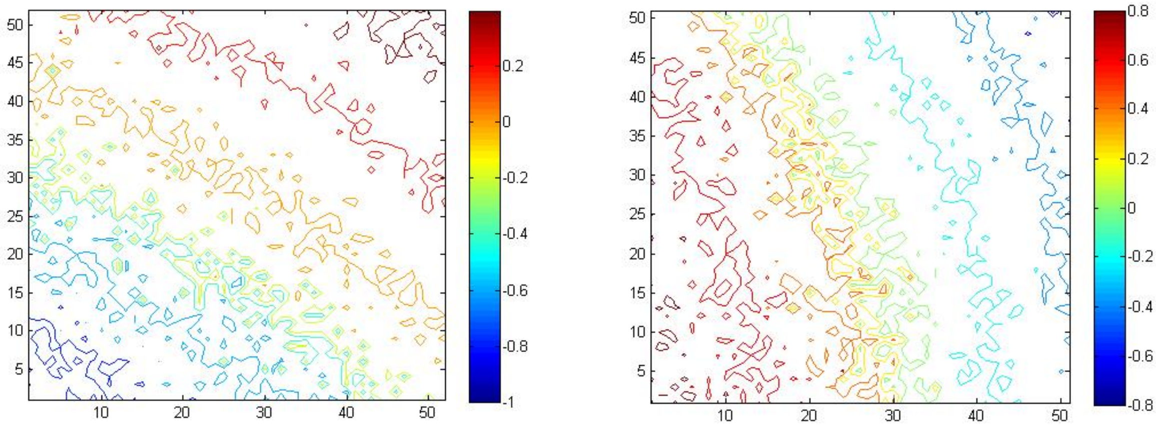

Fig. 4
The field of displacement at maximum loading
a - by the x-axis; b - by the y-axis.

With the values obtained from the study of the displacement field we can calculate using the method of numerical analysis three independent quantities which can be: (a) $\varepsilon_x, \varepsilon_y$ and γ_{xy}, or (b) $\varepsilon_1, \varepsilon_2$ and θ, where case (a) refers to strain components with respect to an arbitrary xy axis system, and case (b) refers to the principal strains and their directions.

In Table 1 is calculated the values of the principal strains, where are noted with $\varepsilon_{1,15}$ the first principal strain, and with $\varepsilon_{2,15}$ the second principal strain, when the specimen is rotated with 15^0. Mentioned, that the results are according with results of previous studies in which similar measures were applied with rectangular rosettes gage.

Table 1

Values of the principal strains

Force [N]	$\varepsilon_{1,15}\left[\mu m/m\right]$	$\varepsilon_{2,15}\left[\mu m/m\right]$
50	7,9006	-7,7006
100	10,1086	-31,3086
150	10,2426	-58,2426
200	8,4357	-88,7357
250	4,4193	-125,2193
300	-2,2187	-160,2813
350	-7,1602	-200,8398
400	-11,2985	-239,8015
450	-16,8386	-280,2614
500	-22,0104	-320,5896

CONCLUSIONS

An original system was designed and developed for the evaluation of deformations of the wood specimens in the longitudinal direction. If this system connected to the computer, it provides the acquisition of data measurements. The processing of this data and their graphic representation is realized by a program written in C++.

The method of image processing is a non-destructive method that can be applied in the analysis of orthotropic material, in this case wood. A facility of the method is the possibility of marking any distinct points for which data referring to the deformation can also be extracted.

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Based on the acquired digital image analysis system, the program can study not only the developed displacement fields, but also the fields of the corresponding strains. These data can be made available to the researcher either as pictures or diagrams, or by transferring data in Excel spreadsheet program.

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