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METHOD OF DETERMINING THE STRUCTURAL PARAMETERS OF WOOD-POLYMER COMPOSITE

Lesław Kyzioł, Lech Murawski

Maritime University in Gdynia
Faculty of Marine Engineering
Morska Street 81/87, 81-225 Gdynia
tel.:+48-58-6901480
e-mail:lkyz@am.gdynia.pl, lemur@am.gdynia.pl

Abstract

A composite material consisting of woody skeleton and polymerized methacrylate has been developed and characterized. This paper presents an experimental program and the results concerning mechanical properties and strength of wood modified with polymerized methacrylate. In the article, there are examples of structural elements made of natural wood. Wood is a composite consisting of the layers of soft and hard wood. Wood is a composite and porous material. The porosity, which is a serious defect of wood, may be simultaneously its advantage. Wood saturation with different impregnates to minimize its disadvantages. If the wood pores will fill the monomer there is obtained the wood polymer composite. This composite is classified as of fiber composites. Such composite is effectively protected against degradation; it is durable in use, and show an improvement in mechanical properties. Design constructions of surface modified wood require the determination of fundamental material constants. Therefore, for the determination of these parameters is very important obtaining the appropriate research material. The surface impregnation of wood allows obtaining strength characteristics in a function of polymer content. This allows to model it's, and then design and perform specific ship structures. In the wood, there are three directions in relation to the annual rings. Wood properties, especially mechanical properties, are different in the selected directions. For the computation takes the orthogonal anisotropy in which there are three mutually orthogonal planes of symmetry, for which there is symmetry properties of the wood.

Keywords: *modified wood, wood polymer composite, methylmethacrylate, material constants, soft layers, hard layers*

1. Introduction

Wood is the material used on structures including marine industry due to its advantages: low specific weight compared to metallic materials, good insulation, vibration damping and sounds, a magnetism, renewability. The principal disadvantages of wood are porosity that is high absorbability and the change of swelling at the time.

Marine structures are exposed to the fouling marine fauna and flora, and the penetration of living organisms into the structure. Fig. 1 shows the structural elements consisting the layers of softwood and hardwood. Porosity is a serious disadvantage of wood but it may be simultaneously an advantage of wood. Wood pores filled a monomer create with the structure of the wood a new material called wood-polymer composite. This material belongs to of fiber composites. In this way, there was obtained an effective protection against degradation and the prolongation durability of use and improves the mechanical properties of wood.

In Poland, the precursor modification of wood was prof. M. Ławniczak [10].

2. The objectives and research background of the modification of wood

In the constructions bending, torsion are the most effort the exterior surfaces. When the surface modification strengthening are the outer layers, there are simultaneously the lowering of the weight and cost of construction. The surface modified wood combines the advantages of natural wood (damping vibrations and noise and thermal insulation, relatively low price and specific gravity) and modified wood throughout (higher hardness, better weather resistance, abrasion resistance and higher strength especially in bending and torsion).

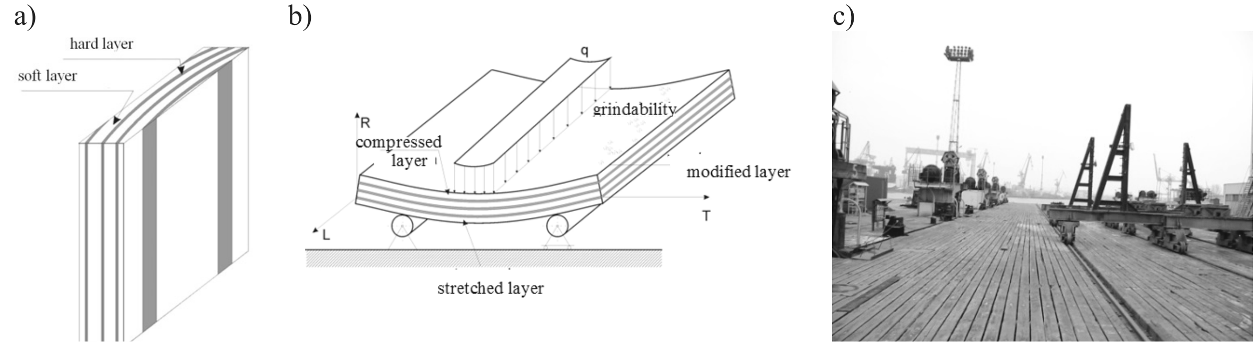

Fig. 1. Structural elements: a) the board, b) load board, c) docking jack

Design of structures requires knowledge of strength characteristics. The experimental material was natural and modified wood with different content of the polymer. The pinewood and methylmethacrylate were used in studies [7, 8].

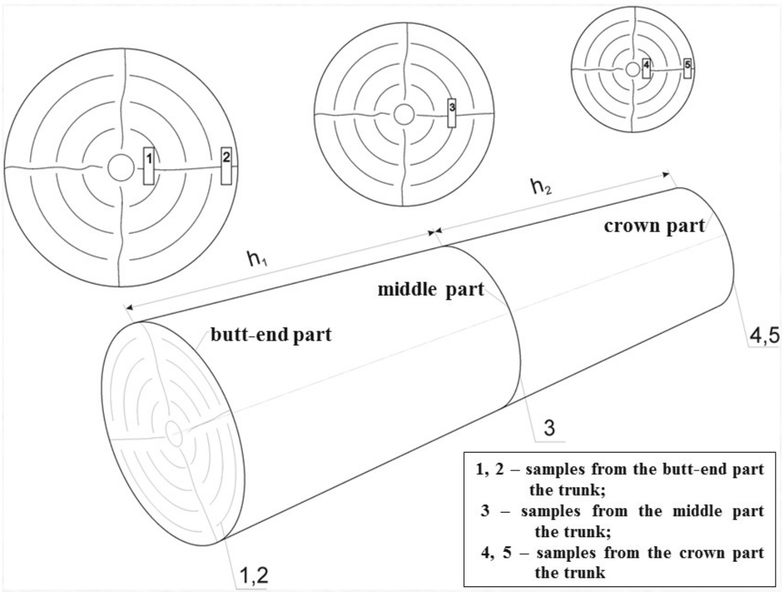

Fig. 2. The place drawing of samples from the trunk of wood

Figure 2 shows the place drawing of samples from the trunk of wood. The samples properly prepared of wood were subjected to impregnation the polymethyl methacrylate (PMMA).

Figure 3 shows a schematic distribution of methylmethacrylate in the sample of pinewood. The impregnation of wood as the porous material is achieved by the capillary pressure [7, 8, 11].

The mathematical model of impregnation wood liquids is based on the thermodynamics of irreversible processes and the equations of balance of mass, momentum and energy. It was necessary to formulate a mathematical model and on the basis of their own to make an adequate verification of this model. It has been shown non-linear and linear equations describing the change in the content of PMMA in wood during saturation.

A detailed description of the equations and the results are presented in [7, 8, 11]

$$\dot{W} = \Lambda_{(i)}[\frac{1}{(aW + \sqrt{\phi_0})^2}) \cdot W_i]_i, \tag{1}$$

where:

$$\Lambda_{(i)} = A_{(i)}\left(1+\sqrt{\phi_0}\right)\sqrt{k_{(i)}}\frac{\gamma}{\eta},\ a=\frac{\rho^s}{\rho^{rf}\phi}=0.88,$$

φ and φ_0 – current and initial porosity of the wood,
ρ^{rf} = 945 [kg/m^3] – actual density of the liquid,
ρ^s = 567 [kg/m^3] – density of dry wood,
φ = 0.68 porosity of the pine wood,
$A_{(i)}$ – coefficient determining the value of the capillary pressure in the direction *i*,
k – permeability coefficient for the direction,
γ – surface tension,
η – dynamic viscosity of the liquid.

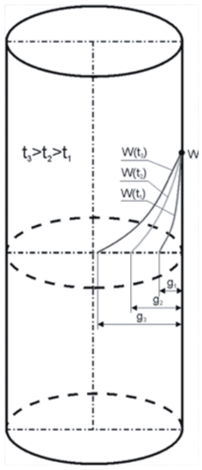

Fig. 3. The distribution of polymer content in the sample of wood: g – the depth of saturation, t – time, h

Equation (1) describes the change in the content of PMMA in the wood during the saturation, for the linear model is following:

$$\dot{W} = \Lambda_{(i)}\cdot W,_{ii},\ \Lambda_{(i)} = aA_{(i)}\left(1+\sqrt{\phi_0}\right)\sqrt{k_{(i)}}\frac{\gamma}{\eta}, \quad (2)$$

with the border condition:

$$-\Lambda_{(i)}\cdot W,_i = \alpha_m(1-a\cdot W)\ \text{ for } x=\pm\text{L}, \quad (3)$$

where:
$\Lambda_{(i)}$ – factor setting the value of the capillary pressure,
α_m – saturation intensity factor.

The coefficients $\Lambda_{(i)}$ and α_m have been determined experimentally, and optimization procedures [7, 8, 11].

3. Model of wood composite

In the wood, there are three directions (Fig. 4). The wood properties, especially mechanical properties, depend on the anatomical directions of the wood [1, 5, 6, 13, 16]. To simplify the calculations shall be adopted the orthogonal anisotropy.

The generalized Hooke`s law is a mathematical statement which relates all components of stress to all components of strain. For orthotropic materials occurs twelve material constants *(E_1, E_2, E_3, ν_{12}, ν_{23}, ν_{32}, ν_{31}, ν_{21}, ν_{31}, G_{12}, G_{23}, G_{31})* [3, 4, 13].

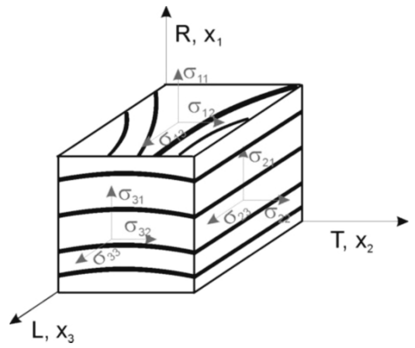

Fig. 4. The components of stress on the walls the elementary parallelepiped of wood

For the wood as a material with anisotropic orthogonal the generalized Hooke's law in a summation convention is expressed [4]:

$$\begin{aligned} \varepsilon_j &= S_{jk} \cdot \sigma_k \\ \sigma_j &= C_{jk} \cdot \varepsilon_k \end{aligned}, \tag{4}$$

where:

$[C_{jk}]$ – stiffness matrix of material; $[C_{jk}] = [S_{jk}]^{-1}$,

$[S_{jk}]$ – flexibility matrix of material,

j, k = 1,2,...,6 (*j* – direction of stress, *k* – direction of deformation).

In the literature, concerning the description properties of the wood is to record letter, signifying the directions of anatomical wood: R – radial direction, T – tangential, L – longitudinal. In the theory of elasticity is used to the indicator tracklog 1, 2, 3, and in particular: x_1 – radial direction, x_2 – tangential, x_3 – longitudinal. In the paper, both the coordinate systems are adopted.

In the flexibility matrix, there are twelve words different from zero. Because of its symmetry with respect the main diagonal, the number of independent words of the flexibility matrix is reduced to nine [4, 7].

4. The material constants in the layers of wood

The aim of the study was to determine the material constants for the surface modified wood. To designate the parameters were used the homogenization method, which was verified experimentally [7, 8]. For the calculation has been accepted that the single layers of wood are the material properties transvers-isotropic.

In Fig. 4 was presented the shape and dimensions of the samples for testing the mechanical properties of a single layer of wood. On the samples were positioned at the rectangular strain rosettes on the plane (x_2, x_3) and an extensometer on the plane (x_1, x_2). The electrical strain gauges measured strains. The single layer formed the measurement part of sample.

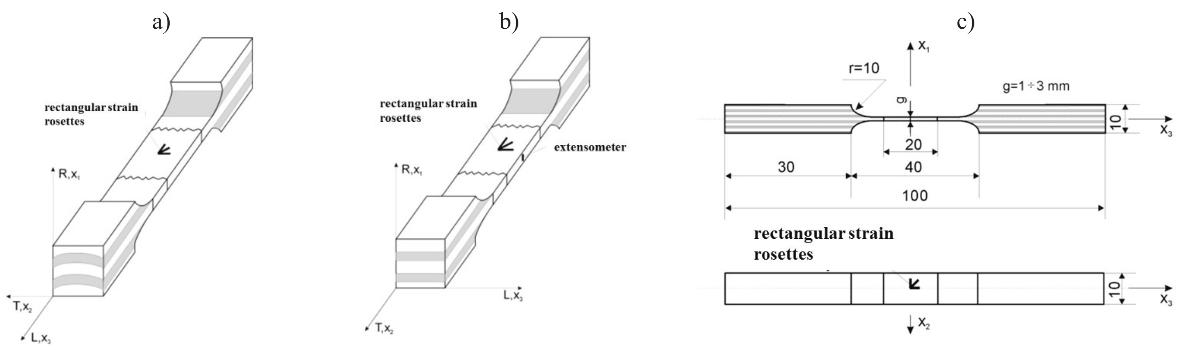

Fig. 5. The geometry of the sample made in the direction of the axis: a) x_3, b) x_2, c) x_3

Test sample consists the measuring part of a length 20 mm and a cross section of 10x2 mm and the gripping part (Fig. 4c). The modification of wood was only the measurement parts of samples. The prepared samples were tested for static tension along the fibres. For the transversal isotropy occur the following compounds (4):

$$S_{11} = S_{22}$$

$$S_{23} = S_{13} = S_{31} = S_{32} = -\frac{\nu_{32}}{E_3} = -\frac{\nu_{31}}{E_3} = -\frac{\nu_{13}}{E_1} = -\frac{\nu_{23}}{E_2}, \tag{5}$$

(because $E_1 = E_2 \Rightarrow \nu_{13} = \nu_{23}$, and $\nu_{32} = \nu_{31}$), (6)

$$S_{12} = S_{21} = -\frac{\nu_{21}}{E_2} = -\frac{\nu_{12}}{E_1} \Rightarrow \nu_{21} = \nu_{12}. \tag{7}$$

The generalized Hooke's law for a single layer of:

$$\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{23} \\ \varepsilon_{31} \\ \varepsilon_{12} \end{Bmatrix} = \begin{bmatrix} S_{22} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{12} & S_{22} & S_{13} & 0 & 0 & 0 \\ S_{13} & S_{13} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(S_{22} - S_{12}) \end{bmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{31} \\ \sigma_{12} \end{Bmatrix}. \tag{8}$$

The coefficients flexibility matrix determined on the basis superposition of results for the two planar problems corresponding to the planes (x_2, x_3) and (x_1, x_2). As a result of measuring the deformations using the rectangular strain rosette on the plane (x_2, x_3) is obtained the deformation of the components. The non-dilatational strains ε_{23} are determined from the transformation formula [2, 14, 15]:

$$\varepsilon_{45^0} = \frac{1}{2}(\varepsilon_{22} + \varepsilon_{33}) + \frac{1}{2}(\varepsilon_{22} - \varepsilon_{33})\cos(90^0) + \frac{1}{2}\varepsilon_{23}\sin(90^0), \tag{9}$$

hence $\varepsilon_{23} = 2\varepsilon_{45^0} - \varepsilon_{22} - \varepsilon_{33}$ while the using compounds (1):

$$S_{44} = \frac{\varepsilon_{23}}{\sigma_{23}} = \frac{2\varepsilon_{45^0} - \varepsilon_{22} - \varepsilon_{33}}{\sigma_{23}}. \tag{10}$$

For example, in Fig. 6, 7 and 8 illustrates the part of a measurement sample from Fig. 5, in which positioned the strain gauge rosette. The rosette measured the strain as a function of load.

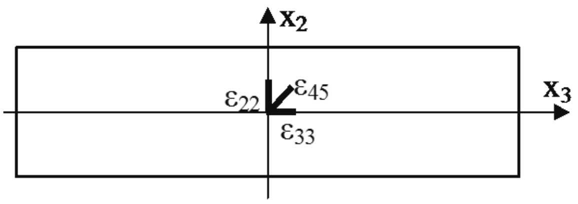

Fig. 6. The measurement of strain the sample subjected to the load in the direction of the axis x_3

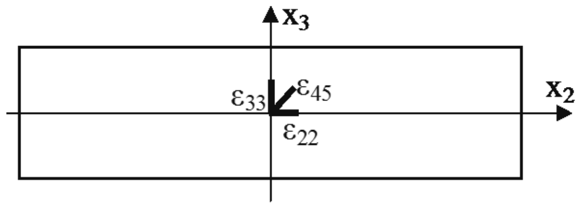

Fig. 7. The measurement of strain the sample subjected to the load in the direction of the axis x_2

By the use of the equations (5) and (6), there were determined $E_1 = E_2$, $\nu_{13} = \nu_{23}$, $\nu_{31} = \nu_{32}$. Measuring the sample strain subjected to tensile in the direction of the axis x_2 (Fig. 8) using the strain gauge in the plane (x_1, x_2 Fig. 5b) has allowed get the strain of component ε_{11}.

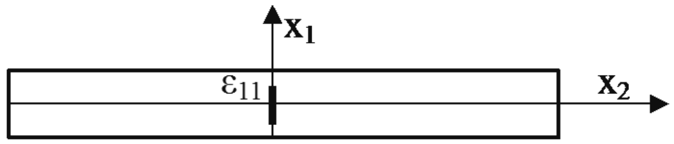

Fig. 8. Measuring the sample strain subjected to tensile in the direction of the axis x_2

The material constants of layers soft and hard have been identified as a result of the research. The example values of the coefficients are presented in Tab. 1 [7].

Tab. 1. The constants of elasticity the layer of softwood and hardwood the natural wood

layers	$E_1 = E_2$ $E_R = E_T$ GPa	$E_3 = E_L$ GPa	$G_{23} = G_{13}$ $G_{TL} = G_{RL}$ GPa	$G_{12} = G_{RT}$ GPa	$\nu_{21} = \nu_{12}$ $\nu_{TR} = \nu_{RT}$	$\nu_{32} = \nu_{31}$ $\nu_{LT} = \nu_{LR}$	$\nu_{23} = \nu_{13}$ $\nu_{TL} = \nu_{RL}$
softwood	1.63	8.60	0.45	0.72	0.13	0.30	0.05
hardwood	3.50	16.0	2.10	1.43	0.20	0.35	0.076

Samples made of the individual layers of softwood and hardwood allowed determination after the five independent material constants of each layer corresponding to the monotropic material (transversal-isotropic).

5. The material constants of wood-polymer composite

Due to the limited dimensions of the transverse trunk separately were performed the measuring parts of samples then appended it to the gripping parts (Fig. 9).

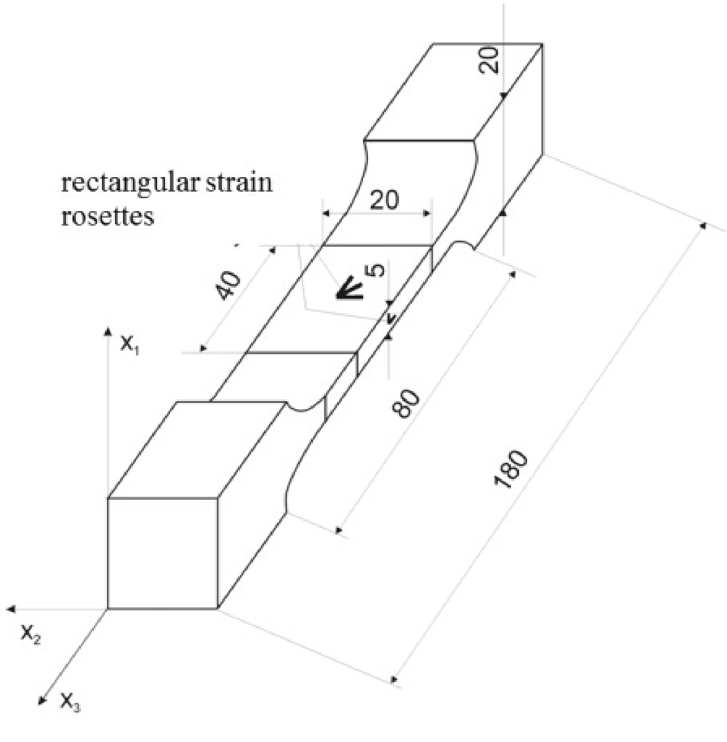

Fig. 9. Sample geometry

In Fig. 10 showed a method for measuring the tension samples in the direction of the axis x_3.

Similarly, measurements were performed subjecting the samples to stretching for the other direction. In the Tab. 2 showed as the example the material constants of natural wood [7].

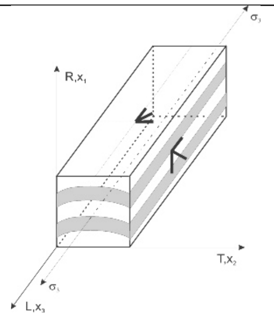

Fig. 10a. The load in the direction of the axis x_3

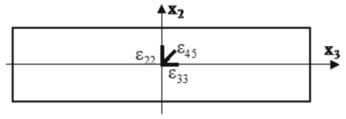

Fig. 10a. Measuring the sample strain subjected to tensile in the direction of the axis x_3

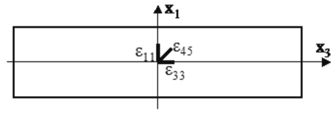

Fig. 10b. Measuring the sample strain subjected to tensile in the direction of the axis x_3

Tab. 2. The material constants of the natural wood

$E_R = E_1$ $[GPa]$	$E_T = E_2$ $[GPa]$	$E_L = E_3$ $[GPa]$	$G_{TL} = G_{23}$ $[GPa]$	$G_{LR} = G_{31}$ $[GPa]$	$G_{RT} = G_{12}$ $[GPa]$	$\nu_{RL} = \nu_{13}$	$\nu_{TL} = \nu_{23}$	$\nu_{LT} = \nu_{32}$	$\nu_{RT} = \nu_{12}$	$\nu_{TR} = \nu_{21}$	$\nu_{LR} = \nu_{31}$
2.15	2.35	11.85	0.72	1.04	0.91	0.06	0.07	0.35	0.58	0.66	0.32

6. Summary and conclusions

In the available literature, concerning the modified wood there is no basic data for the designers of marine structures. There is a lot of literature which concerns the technology and the physicochemical properties of the modified throughout wood. The material has a density almost double than the natural wood, high production costs due to the large amount of polymer in the wood, and there is no possibility to shape its properties. The realization of this method of small sized elements is not expensive, but costs are high the realization the subassembly of the marine structures.

In many studies are given the material parameters of natural wood composed of the soft and hard layers. There is need for the material constants of substitute the surface modified wood and the material constants layers of soft and hard wood with different polymer content. Studies to aiming at determine the material constants the surface modified wood of polymer require careful planning and proper development of its methodology. The material must be very carefully selected for the study. Wood is a natural composite and is characterized by alternating layers of hard and soft.

Properties of wood are different and depend on the place of sampling from the trunk of wood. The used method allowed determine the material constants of single layers of wood, and a composite made up of these layers. The research allowed streamlining modelling the proprieties both single layers and the whole composite. This method allows for the modelling the properties of other composite materials and the porous materials.

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