# EQUIPMENT FOR TESTING THE WORM AND WORM GEAR ASSEMBLY FROM "LIQUID WOOD" AND COMPARATIVE MEF ANALYSES

**Ciprian Ciofu[1], Constantin Carausu[2], Simona Nicoleta Mazurchevici[3], Viorel Paunoiu[4], Bogdan Chirita[5]**

[1]"Gheorghe Asachi" Technical University of Iasi, Faculty of Mechanical Engineering,
Str. Prof. Dr. Doc. Dimitrie Mangeron, Nr. 43, Iasi, 700050, Romania
[2,3]"Gheorghe Asachi" Technical University of Iasi, Faculty of Machine Manufacturing and Industrial Management,
Str. Prof. Dr. Doc. Dimitrie Mangeron, Nr. 43, Iasi, 700050, Romania
[4]"Dunarea de Jos" University of Galati, Department of Manufacturing Engineering,
Domnească Street, No. 111, 800201, Galati, Romania
[5]"Vasile Alecsandri" University of Bacau, Department of Industrial Engieenering,
Cal. Marasesti, No 157, Bacau, Romania

Corresponding author: Simona Nicoleta Mazurchevici, simona0nikoleta@yahoo.com

***Abstract:*** On the background of necessity for a sustainable resource of raw materials as well as environmental problems caused by plastic and metallic materials, hardly degradable, car manufacturers are always looking for new materials, especially composites, with low environmental impact, that ensure the same performance, but beeing produced as ecologically as possible.
In the paper is presented an equipment for the analyze of exploitation behavior of the worm - worm gear obtained from Arboblend V2 Nature intended of windscreen wipers operation of vehicles. For the comparative MEF analyses, made in this paper, three materials were taken into account: two with the high rate of biodegradation Arboblend V2 Nature and PLA (polylactic acid) and one nondegradabile ABS (acrylonitrile-butadiene-styrene). This paper describes the operation of the worm gear testing assembly, finite element modeling of worm gear static behavior and simulations regarding stress and deformation states of worm wheel for ABS, PLA and Arboblend V2 Nature. The proposed benchmark aims the experimental validation of the proposed model and verification of this one by finite element simulation.

***Key words:*** worm gear assembly, "liquid wood", Arboblend, PLA, ABS.

## 1. INTRODUCTION

The continuous occurrence of many polymers with very different characteristics and the need to improve their processing technologies has led to the explosive development of the plastics industry. However, in the time of the development as substitute material of metals or other deficient materials, was taken into account only the substitution in terms of production costs and property performance, but not in terms of their negative impact on the environment. Over the years, scientific researchers have increasingly paid attention to this detail. Thus, thermoplastic material from synthetic or natural modified polymers has been developed that exhibits both comparable properties with those of fossil-derived polymers (depleting material sources) but also the ability to be recyclable and biodegradable up to 100%, [1].
In search of viable solutions in what concern this problem, the Tehnaro Company, together with the German Fraunhofer Institute for Chemical Technology, has carried out studies and developed - based on wood components - a new commercial material generically called "liquid wood". The developed material can be processed in the same way as well as thermoplastic materials. "Liquid wood" is in the form of three different types of materials Arboform, Arboblend and respectively Arbofill. In this work Arboblend V2 Nature was chosen due to its mechanical and structural performance, but also because of its high degradability ratio (around 80%) [1, 2, 3]. Another biodegradable material that can be used in this application is Arbofill Fichte take into account also the mechanical and thermal properties, [4-6].
Arboblend® is a thermoplastic material based on biopolymers such as lignin (matrix), starch, cellulose, organic additives, natural resins or wax and natural reinforcement fibers. It exhibits properties comparable as high impact resistant plastic materials (for example ABS), [2]. This material is applicable in various fields of activity such as automotive, consumer, construction, toy, etc. [2, 3]
Simulations were performed for three types of thermoplastics Arboblend V2 Nature, ABS and PLA.
Polylactic acid (PLA) is a thermoplastic produced from renewable resources, being biodegradable in the

presence of oxygen, and difficult to be recycled. It is commonly used for packaging industry, sheets, glasses and water bottles manufacturing industry. It is considered to be more environmentally friendly than ABS (acrylonitrile-butadiene-styrene) is an oil-based plastic, tougher, used to obtain rigid objects from plastic material. ABS is not biodegradable but can be easily recycled [3,7, 8].
3D modeling or CAD (Computer Aided Design) allows to engineers and designers the building of realistic computerized models of parts and assemblies. These models are used to run various complex simulations. A wide range of parameters can be followed by simulation such as tensile, strains, impact, or temperature resistance, before creating a physical model, thus ensuring a faster and cheaper workflow.
Simulation of worm – worm gear assembly was conducted using SolidWorks 3D CAD software. The design data was 100% modifiable and the relationship between the parts, the assembly and the execution drawing were always updated.
The present paper describes the operation of the worm - worm gear testing equipment, the finite element modeling of the worm gear static behavior (made of ABS, PLA and Arboblend V2 Nature), simulations regarding the stress statuses and the deformations of the worm gear in case of the above-mentioned materials.

## 2. DESCRIPTION OF THE EQUIPMENT OPERATION

The proposed stand aims the model experimental validation and the verification of this one by finite element simulation.
Vehicles fall into the category of durable goods and conventional their lifetime is considered as an average of 10 years. According to the classification of the fixed assets used in the economy, they fall into group 2.3.2. - Transport means and are framed with a service life between three and nine years, depending on the operating regime, [9].
In a temperate continental climate, as in the Romania case, are between 100 and 200 precipitation days annually, figure 1, [10]. Thus, for the proposed model validation, we will consider an estimated number of 150 rainfall days.
Considering the average life of a vehicle as five years and an average use of about two hours per day, it is deduced that the operation of a wiper mechanism will have a number of 2x150x5 = 305 operating hours.
Thus, the stand will operate a number for 305 hours, applying a maximum constant load on the entire engine-gear assembly. After the end of the working time, the gear unit will be dismantled and the components will be checked and compared with the original model, in the absence of loads.
For a more faithful result compared to a normal vehicle operation, 25% of the operating time will be at -15°C and 25% of the test period will be conducted under temperature conditions above 40°C.
Atmospheric humidity or solar rays are considered as having no influence on the components as they are mounted in a closed, sealed and non-accessible enclosure during use.
Tests will be carried out using two similar mechanically and cinematic mechanisms. A mechanism will be tested in the standard configuration, and the second one will have the worm gear obtained by 3D printing technology using Arboblend V2 Nature material.

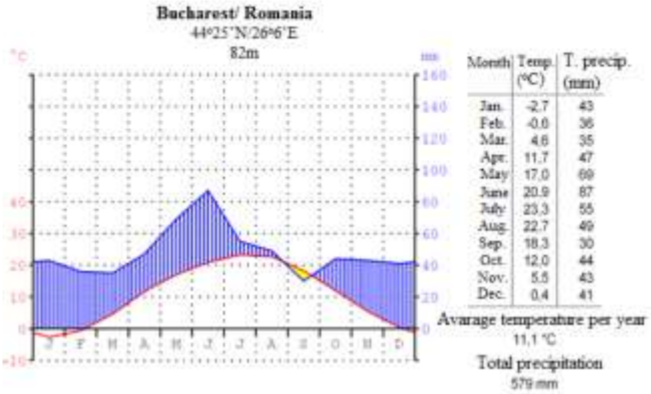

Fig. 1. The precipitation average graph during one year for Bucharest, [10]

We will observe the wear due to friction, of deformations, of quality surface and shape, of tested parts, and the behaviour of these one in the presence of mineral-synthetic lubricants. Also, due to the different structure, during operation due to the elastic deformations which occur within the gear, the kinematics will change, thus following the behavior of the new material (Arboblend V2 Nature) in certen conditions, behaviour which can not be estimated by FEM simulation.
Throughout the tests, which will be performed can be monitored the actual power consumption of the electric motors. From this, will be observed the behavior of the new material subject to mechanical demands compared to the existing solution and materials.
The worm – worm gear assembly is made from Arboblend V2 Nature material, superior to many plastics from mechanical and thermal properties point of view.
The equipment (figure 2) consists of the following parts: 1-control panel; 2-weight; 3- counter operating cycles; 4-electric engine; 5- flywheel; 6-brake and 7-support table.
On the support table 7 is rigidly mounted the wiper -

engine assembly consisting of the worm - worm gear (8) used to transmit the movement from the engine 4 to the flywheel 5. By using the brake 6 it simulates the normal operation of the wiper motor assembly. The load can be varied by using different weights 2. The counting of the working cycles is done with the counter 3 mounted directly on the support table 7. The visualisation of power consumption respectively equipment on / off are made by the control panel 1.

Changing properties at temperature variations can modified the gearing behavior. Therefore, in order to follow any changes in the monitored parameters due to thermal influences, the test the installation will be subjected to variations of temperature. The enclosure where the experimental equipment will be located will have the possibility of varying the thermal conditions.

A thermometer (not shown in figure 2) will monitor the temperature of the environment in which the experiments will be performed. The temperature at which the worm gear will operate will be varied between -18°C and + 40°C, and will allow tracking of gear behaviour, made from the three materials, in similar conditions to those on road vehicles.

Typically, the worm – worm gear assembly (figure 3) is made of plastics that presents low friction coefficient. According to the literature, [7, 8, 11], most of the widely used plastics materials, PA46, PA6, PA66, PA6E, POM, etc.) have coefficients of friction between (0.2-0.45). According to the research carried out so far, the friction coefficient for Arboblend V2 Nature has the value of 0.16 in cases of disk rotation and 0.13 in case of disk oscillation, consequently–lower values than the plastics presented above, [12, 13].

Arboblend V2 Nature is a biodegradable material with a biodegradation rate of approximately 45%, [14] over 140 days.

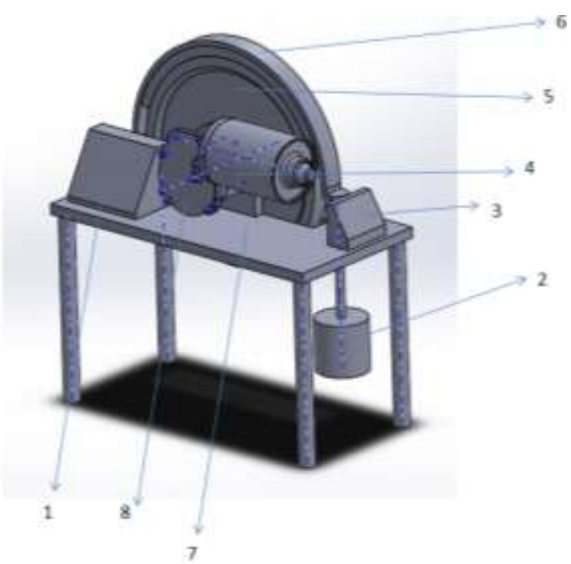

Fig. 2. Equipment for testing the worm-worm gear made from liquid wood

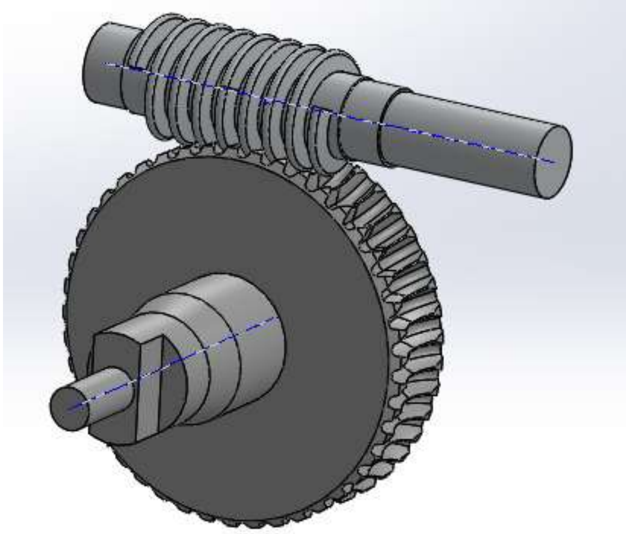
Fig. 3. Worm – worm gear assembly

These one can be injected using the same injection technology as in case of conventional plastic with the mention that the melting temperature is around 150°C much lower than the melting temperatures for the plastic materials mentioned above, which means a significant energy saving and implicitly a higher productivity. Secondly, considering the increase in the number of cars registered worldwide, [15], to77.3 million in 2016, it is justified to use a biodegradable material with superior properties or at least similar to often used plastics.

In order to notice if this material resists from mechanically point of view, the paper also presents a simulation with finite element method on the stresses state and deformations for Arboblend V2 Nature and PA6 plastic material.

## 3. RESULTS OF FINITE ELEMENT MODELING

For the finite element modeling of the worm gear static behavior of the worm wheel were chosen three materials whose physical and mechanical characteristics are presented in table 1.

Table 1. Physico-mechanical properties of the materials considered in modelling, [7, 8, 11-14]

| Material | Tensile strength [MPa] | Elastic modulus [MPa] | Poisson's ratio | Shear modulus [MPa] | Mass density [Kg/m$^3$] |
|---|---|---|---|---|---|
| ABS | 40 | 2410 | 0.3897 | 862.2 | 1070 |
| PLA | 35 | 2000 | 0.394 | 318.9 | 1020 |
| Arboblend V2 Nature | 22.8 | 5100 | 0.39 | 270 | 1250 |

The support of the worm gear was made on the cylindrical surface of the spindle, and the loading was made on four successive teeth (find in the gear at a time with the worm screw) according to figure 4.

The worm gear support modeling was achieved by blocking all freedom degrees.

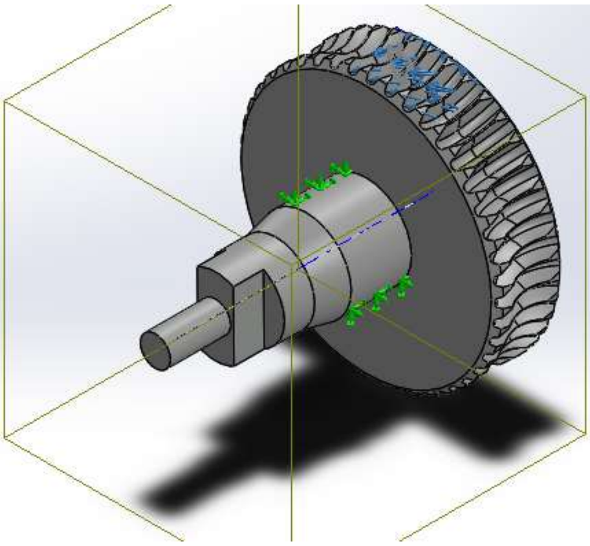

Fig.4. Constraints and loads modelling

Discretization was performed with 16673 solid tetrahedron elements. The outside temperature was set at 25°C.

## 3. RESULTS AND DISCUTIONS

### 3.1 Stress state

Figures 5-7 are representing the stress states of the worm gear made from ABS, PLA and Arboblend V2 Nature materials.

The obtained results reveal very small differences between the stress states of worm gear made of the three materials: 12.59MPa for ABS, 12.58MPa for PLA and 12.57MPa for Arboblend V2 Nature. The maximum equivalent stress value is located in the area of the stress concentrator at the intersection of the spindle with the front surface of the worm gear.

Also high stresses are observed at the teeth base to which load was applied, the stresses are around 9.3MPa.

### 3.2 Deformation state

Figure 8-10 presentes stress state of worm gear for ABS, PLA and Arboblend V2 Nature materials cases.

Maximum deformation is located at the tip of the worm gear teeth to which load was applied. The shortest deformation, 0.068mm, has been highlighted by the worm gear made of Arboblend V2 Nature, followed by ABS (0.144mm) and PLA (0.174mm).

Deformations of the teeth have implications on the contact nature between the gear teeth and can significantly change its behavior and wear during operation.

The planned experiments, in the future, will have to follow the influence of these deformations on the functional parameters and the reliability of the gear.

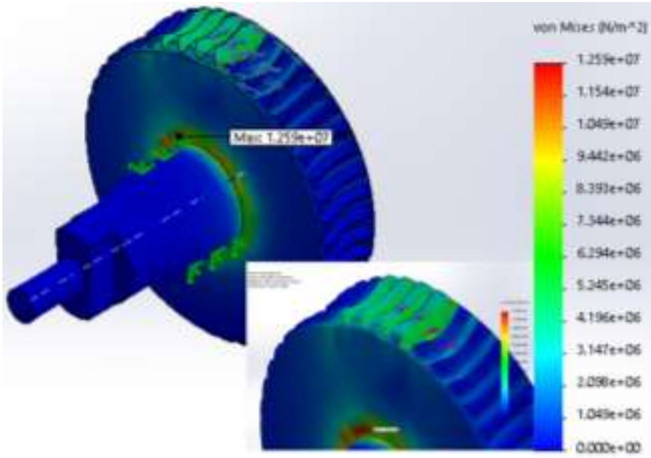



Fig. 5. Worm gear stress state, made from ABS

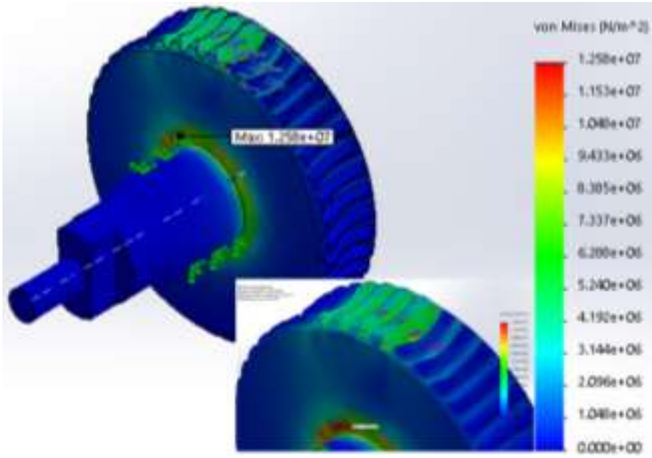



Fig. 6. Worm gear stress state, made from PLA

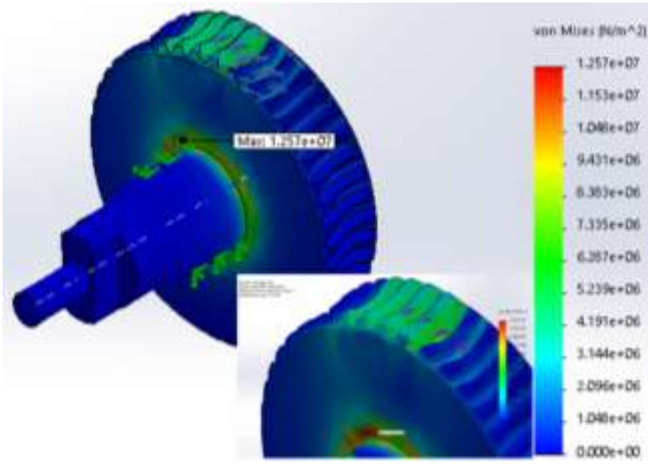



Fig. 7. Worm gear stress state, made from Arboblend V2 Nature

Strain distribution is shown in figures 11-13. The location of the maximum strain is at the joining of the spindle with the gear/wheel front surface. The lowest value of the specific deformation is for the Arboblend V2 Nature worm gear ($2.28x10^{-3}$), followed by the ABS ($4.84x10^{-3}$) and the PLA ($5.8x10^{-3}$) respectively. The results for the strain maintain the established hierarchy for deformation of worm wheels/gear in case of the four materials, the figures 11-13.

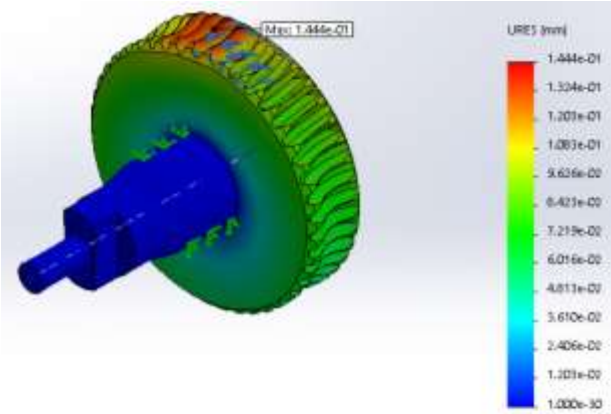

Fig. 8. Deformation state for worm gear made of ABS

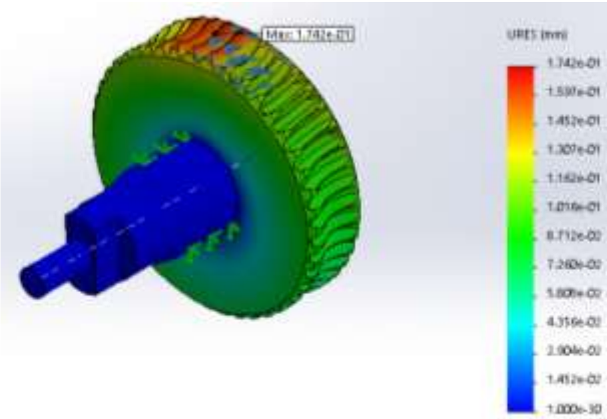

Fig. 9. Deformation state for worm gear made of PLA

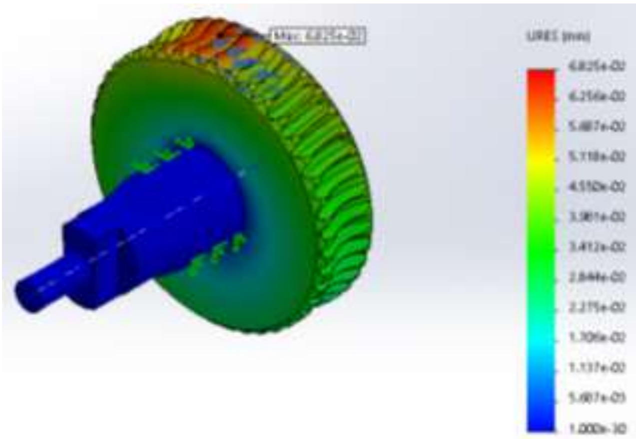

Fig.10. Deformation state for worm gear made of Arboblend V2 Nature

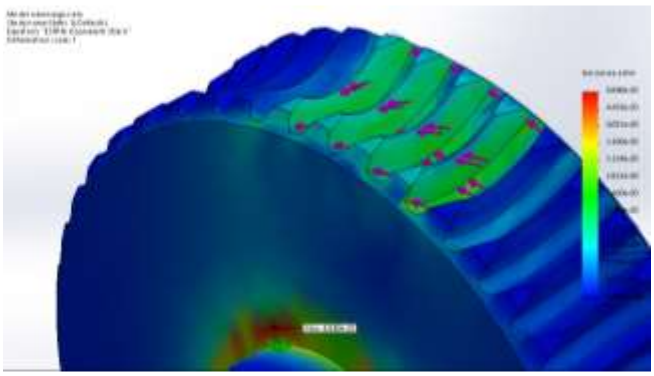
Fig. 11. Strain distribution for ABS worm gear

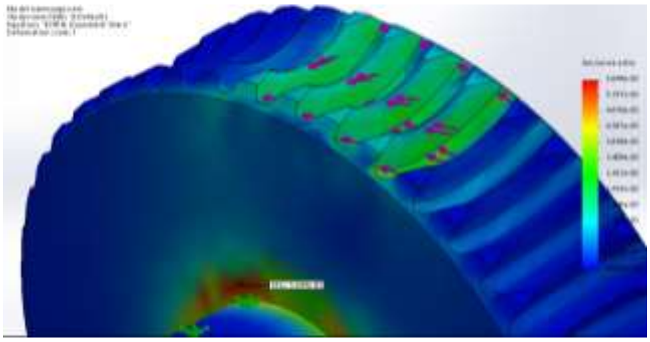
Fig. 12. Strain distribution for PLA worm gear

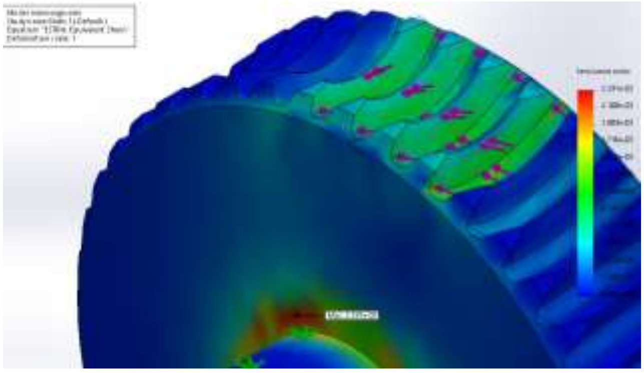
Fig. 13. Strain distribution for Arboblend V2 Nature worm gear

Another area where large strains are observed is located at the base of the four teeth subjected to loading. Thus, for ABS, strain in this area was maximum $3.125 \times 10^{-3}$, for PLA, strain was $3.49 \times 10^{-3}$, while for Arboblend V2 Nature - $1.52 \times 10^{-3}$.

## 4. CONCLUSIONS

The experimental installation will follow the operation behavior of the worm-worm gear assambly made of Arboblend Nature V2 in different conditions: variations in loads and temperature, that will simulate the real operating conditions of the windscreen wiper. The equipment will also follow changes in energy consumption caused by changes in operating conditions.

The simulations of stress states of worm gears for the materials considered in the research (Arboblend V2 Nature, PLA and ABS) revealed small difference between the values obtained (some decimals), with an average value of 12.58 MPa. The locating of the maximum stress value is in the area of the stress concentrator situated at the junction between the spindles with the worm gear front surface. In what concern the maximum stress in the toothed area, this one is located at the base of the tooth and has similar values (about 9.3MPa) for all three studied materials.

The maximum deformation value (located at the level of the worm gear teeth tip) and that of the maximum strain (located at the junction of the spindle with the wheel front surface) is significantly lower compared to the other two materials PLA and respectively ABS. On the presented stand in this paper, experiments will be carried out in the future by which will be noticed whether the deformations produced during the operation of the worm gear influence in a large extent the functional parameters and the over time reliability.

Following the research and the obtained results on the engine wiper assembly consisting of the worm-worm gear realised from biodegradable polymer Arboblend V2 Nature, it can be concluded that, can replace successfully the plastic materials from the point of view of both mechanical performance and positive impact on the environment.

## 5. ACKNOWLEDGEMENTS

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISDI, project number PN-III-P1.2-PCCDI-0446/82PCCDI/2018, acronym TFI PMAIAA/ FAMCRIA, within PNCDI III.

## 6. REFERENCES

1. Ben Redwood, B., Schöffer, F., Garret, B., (2017). The 3D Printing Handbook Technologies, design and applications, Hardcover, November 14.

2. Pilla, S., (2011). *Engineering Applications of Bioplastics and Biocomposites- An overview*, Handbook of Bioplastics and Biocomposites Engineering Applications, pp. 1-14, John Wiley & Sons (New Jersey).

3. Plavanescu (Mazurchevici), S. (2014), *Biodegradable composite materials – Arboform: A Review* Int. J. of Mod. Manuf. Technol., VI(2), 63-84.

4. Nedelcu, D., (2013), *Investigation on microstructure and mechanical properties of samples obtained by injection from Arbofill*, Composites Part B: Engineering 47, 126-129

5. PM Simona, C Constantin, C Radu, N Dumitru, *The influence of technological parameters on the dynamic behavior of "liquid wood"samples obtained by injection molding*, AIP Conference Proceedings 1896

6. Nedelcu, D., Plavanescu, S., Carausu, C., (2016). *The Influence of Technological Parameters on Tensile Strength of Liquid Wood Specimens Obtained by Injection Molding*, Proceedings of the ICMTE2016 International Conference, October 5-7, Seoul, Korea, 18-18.

7. Available from: http://my3dmatter.com/, Accessed: 05/08/2018.

8. Available from: https://all3dp.com/1/3d-printer-filament-types-3d-printing-3d-filament/, Accessed: 03.08.2018.

9. Stanciu, M., D., Terciu, O., M., Curtu I., (2014) - *Compozite lignocelulozice. Aplicatii in industria automobilelor* (*Lignocellulosic composites. Applications in the automotive industry*), Transylvania University Publishing House, (Brasov).

10. Available from: http://www.w-hanisch.de/geoklima/, Accessed: 05/08/2018.

11. Available from: http://www.eplas.com.au/assets/125/files/msvc.pdf, Accessed: 08/09/2018.

12. Nedelcu, D., Comaneci, R., (2014). *Microstructure, mechanical properties and technology of samples obtained by injection from Arboblend*, Ind. J. of Eng. & Mater. Scis., 21, 272-276.

13. Broitman, E., Nedelcu, D., Mazurchevici, S., Glenat, H., Grillo, S., (2018), *Tribological and Nanomechanical Behaviour of Liquid Wood*, ASME, J. of Tribol., 141(2), Paper No: TRIB-18-1012.

14. Available from: https://www.tecnaro.de/en/home.html, Accessed: 05/08/2018.

15. Available from: www.profit.ro, Accessed: 05/08/2018.

Received: June 10, 2018 / Accepted: December 15, 2018 / Paper available online: December 20, 2018 