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STRENGTH PROPERTY OF POLYMER-WOOD COMPOSITE

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Abstract

Wood is one of the oldest construction materials. Nowadays, in the shipbuilding industry wood is almost forgotten. Wood has a lot of advantages in comparison to other materials, e.g. steel. However, some of wood characteristics are inconvenient. Layers are integrated part of wood construction - it is a natural composite. It is a big advantage of the wood, but there is too big difference between soft and hard wood's layer. Modified wood might be very interesting "new" material for marine industry. Especially, polymer-wood composite seems to be very promising. One of the authors developed surface saturation methodology of the wood by polymer. Several measurement tests were performed. Some of the new material characteristics have been specify as a results of the tests. Stiffness and averaged material constants have been determined as well as material data of separate composite layers. The experiments were simulated by numerical calculations. Numerical analysis was compared with measurements. After model verification, several other analyses (e.g. detailed stress distribution in the composite) were performed. That kind of analysis of material data where very difficult, or even impossible, for obtain by measurements. Numerical analysis was performed by Patran-Nastran commercial software based on Finite Element Method. The authors plan to use experimental and calculations data for more specified analysis (included dynamic analysis) and plan to improve that polymer-wood composite can be used in marine industry with benefits.

Keywords: *wood, polymer, composite, Finite Element Method, marine materials*

1. Introduction

Wood is one of the oldest construction materials, especially in the shipbuilding. From the earliest times up to 19th century, boats and each kind of ships where build from wood. Nowadays, in the shipbuilding industry wood is almost forgotten. Wood has a lot of advantages in comparison to other materials, e.g. steel. Wood is relatively light, has a high corrosion resistance and high vibration damping [11]. It is very important for the structures working in the sea environment [5, 6]. However, some of wood characteristics are inconvenient. Generally speaking, building technology of structures from the wood is costly. Layers are integrated part of wood construction – it is a natural composite [1, 4, 8-10]. It is a big advantage of the wood, but there is too big difference between soft and hard wood's layer.

The authors decided to investigate whether it is possible to develop a material having all the advantages of the wood and not having its disadvantages. Modified wood might be very interesting new material for marine industry. Especially, polymer-wood composite seems to be very promising. One of the authors developed surface saturation methodology of the wood by polymer [2]. After implementation of modified wood polymerisation, its characteristics have to be checked. Several measurement tests were performed. Some of the new material characteristics have been specify as a results of the tests. Stiffness and averaged material constants have been determined as well as material data of separate composite layers. However, not all detailed new material characteristics can be determined on the base of measurements.

In the paper, numerical analysis of the polymer-wood composite was presented. Firstly, the experiments were simulated by numerical calculations. Results of the numerical analysis were compared with measurements. After model verification, several other analyses (e.g. detailed stress distribution in the composite) were performed. Numerical analysis was performed by Patran-Nastran commercial software based on Finite Element Method [7]. In the paper five types of polymer-wood composites was analysed (details of the modification process is presented in the author's patent [3]):

- Composite 1 – full modified wood (infinite saturation time; modification method so far used by other researchers),
- Composite 2 – modified wood, soft outside layers (authors' modification methodology – controlled saturation in soft and hard layers),
- Composite 3 – modified wood, hard outside layers (authors' modification methodology – controlled saturation in soft and hard layers),
- Composite 4 – natural wood, soft outside layers,
- Composite 5 – natural wood, hard outside layers.

2. Numerical model verification

Stiffness characteristics determination of the polymer-wood composite was one of the main measurement tests. The scheme of the experiment was shown in Fig. 1. The material sample was built with eleven layers. Specimens were loaded by force from 0 up to 500 N with 25 N increments. Several other tests were performed for determination material constants of each different layer [2].

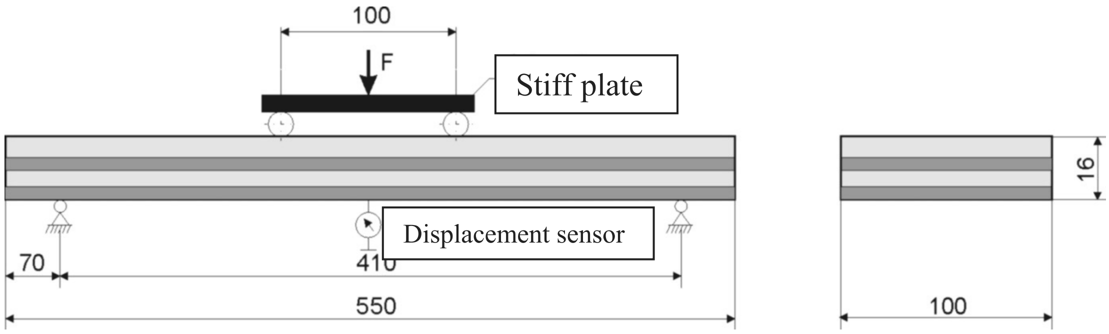

Fig. 1. Scheme of the plate sample of modified wood measurement method

Numerical model of the modified wood plate have to map layers with different material characteristics. Each layer has different orthotropic material constants, determined by measurements. Model of the plate was built with the Patran preprocessor. It is presented in Fig. 2. Analysed plate is symmetrical, therefore only half of the plate is modelled. Boundary conditions (shown in the figure) model the second part of the plate. The model contains about 73 thousands elements and over 233 thousands degree of freedom. Soft wood layer is two times thicker than hard layer. Soft layer is modelled by six elements of the high direction and hard layer is modelled by three elements. Fragment of the model, showing details of the modelling layers, is shown in Fig. 3.

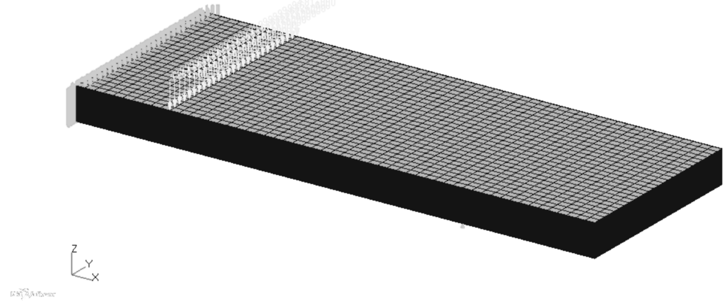

Fig. 2. FEM model of the polymer-wood composite

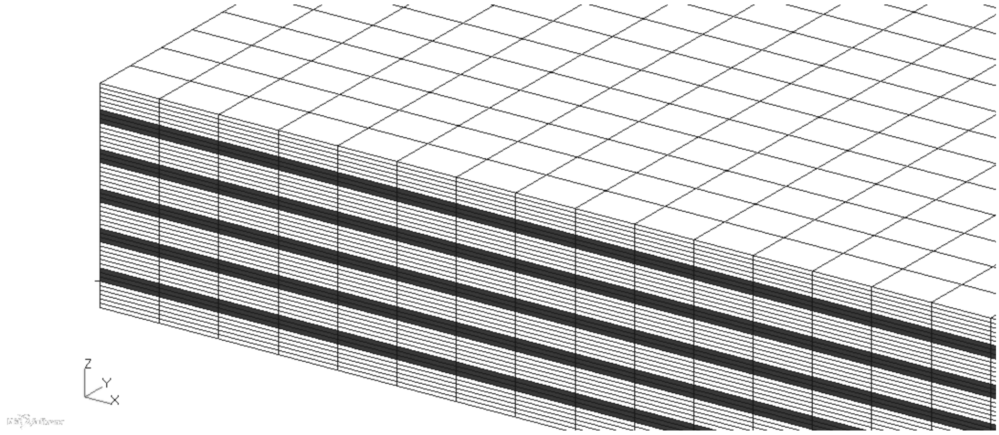

Fig. 3. Layers details of the polymer-wood composite of the plate

The FEM (Finite Element Method) model was verified by displacements comparison with measurement tests. Example (composite 3) of general view of deformation of the analysed plate is presented in Fig. 4. The measurements were performed for four types of plate (composite 2-5): two serial of the tests (with soft and hard layer on the top) for natural wood and two serial of tests for modified wood. All tests were compared with numerical calculations. In the Fig. 5 and 6 measured and calculated displacements are presented. Measurements are approximated by linear interpolation. Deformation of the natural and modified wood with hard layers on the top and bottom surface is presented in Fig. 5. In Fig. 6 deformation of the natural and modified wood with soft layers on the top and bottom surface is shown.

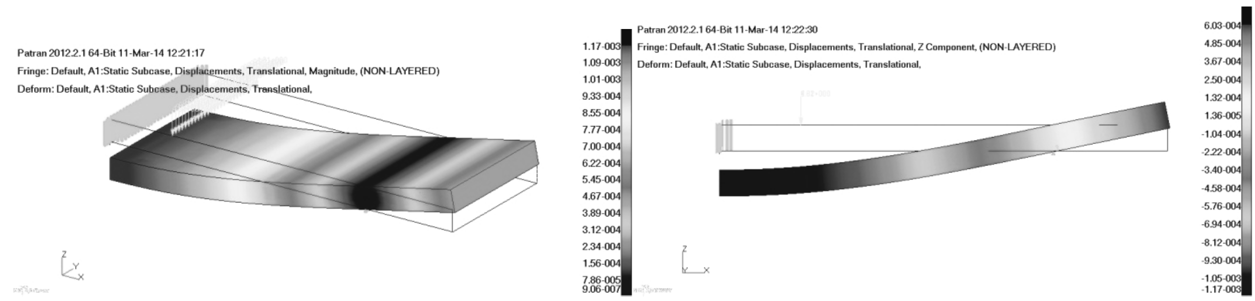

Fig. 4. Magnitude and vertical displacement of composite 3

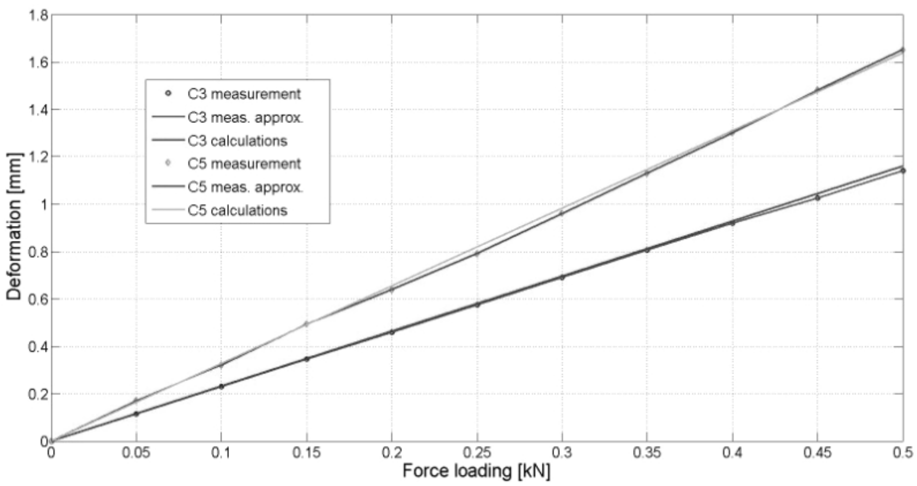

Fig. 5. Deformation of the natural (C5) and modified (C3) wood with hard outside layers; measurements – calculation comparison

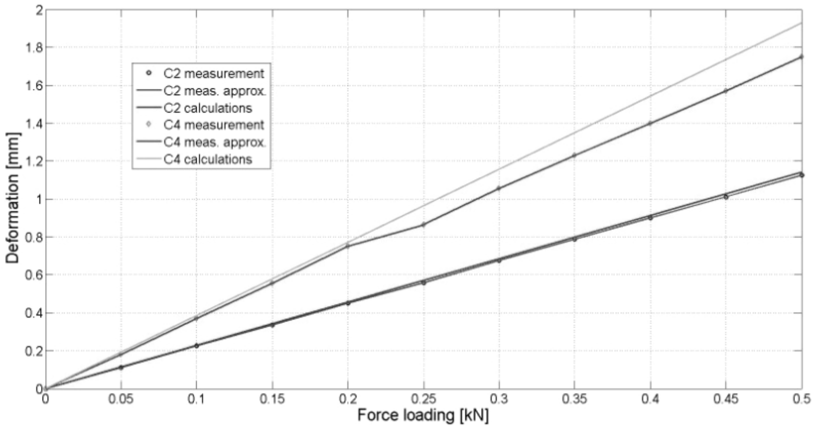

Fig. 6. Deformation of the natural (C4) and modified (C2) wood with soft outside layers; measurements – calculation comparison

Compatibility between measurements and calculations is very good, except "composite 4." Deformation of natural wood named "composite 4" is nonlinear starting from loading 250 N. Stiffness for a range of loads 0-200 N is different than stiffness for a range of loads 250-500 N. In our opinion, during plate loading some of wood fibres was broken. This is a reason of difference between calculations and measurements, only for that type of composite. Relative deformation errors for all kind of wood composite are presented in Fig. 7. Generally speaking, the errors for natural wood (C4, C5) are highest in comparison to errors for modified polymer-wood composite. Saturation is a reason for material constants stabilisation and linearization. It is another advantage of a modified material. Relative calculation errors for polymer-wood composite are less than 2%. FEM model of the composite has been verified.

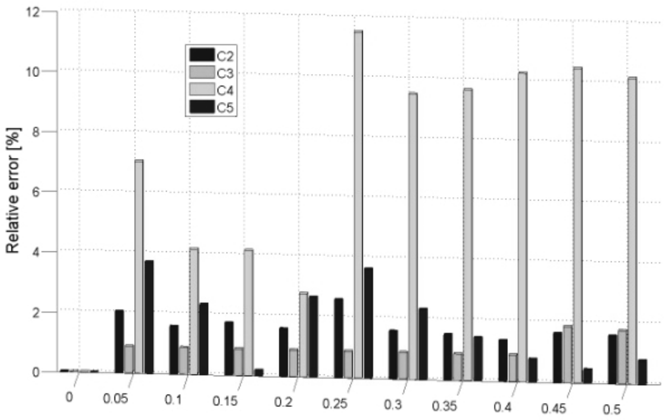

Fig. 7. Relative error of the composites deformations; comparison between calculations and measurements

3. Strength characteristics

Stiffness is one of the most important structure characteristic, especially from vibration analysis point of view. Deformation of all types (see chapter 1) of polymer-wood composite was calculated. The influence of saturation process on wood characteristics was analysed. Firstly, composites with similar layer distribution (e.g. with hard outside layers) were compared. In Fig. 8 displacements of all five types of composites is presented. Comparison between natural wood deformation as well as polymer-wood composites with authors' saturation process is shown in Fig. 9.

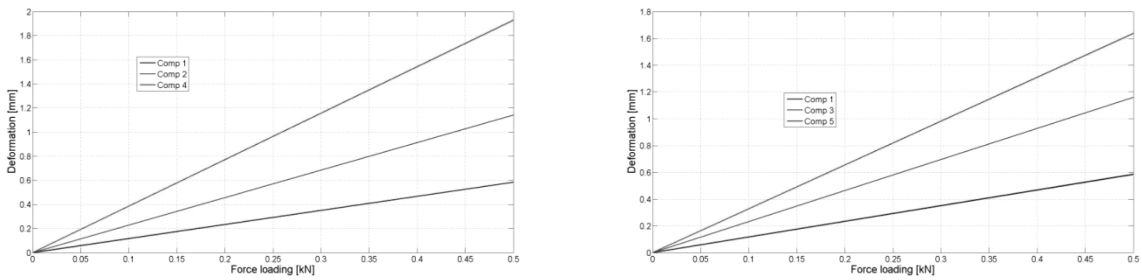

Fig. 8. Deformation of the wood with soft outside layers and with hard outside layers

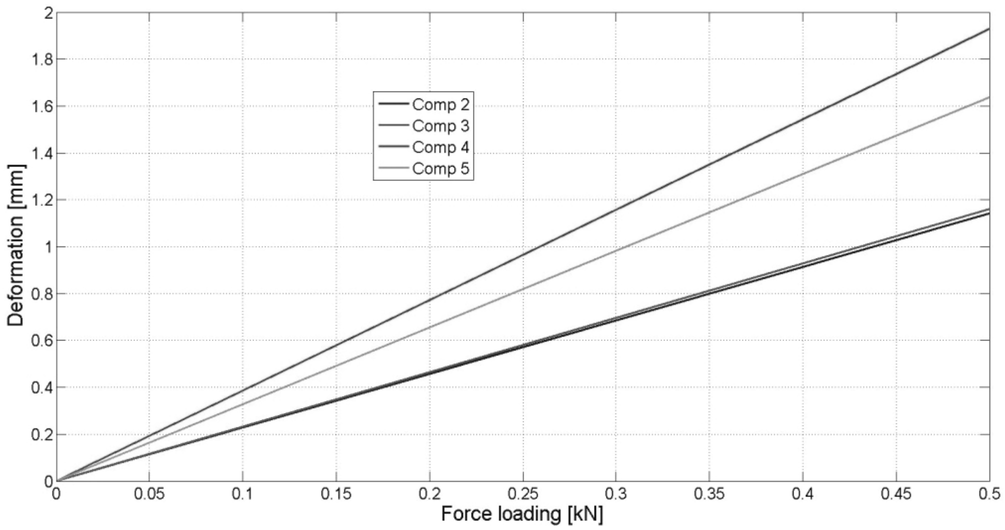

Fig. 9. Comparison between natural wood deformation and polymer-wood composites

Deformations of the analysed plate are linear and stable. Therefore, stiffnesses are constant, and are equal to the following values:

- full modified wood (Comp 1) $k_1=8.55\times10^5$ N/m,
- modified wood with soft outside layers (Comp 2) $k_2=4.38\times10^5$ N/m,
- modified wood with hard outside layers (Comp 3) $k_3=4.31\times10^5$ N/m,
- natural wood with soft outside layers (Comp 4) $k_4=2.59\times10^5$ N/m,
- natural wood with hard outside layers (Comp 5) $k_5=3.05\times10^5$ N/m.

Saturation with polymer using causes the stiffness increasing (Fig. 8). If the saturation process is longer, the stiffness is higher, but it is not a linear change. If the saturation time is very long, (full-modified wood) the structure of the wood is nearly homogeneous – practically it is not a composite structure. Natural wood stiffness characteristics are strongly depended on hard and soft layers distribution. Saturation performed on the base of authors' technology gives us better wood characteristics with simultaneous maintaining the composite structure of the wood. What is more, stiffness characteristics of the modified wood are practically independent from hard and soft layers distribution (Fig. 9).

Detailed stress distribution in the composite structures is very hard to measure. Above presented numerical model of the polymer-wood composite has been verified and can be used for stresses determination. An example of modified wood with soft outside layers, stresses distribution is shown in Fig. 10. The most interesting stresses are presented – Von Misses and stress distribution along plate length. Layers are visible in the Fig. 10, in the polymer-wood composite. But, in the Fig. 11, on the natural wood (with soft outside layers) model enlargement, the layers are clearly visible.

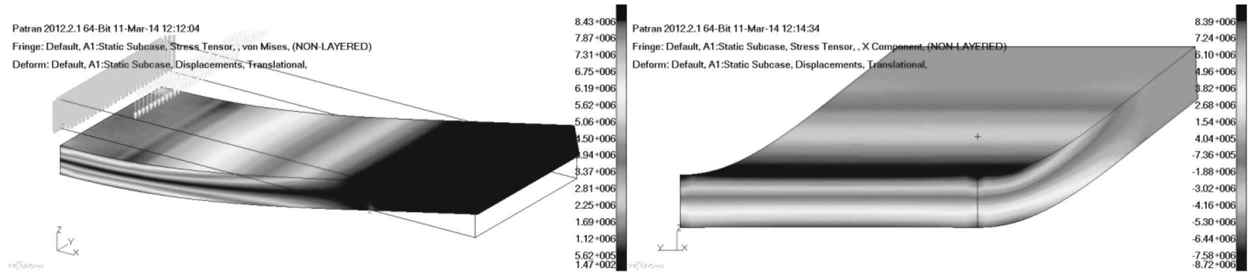

Fig. 10. Stresses distribution of the composite with soft outside layers; Von Misses and X direction

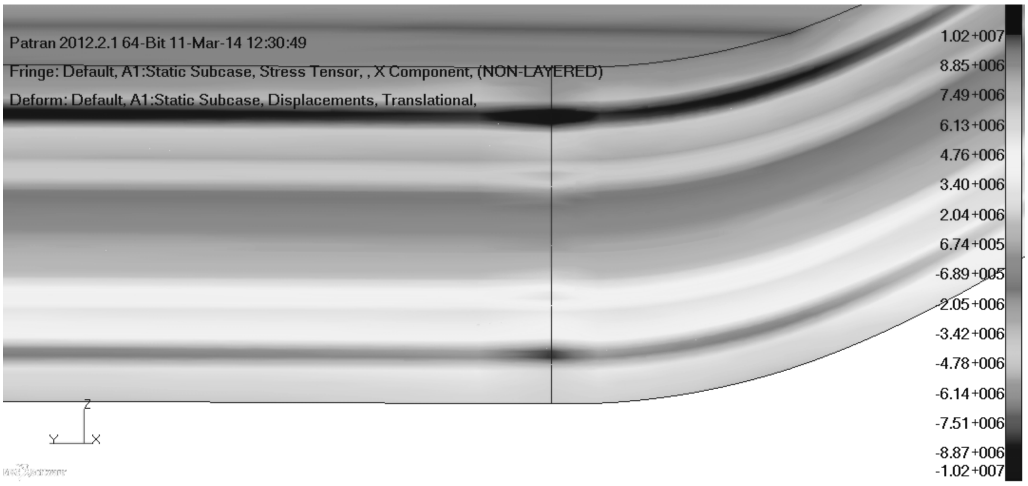

Fig. 11. Stresses distribution of the natural wood in the X direction

The highest stress level of the bending plate is not placed on the external surfaces, as we can see in Fig. 11. It is typical for the composite with soft outside layers. Comparison of Von Misses stress distribution for all types of analysed composite structures is presented in Fig. 12. The stresses are specified for the plate middle part, in the length and width direction. Stress distribution is shown as a function of composites height. Von Misses stresses are symmetrical to bending neutral axis (surface). Therefore, for better visibility, composites with soft outside layers are presented only on the left part of the figure and vice versa. Even more interesting is stress distribution in the longitudinal direction. An examples of calculation exact results for composites with hard outside layers and interpolation values for composites with soft outside layers are presented in Fig. 13. Comparison of stress (in longitudinal direction) distribution of modified polymer-wood composites with different layer distribution is shown in Fig. 14.

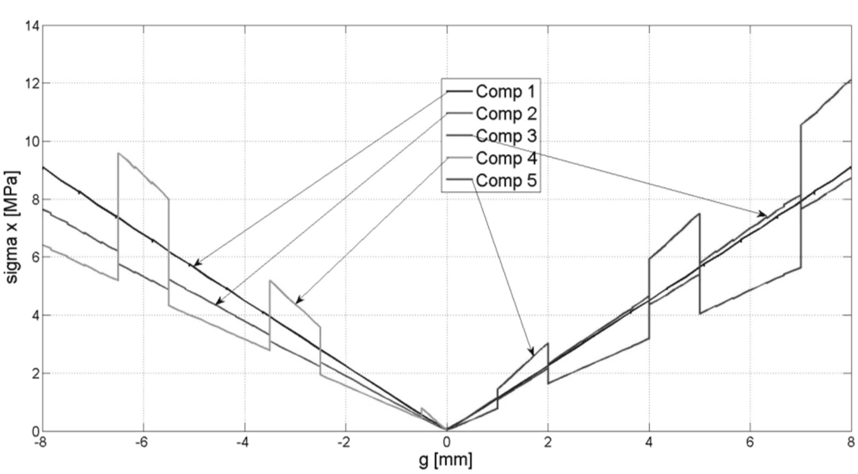

Fig. 12. Von Misses stresses for all types of analysed composites

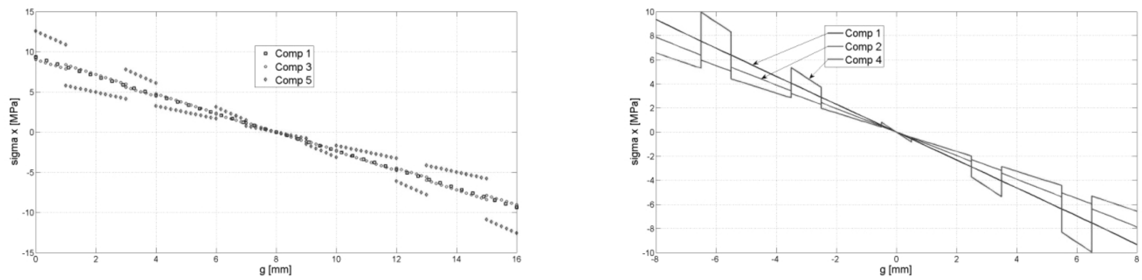

Fig. 13. Stresses in the longitudinal direction; calculated results for composites with hard outside layers and interpolation values for composites with soft outside layers

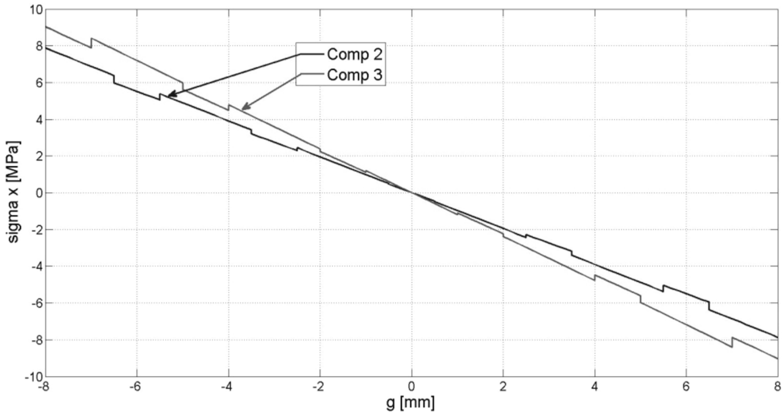

Fig. 14. Comparison of stress distribution of modified polymer-wood composites with soft and hard outside layers

Stress distribution of the full-modified wood (the saturation time is "infinite" long) is linear. The structure of the full-modified wood is nearly homogeneous – practically it is not a composite structure (similar conclusion based on deformation analysis). Natural wood has very big stresses changes from layer to layer. What is more, the highest stress level might be placed below outer surfaces. Typical measurements (e.g. based on strain gauges glued on the outer surface) have to take into consideration these characteristics. Modified (according to authors' technology) wood has clear structure of the composite. Stress changes from layer to layer are visible but limited. What is more, stress level is not strongly depended on layer type distribution. All those analysis observations empowers authors to conclude that polymer-wood composite is very promising material. Modified wood has most of natural wood advantages and is free from most of its disadvantages.

4. Conclusions

Compatibility between measurements and calculations is sufficiently good; FEM model of the composite has been verified. Relative deformation errors for natural wood are highest in comparison to errors for modified polymer-wood composite. Saturation is a reason for material constants stabilisation and linearization.

Wood saturation by polymer is a cause of the stiffness increasing. If the saturation process is longer, the stiffness is higher, but it is not a linear change. If the saturation of the wood is full, the modified wood structure is nearly homogeneous – practically it is not a composite. Stress distribution of the full-modified wood is linear.

Natural wood stiffness characteristics are strongly depended on hard and soft layers distribution. The wood has very big stress changes from layer to layer. What is more, the highest stress level might be placed below outer surfaces. Typical measurements (e.g. based on strain gauges glued on the outer surface) have to take into consideration these characteristics.

Saturation performed on the base of authors' technology gives us better wood characteristics with simultaneous maintaining the composite structure of the wood. What is more, stiffness characteristics of the modified wood are practically independent from hard and soft layers distribution. Stress changes from layer to layer are visible but limited. What is more, stresses level are similar for both types of composited - are not depended on layer type distribution. All those analysis observations empowers authors to conclude that polymer-wood composite is very promising material. Modified wood has most of natural wood advantages and is free from most of its disadvantages.

The authors plan to use experimental and calculations data for more specified analysis (included dynamic analysis) and plan to improve that polymer-wood composite can be used in marine industry with benefits.

References

[1] Galuppi, L., Royer-Carfagni, G., *Buckling of three-layered composite beams with viscoelastic interaction,* Composite Structures, 107, pp. 512-521, 2014.
[2] Kyzioł, L., *Modified wood on marine structures*, AMW, Gdynia 2010.
[3] Kyzioł, L., *The method of modifying the natural wood to shape its properties*, Patent specification, PL 192121, B1, 2006, application number 341689.
[4] Mouritz, A. P., Gellert, E., Burchill, P., Challis, K., *Review of advanced composite structures for naval ships and submarines*, Composite Structures 53, pp. 21-41, 2001.
[5] Murawski, L., Szmyt, M., *Stiffness characteristics and thermal deformations of the frame of high power marine engine*, Polish Maritime Research No 1(51), Vol. 14, pp. 16-22, 2007.
[6] Murawski, L., *Software for the Dynamic Analysis of Machines Placed on Elastic Pads*, Journal of KONES Powertrain and Transport, Vol. 20, No 2, pp. 307-314, Warsaw 2013.
[7] Osiński, Z., *Vibration damping*, PWN, Warsaw 1997.
[8] Strzelecki, T., *Heterogeneous medium mechanics*, *The theory of homogenization*, Dolnośląskie Wydawnictwo Edukacyjne, Wroclaw 1996.
[9] Tabiei, A., Wu, J., *Three-dimensional nonlinear orthotropic finite element material model for wood,* Composite Structures, 50, pp. 143-149, 2000.
[10] Wilczyński, A. P., *Polymer Composites fibrous*, WNT, Warsaw 1996.
[11] Zienkiewicz, O. C., Cheung, Y. K., *The Finite Element Method in Structural and Continuum Mechanics*, McGraw-Hill, London 1967.