ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 13 N° 4 2017
pp. 205-211

NUMERICAL AND EXPERIMENTAL APPROACH OF BEHAVIOUR OF THE WOOD BASED COMPOSITE SUBJECTED TO CYCLIC BENDING

Mariana Domnica STANCIU
Transilvania University of Brasov, Faculty of Mechanical Engineering
29 Eroilor Blvd, 500036, Romania
E-mail: mariana.stanciu@unitbv.ro

Horațiu TEODORESCU-DRĂGHICESCU
Transilvania University of Brasov, Faculty of Mechanical Engineering
29 Eroilor Blvd, 500036, Romania
E-mail: hteodorescu@yahoo.com

Andrei URSĂRESCU
Transilvania University of Brasov, Faculty of Mechanical Engineering
29 Eroilor Blvd, 500036, Romania
E-mail: ursarescu.andrei@yahoo.com

Pavel Cristian LĂBONȚ
Transilvania University of Brasov, Faculty of Mechanical Engineering
29 Eroilor Blvd, 500036, Romania
E-mail: pavelcristian@live.com

Cornel Sandi BIȚ
Transilvania University of Brasov, Faculty of Mechanical Engineering
29 Eroilor Blvd, 500036, Romania
E-mail: cbit@unitbv.ro

Abstract:

Wood mass reduction and the modern tendency concerning a proper use of the lignocellulosic waste have led to the conception of different biocomposite materials with properties similar to those of wood but with an increased dimensional stability. Flaxwood is such a material – a composite material based on wood fibers and polylactic matrix, an alternative to the massive wood, having a homogeneous and an ecological structure, appreciated for its dimensional stability within an environment with humidity variation and being used in musical instruments structure especially.

This paper presents a comparative analysis of the numerical and experimental results for specimens made of flaxwood, subjected to a pulsating cyclic bending. The experimental tests have been performed to determine both the elasto-plastic behavior and the mechanical and structural degradation speed for the material subjected to a cycling bending. Therefore, within the first stage of the study, modulus of elasticity, strain and strength for the specimens under bending, before and after the cyclic loading have been determined. The bending modulus of elasticity has decreased with 8% after 11 cycles of loading, the strength with 5.2% while the strain with 6%. The structural changes in the two phases (before and after the cyclic loading) have been analyzed using SEM. Within the second part of the study the behavior of the lignocellulosic material has been investigated using the finite elements method (FEM), in a hypothesis of an elasto-plastic material (MEP) and of a linear elastic material (MLE). The relative error between the value of the experimental stress and that resulting from the analytic calculus was approximately 0.3%. The best finite elements model from the stresses relative errors point of view (compared with the experimental results) is that of the specimen considered an elasto-plastic material. In such a case the relative error is of approximately 0.8%.

Key words: *wood based composite; pulsating cyclic loading; elasto-plastic behaviour; bending; finite elements method.*

INTRODUCTION

Wood is a hygroscopic material that changes its shape and dimensions when exposed to humidity variations, therefore presenting a dimensional instability behavior. This is the reason why the use of wood in musical instruments production especially means to be able to control both the technological parameters which to insure optimal conditions for wood dimensional stability and the environmental conditions during the storage and the usage of the musical instruments. On the other hand it is to be noted that the storage and the usage of the musical instruments depends upon the users which are not always informed about the wood properties (advantages and disadvantages). At present there is an important tendency to replace the wood with wood based composite whose properties to satisfy the dimensional stability requirements. In the future, a nearly complete replacement of wood with this kind of materials has been predicted, the use of massive wood in musical instruments production risking to become a luxury. Modern studies concerning the wood based composites are looking to improve both the mechanical and technological properties and their long-term viability. During cyclic loading applied on medium density boards (MDF), particleboard (PB), plywood (PL), oriented structural board (OSB), a rapid decrease in fatigue life to a range of 400 to 10 cycles was observed for a stress level of 70% of the average MOR (Bao 1996). In case of composite based on polylactic acid reinforced with cellulose and low density polyethylene filled with cellulose fibres, the incorporation of cellulose into PLA matrix lead to stiffer but slightly more brittle and weaker materials, since Young's modulus increases and tensile strength and elongation at break slightly decrease (Shumigin 2011). Durability of different wood based composites related to adhesive's type was evaluated by cyclic bend stress test (Gaborik et al. 2016). The fatigue life of wood based composite (OSB and plywood) could be predicted by monitoring the energy loss per cycle in a test with several loading cycles, as is mentioned by Sugimoto (2006). Stanciu (2016) noticed that the high tensile strength of the composite is due to reinforcement and type of fibres used, while flexural strength is due to the elastic characteristics close of the two components - matrix and reinforcement, which makes both components to work together. Experimental tests has shown that the failure in a laminated composite is very often progressive in nature, occurring by a process of damage accumulation (Mortazavian 2017; Eftekhari 2016).

Therefore, the problems that arise with these materials concern with the incompatibility at the level of the interface between matrix (PLA) and wood fibers (Oksman 2003; Zhang 2012). Therefore, the fibers percentage has a very important influence on the mechanical properties and on the behavior of lignocellulosic composite materials when subjected to cyclic loadings (Huda 2006).

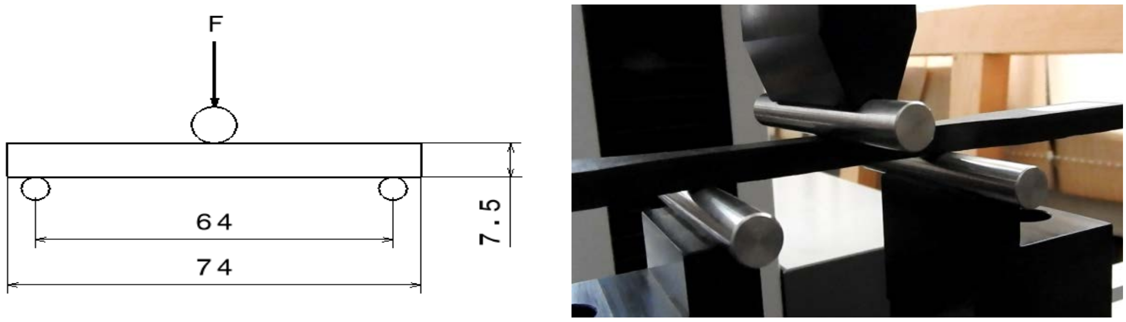
OBJECTIVE

This paper presents an analysis of the elasto-visco-plastic behavior for a wood based composite material having a polylactic matrix – commercial name: flaxwood, largely used in the field of automotive construction industry, civil engineering, furniture and musical instruments production. This analysis will follow the determination of the elasto-visco-plastic properties of such a composite material in two states (initial state and after subjected to a pulsating cyclic loading in bending). Based on these experimental results a FEM simulation of the material behavior has been done, starting from the hypothesis of a linear elastic material (MLE) and then for an elasto-plastic material (MEP).

MATERIAL, METHOD, EQUIPMENT

Experimental set-up

The flaxwood specimens were cut to a length of 84*mm*, the length of the calibrated portion (distance between the testing machine supports) being of 64*mm*, average width: 10*mm* and average thickness: 7.5*mm*. All these specimens have been divided in categories: first set – composed of 5 specimens, has been subjected to three points bending till rupture, determining the modulus of elasticity in bending, rupture loading, maximum stress and strain. The second set has been tested to 10 pulsating cycles, at a load value representing 70% of rupture load determined for the first set (Fig. 1).



a b

Fig. 1.
LR5K Plus Lloyd's Instruments – Three points bending test of wood based composite (flaxwood): a - The principle of three points bending; b - sample subjected to bending during the test.

During the experimental tests the specimens have been subjected to three points bending, with a velocity of 5mm/min. These tests have been performed on an universal testing machine type LR5K Plus Lloyd's Instruments (Fig. 1) – owned by the Mechanical Engineering Department – *Transylvania* University of Brasov, present the following characteristics: maximum load domain – 5kN; maximum driving domain: 975mm; load resolution:<0,01% of the used load cell; extension resolution: <0.1 microns; force cell: XLC-100K-A1; analyzing software: NEXYGEN MT. The experimental results have been collected in electronic format using the software NEXYGEN Plus.

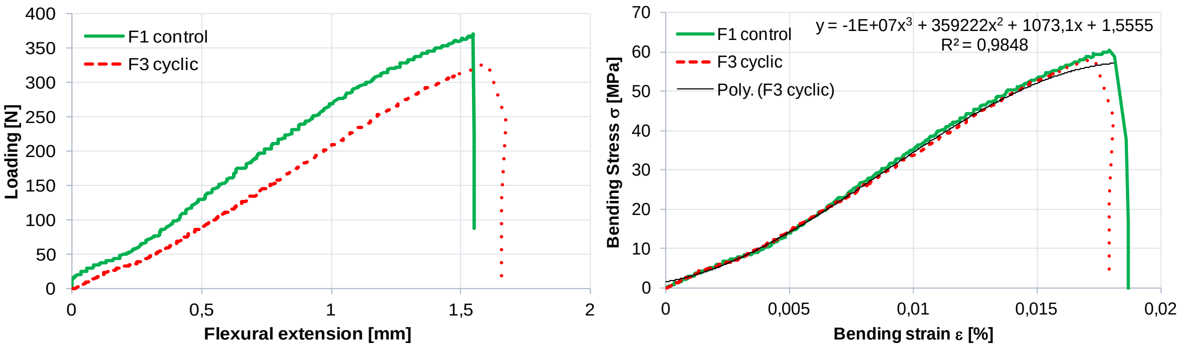
Numerical simulation

To reduce the costs implied by an experimental investigation the finite elements analysis represents a very good solution for the study of a mechanical structure behavior. Therefore, the engineer has to use different computing models that cannot be verified with the experimental tests results or there are not analytical models to compare the results. The main objective of this chapter is to identify the proper mathematical (numerical) model to describe, as precisely as possible, the real behavior of a lignocellulosic composite when subjected to bending. Such a model can be used later to simulate complex mechanical structures made of such a material. The finite elements model – shell type correspond to the real test for a specimen under static bending. Knowing the material function $\sigma = f(\varepsilon)$ geometric and sectional properties and the limit conditions, the recoded loadings during experimental tests are to be applied. Once determined the maximum loaded element, the stresses, displacements and strains will be extracted and compared with the experimental and analytical results. Due to the modeling of the contact conditions the model becomes nonlinear, and the estimated time for resolving the matrix equations increases very much. Therefore, the obtained model represents the best compromise between results accuracy and the necessary time to resolve the equations system.

RESULTS AND DISCUSSION

Three points bending – static loading before and after cyclic stresses

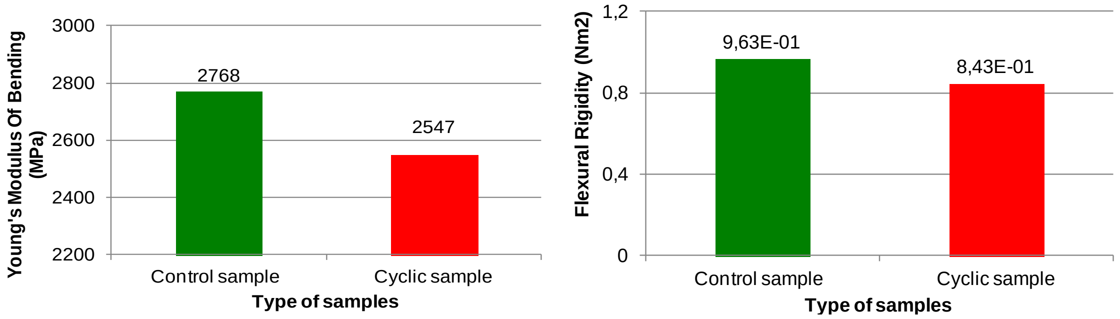
Concerning the behavior of the control specimens and of those subjected to cyclic loading, all under static bending, it is to be observed a decrease of the rupture load with approximately 9% and also a light modification of the material behavior in the elasto-plastic domain, the deformation energy storage capacity being also diminished (Fig. 2a). Both the strength and the strain under bending have a decreasing tendency with 5-6% (Fig. 2b). Although the material rigidity does decrease with the increase of the loading cycles, it is to be noted that the lignocellulosic composite material is stable from the mechanical point of view, the characteristic stress-strain curve having the same mathematical expression, both before and after the cyclic loading (Fig. 2b). The composite material analyzed in the two phases has shown a brittle rupture, as it may be observed in Fig. 2a, b.



a **b**

Fig. 2.
Load-displacement (a) and stress-strain (b) functions under static bending.

From all specimens subjected to cyclic loadings, a percentage of 80% did breaking during the loading cycles. Only the remaining ones could be tested to static bending. Therefore, the average value of the modulus of elasticity in bending has decreased with approximately 8% while the flexural rigidity with approximately 12% (Fig. 3, a and b). It is very important to know about this tendency when using a wood based composite for musical instruments structure where flaxwood components are subjected to cyclic loadings with a relatively reduced load intensity.

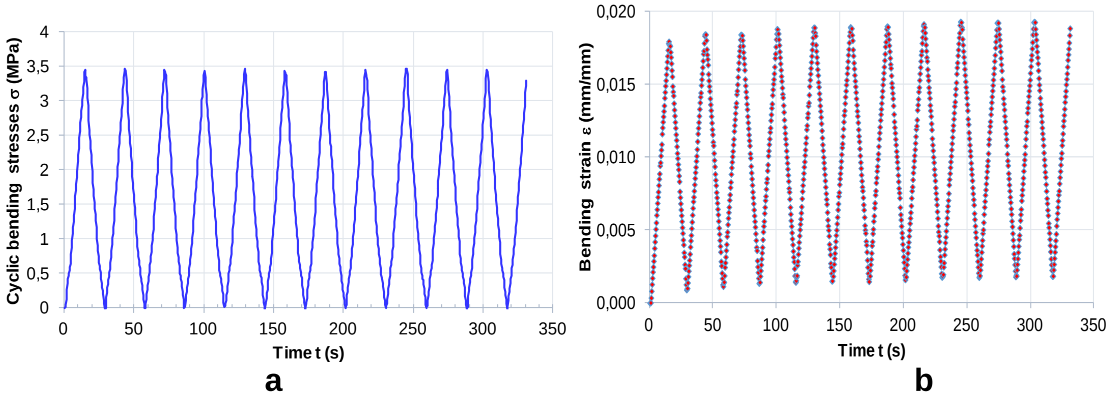


a **b**

Fig. 3.
a - Variation of the modulus of elasticity; b - variation of flexural rigidity in case of control specimens and of those under a cyclic loading.

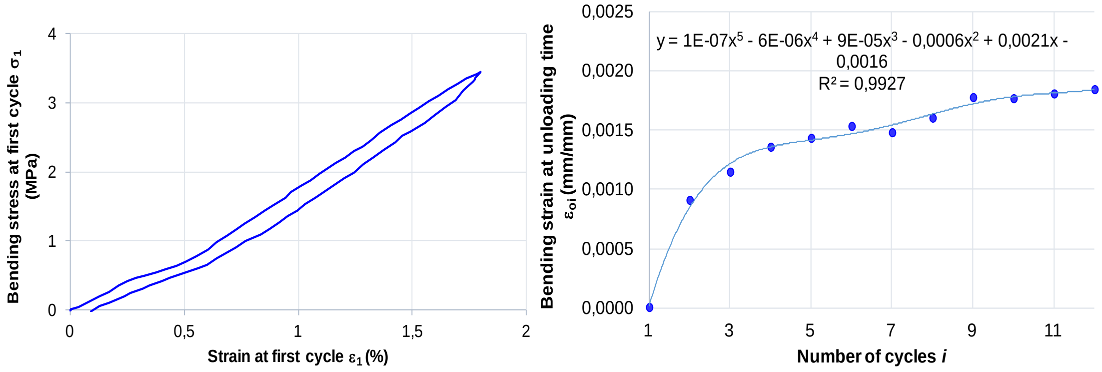
Three points bending – cyclic loading

In case of pulsating cyclic loadings the specimens have been periodically loaded with 250N, load variation speed of 5mm/min, during 11 cycles. From Fig. 4 it is to be noted that the stress has approximately equal values for each pulsating cycle, compared with the strain whose tendency is to increase with the number of cycles. The plastic strain recorded after the first loading cycle is of 0.09% (Fig. 5a) while the final strain value (after 11 loading cycles) is of approximately 0.18%. So, 50% of plastic deformation has been obtained after the first loading cycle while, during the next cycles, a reduction of the deformation rate took place according to equation from Fig. 5b.



a **b**

Fig. 4.
Cyclic variation of bending stress (a) and (b) strain.



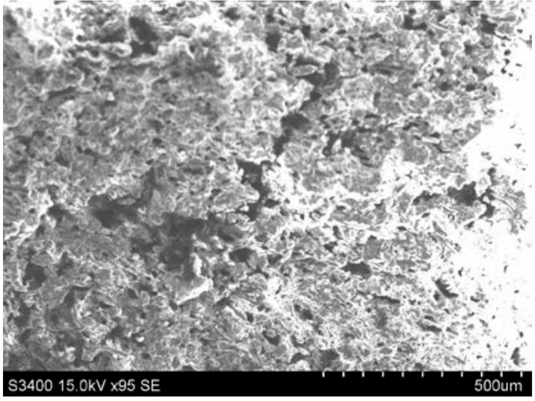
a **b**

Fig. 5.
Strain variation in the plastic domain: a - after the first loading cycle; b - for each loading cycle.

SEM analysis

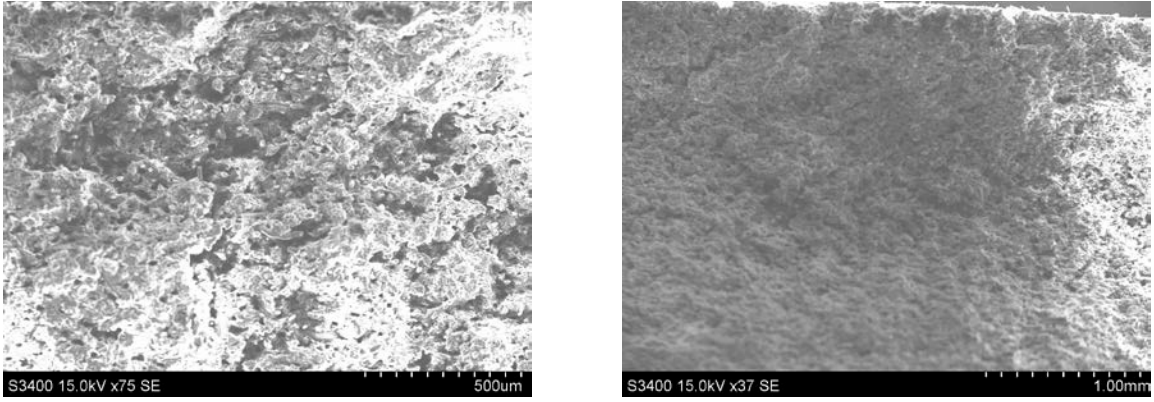
During the investigating research the analysis has been performed using a scanning electron microscope - Hitachi S-3400N type II. This analysis has been concentrated on specimens surfaces topographic study in the section where fracture took place under static bending and after a cyclic loading. In Fig. 6 the topographic images of the stretched area and compressed area have been represented.

Unloaded specimen



Specimen under static loading in bending

Stretched area
Compressed area



Specimen under cyclic loading

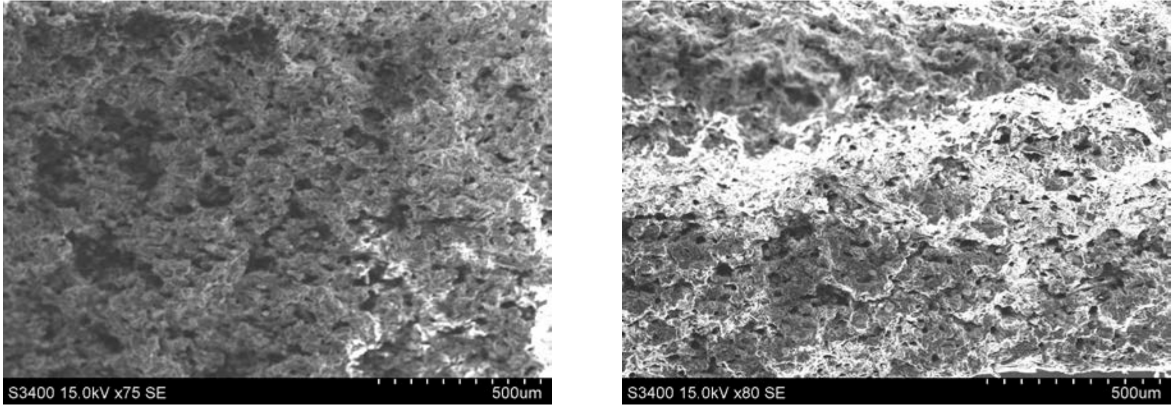


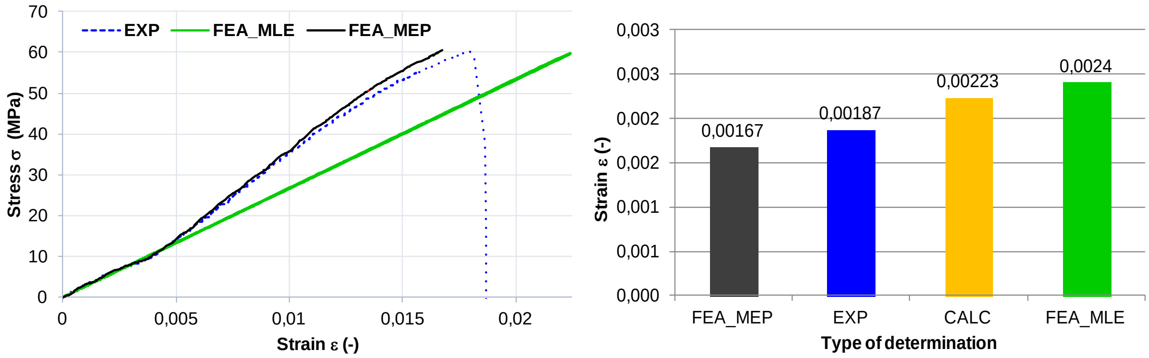
Fig. 6.
Lignocellulosic composite surface topographic analysis in the section where specimens fracture took place.

Structural modifications due to the normal stresses variation in section are mainly present within the compressed area where the structure becomes compact. For the stretched area the elements insuring the strength in tension are represented by the material lignocellulosic fibers. If comparing the compressed surface topography under static bending with that of under pulsating cyclic bending it is to be observed that these are different: more compact and homogeneous in the first case, the strength being insured by the matrix and nonhomogeneous in case of cyclic loading where a fibers dislocation in the matrix takes place during specimens upload-download (Fig. 6).

Cyclic loading behavior FEM analysis

Within the first phase the lignocellulosic composite material has been modeled in two hypostases: linear–elastic material (denoted by MLE) and elasto-plastic material (denoted by MEP). Fig. 7 presents the two material curves, used for material modeling, and the experimental curve. The linear-elastic material characteristic curve represented in Fig. 7, has the same slope with that experimentally determinated. It follows that the modulus of elasticity values are also equal.

To determine the elasto-plastic material characteristic curve using FEA it has been necessary to introduce in the computing program the value of: real stress (σ_r), real strain (ε_r) and plastic strain (ε_p). This modeling has been applied to the stress (and strain) values greater than 11MPa – considered the material elasticity limit according to the characteristic curve experimentally determinated – Fig. 7. In the stress-strain function graphical representation (Fig. 7) one can observe that the elasto-plastic modeling approximates much better the real behavior compared with the linear-elastic modeling, both for stresses and for strains. The relative error is approximately 0.8% in case of stresses and 5% in case of displacements. Even if the maximum stress obtained through a linear – elastic modeling is of 60MPa (witness specimen rupture stress value approximately) it is to be observed that the strain value at rupture is with 27% greater than that experimentally determinated.



a **b**

Fig. 7.
Experimentally determinated characteristic curves – FEA (a); Strain relative error variation (b)
(Exp – experimentally curve; FEA_MLE – characteristic curve for a linear – elastic material;
FEA_MEP- characteristic curve for an elasto-plastic material; CALC – analytically computed value).

After the finite elements model processing, the main quantities of interest were: stresses, displacements and strains, in the most loaded nodes of structure. In Fig. 8 the stresses and displacements distribution have been represented, in case of a specimen modelated with an elasto-plastic material and also the maximum point of these values.

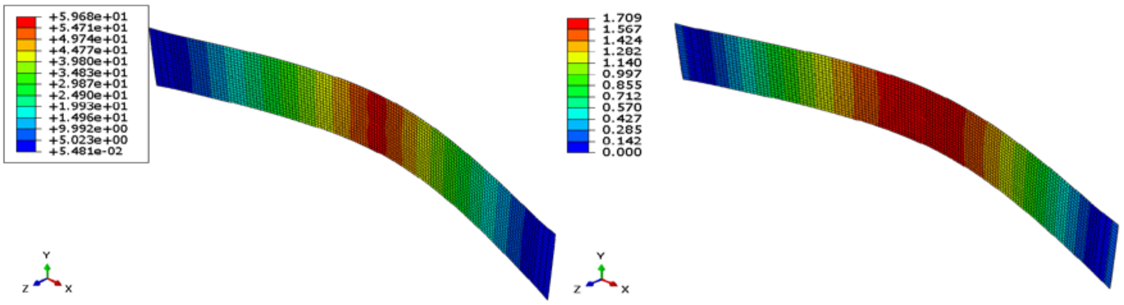


Fig. 8.
Displacements and stresses distribution in case of the modeling of an elasto-plastic material.

In case of the cyclic loading modeling, the results obtained have been represented in Fig. 9, where one can comparative observe the strain variation in time for the maximum loaded node.

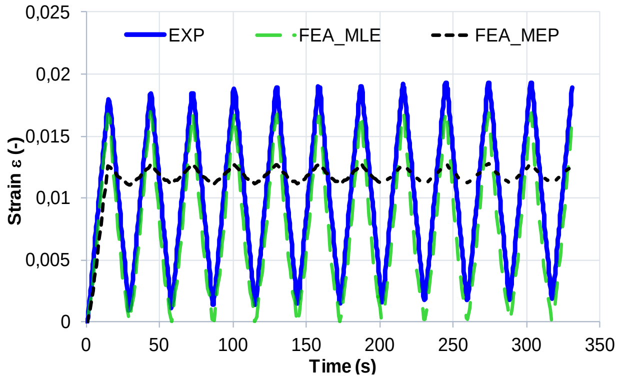


Fig. 9.
Strain variation - experimental and numerical determinations.

In contrast to the simulation of the behavior under static bending, in which the elasto-plastic model does show the real behavior of the composite material, in case of cyclic loadings one can observe an overlapping of the linear-elastic model behavior with that of the real material. This is the reason why it may be concluded that the numerical analysis of lignocellulosic composite structures implies the adequacy of the material mathematical models to the type of loading. From static loadings FEA analysis the material model corresponding to the real behavior is an elasto-plastic one while, in case of dynamic loadings, the proper model is linear-elastic, with an increment applied to the modulus of elasticity to simulate the viscous behavior.

CONCLUSIONS

This paper presents an analysis of the lignocellulosic composite materials under cyclic loadings, the study being concentrated on a commercial material – flaxwood. This analysis has been performed through experimental and numerical investigations.

The results obtained have highlighted the following aspects:

- the investigated lignocellulosic composite presents a low strength under bending but a relatively high rigidity compared with other materials, the strain being of 0.0187%;
- specimens rupture mode indicated a brittle behavior;
- under cyclic loadings, the material capacity to store deformation energy decreases with 50%, even after the first loading cycle, and more than 80% of tested specimens showed a sudden decrease of strength under cyclic bending, through their rupture after the fourth and the fifth loading cycles;
- during the cyclic loadings structural changes occur, represented by the damage of the interface matrix-wood fibers that, finally, lead to the material rupture, (Fig. 6);
- in case of the numerical modeling the "reverse engineering" method has been chosen for simulation, interpolating the experimental data with theoretical data, resulting two distinct mathematical models according to the loading type: static (elasto-plastic model) or dynamic (linear-elastic model).

ACKNOWLEDGEMENT

This paper was supported by Program partnership in priority domains - PNIII under the aegis of Ministry of Research and Innovation and Executive Agency for Higher Education, Research, Development and Innovating Funding from Romania, project no. PN-III-P2-2.1-BG-2016-0017/85 SINOPTIC.

This research takes part from an extensive research conducted by professor Ioan CURTU who passed away at the end of 2016th year. We are grateful for all scientific knowledge and skills that we learned from him.

REFERENCES

Bao Z, Eckelman C, Gibson H (1996) Fatigue strength and allowable design stresses for some wood composite used in furniture. Holz als Roh- und Werkstoff 54:377-382.

Shumigin D, Tarasova E, Krumme A, Meier P (2011) Rheological and mechanical properties of poly(lactic) acid/cellulose and LDPE/cellulose composites. Materials Science 17(1):32-37.

Gaborik J, Gaff M, Ruman D, Zaborsky V, Kasickova V, Sikora A (2016) Adhesive as a factor affecting the properties of laminated wood. Adhesive & Lamination, Bioresources 11(4):10565-10574.

Sugimoto T, Yamasaki M, Sasaki Y (2006) Fatigue and hysteresis effects in wood-based panels under cyclic shear load through thickness. Wood and Fiber Science 38(2):215–228.

Stanciu MD, Harapu A, Teodorescu Drăghicescu H, Curtu I, Savin A (2016) Comparison between viscous elastic plastic behaviour of the composites reinforced with plain glass fabric and chopped strand mat. Materials Science and Engineering 147**,** doi:10.1088/1757-899X/147/1/012097

Mortazavian S, Fatemi A (2017) Fatigue of short fiber thermoplastic composites: A review of recent experimental results and analysis. Int J Fatigue http://dx.doi.org/10.1016/j.ijfatigue.2017.01.037

Eftekhari M, Fatemi A (2016) On the strengthening effect of increasing cycling frequency on fatigue behavior of some polymers and their composites: experiments and modeling. Int J Fatigue 87:153–66.

Oksman K, Skrifvas M, Selin JF (2003) Natural fibres as reinforcement in polylactic acid (PLA) composites. Composite Science and Technology 63(9):1317–1324.

Zhang Q, Shi L, Nie J, Wang H, Yang D (2012) Study on poly(lactic acid)/natural fibers composites. Journal of Applied Polymer Science 125(52):E526-E533.

Huda MS, Drzal LT, Misra M, Mohanty AK (2006) Wood-fiber-reinforced poly (lactic acid) composites: Evaluation of the physicomechanical and morphological properties. Journal of Applied Polymer Science 102(5):4856–4869.