HYDRODYNAMIC ENERGIE SYSTEMS USING CELLULAR BIOMIMETIC STRUCTURES

CUȚAC[1] Laura[1] Mihaela[1], NEAGU[2] Mădălin[2] Florentin[2], DELLE CURTI[3] Vincenzo[3], PhD. Andrei[4] Cristian[4] MANDOC[4], univ. prof. Constantin[5] Gheorghe[5] OPRAN[5]

[1]Faculty: FIIR, Specialization: IEMA, Year of study: I, e-mail: cutaclaura@yahoo.com

SUMMARY: Hydrodynamic energy systems produce renewable electricity by harnessing the kinetic energy of a body of water, energy resulting from their movement. Among the objectives of this scientific research are the realization of a preliminary model of a hydroelectric turbine as well as the realization and testing of cellular biomimetic structures that will be used, after optimization, in the manufacture of the turbine blade, increasing efficiency and reducing its weight.

KEY WORDS: turbine, cellular structures, biomimetic, composite, additive manufacturing

1. Introduction

The planet is becoming more and more polluted and new sources of energy made from less pollution methods are being sought. To minimize pollution, the most sought methods are in nature, using water, wind and sun. Analyzing the three main categories, two of them are limited: the sun can be used when it is in the sky and the wind can be used at a certain speed, there is the possibility that it may be non-existent for a certain period. On the other hand, the water (flowing) has no limitations, in the best case, it can increase its flow in certain periods where the precipitations have made this place leading to a much better efficiency.

The hydrographic area is very extensive and deserves to be exploited in this way, the research direction of this work is the development of a small hydroelectric turbine that could be located in the riverbed and springs. In order to develop something special compared to what is on the market, the research focuses on optimizing the structure of the turbine blade, namely to avoid its full filling with the help of sandwich cellular structures inspired by biomimetics.

2. Preliminary hydroelectric turbine

Renewable energy is one of the most important challenge that our planet must win, for this reason the engineers around the world are studying new technologies to overcome the energy production through the carbon.

In our project we have developed a lightweight power generation solution to deliver reliable, predictable and low-cost energy. This kind of technology is represented by a hydroelectric turbine made up by polymeric and composite material for direct use in rivers, irrigation canals or tail races channeling water from existing dams. It has made up by some other subcomponents, as shown in the Figure 1.

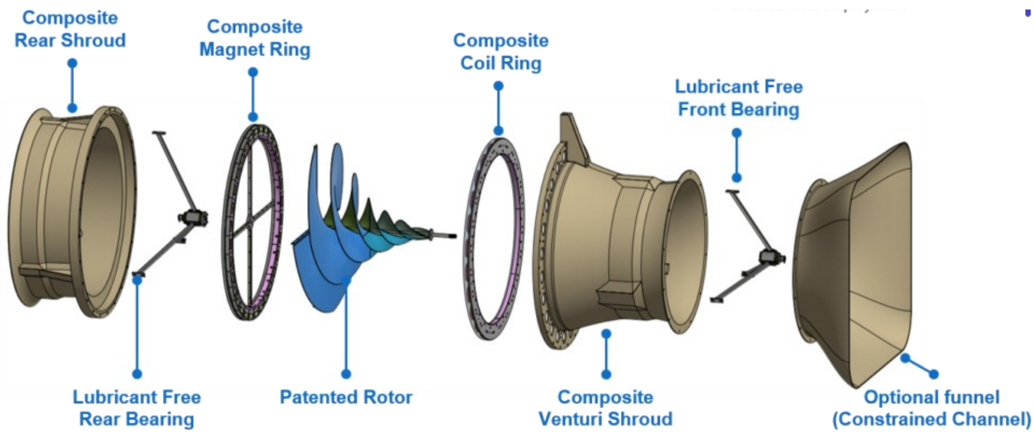


Fig. 1. Hydroelectric turbine components [22]

The first one of them is the composite rear shroud, used to cover the rear part of turbine and it is connected to the turbine through the lubricant free rear bearing and the composite magnet ring.

The front part has made up by the composite Venturi shroud connected to the rear shroud through the composite coil ring. This component is very important, because this kind of turbine works with the axial water flow and the Venturi shroud is useful to increase the speed of the water, accelerating its flow in the throat section.

The next one component is the lubricant free front bearing, its function is to constrain the Venturi shroud with the funnel channel. In this section the water flow enters inside the turbine from the external environment.

The most important component is, of course, the turbine and in the Figure 2 and 3 is shown the design realized on CATIA software. This design is not the final one but could be useful to realize a small prototype of it. As we see in the figure the hydroelectric turbine blade got a very complex spiral-shaped. Spiral blades have been developed and used by others before, but not to this level. Most hydroelectric turbines include propeller or fan shaped blades arranged radially around the center axis and activate a rotor other electricity generating mechanism within the turbine when rotated by water that is channeled downward into the turbine. These turbines work best in high-head water systems, where the water drops over a longer distance, picking-up speed and water pressure to enable higher energy output. The spiral-shaped blade, also called a "full capture", combined with the nacelle increases water pressure available for capture, extracting more energy than previously thought possible.

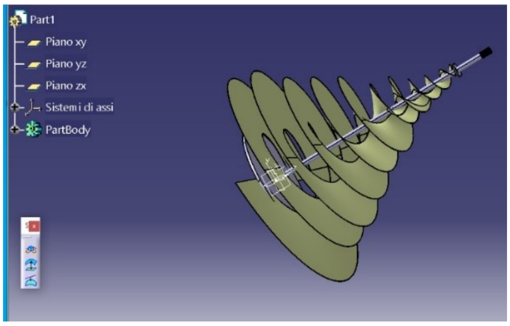


Fig. 2. Hydroelectric turbine blade

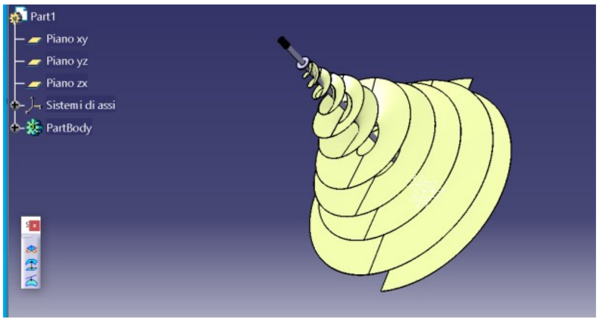


Fig. 3. Hydroelectric turbine blade

The advantages of this kind of technology are various, but the most relevant are:

- Simple modular Design
- No gearbox or lubricants to maintain
- Minimal part count for easy transportation
- Ease of assembly in remote locations
- Creates local employment

In the Figure 4 is shown the full assembled turbine with their dimensions and components.

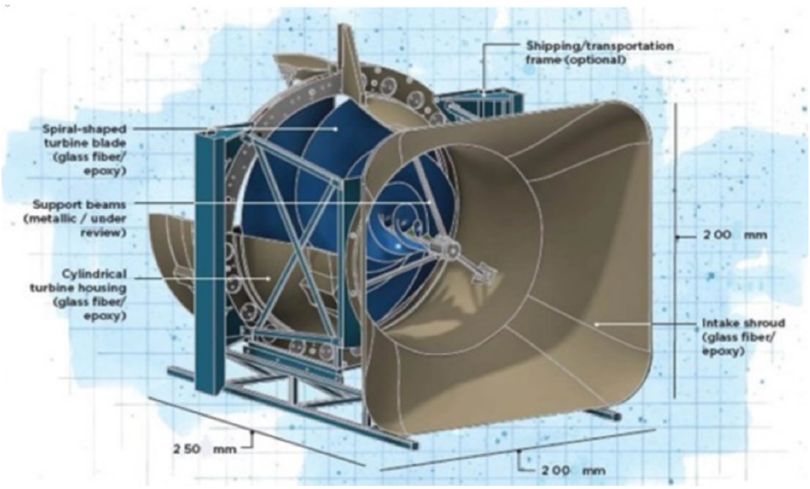


Fig. 4. Hydroelectric turbine assambly [21]

3. Manufacturing and testing equipment

Liquid Crystal MAGNA is a 3D printer that uses DLP technology (Digital Light Processing). This type of printer uses ultraviolet light to polymerize the resin in the tank. The polymerization is done on the printing bed which rises layer by layer, the mark being formed upside down on it. At the bottom of the tank is a transparent screen that reflects the layers of the part to be polymerized. UV light is transmitted by a laser in a matrix of micro-mirrors, micro-mirrors that transpose through a lens the image found on the bottom of the tank (transparent screen). After printing, the finished part must be cleaned of excess resin [6] [7].

Daylight high tensile MAGNA resins fall into three categories: rigid (High tensile white, Draft, Hard, Concept, Dental pattern White, etc.), durable (Durable, Duramax, Durable DL110H) and resins developed by BASF (Badische Anilin-und Soda-Fabrik) [8].

Fig. 5. 3D Liquid Crystal MAGNA printer [6]

Fig. 6. 3D MARKFORGED X7 printer [10]

The MARKFORGED X7 printer works on the principle of 3D printing FDM (Fusion Deposition Modeling), the construction of the part is done by depositing layer by layer of the extruded material. The thermoplastic filament roll is loaded into the printer, and once the extrusion nozzle reaches the set temperature, the filament melts and construction begin on the first layer of the mark on the machine table through the printer's extrusion head. The extrusion head is attached to a three-axis system that moves in the x, y and z directions, allowing movement to make the next layers [9] [10].

The plastics used by this printer are: Onyx, Onyx FR, Onyx ESD and Nylon White, all of which can be reinforced with fiberglass, carbon fiber and kevlar fiber [11]

INSTRON DX is a device with a high capacity for testing tension, compression and flexion. It has two more secure and efficient flexion and compression testing pieces. It features a multi-function productivity panel with an ergonomic display that allows the operator to perform regular tests and view various information.

Typical applications of this machine are: metals (bars, plates, pipes and tubes, reinforcing and structural bars), fasteners, wire and various composites. This test equipment can be used in accordance with international standards, such as: ASTM A370, ISO 6892-1, BS 4449, etc. [20].

4. Used materials

The resin called "Daylight High Tensile" will be used to make the test pieces on the Liquid Crystal MAGNA printer. It can be noted that it has an exceptional tensile strength and elongation comparable to acrylics. Printed parts cannot be easily deformed or compressed, while having high precision and minimal shrinkage. It is one of the most widely used materials in engineering, prototyping, tools and dies [12]. The properties of Daylight High Tensile material can be seen in Table 1.

Onyx is an ideal one-piece material that is based on a very hard nylon that offers parts with a stiffness equal to or greater than any pure thermoplastic material available for professional 3D printers. This material can be used in its pure state or can be further strengthened with different types of fiber: continuous carbon, kevlar or fiberglass [13] [14]. The properties of the Onyx material can be seen in Table 1.

Onyx has a degree of thermal deformation at 145 ° C while Daylight High Tensile has a degree of deformation at only 95 ° C.

Table 1. Material properties [12], [14]

Properties	Daylight High Tensile	Onyx
Density [g/cm^3]	1,16	1,2
Viscosity [cPs]	980	-
Flexural strength [MPa]	95	81
Tensile modulus [MPa]	3060	1400
Flexural modulus [MPa]	2200	2900
Ultimate tensile strength [MPa]	81	36
Impact strength notched izod [J/m]	22,7	330

5. Making test pieces

Taking into account the current standards (ASTM C393, ASTM D638) applied to sandwich structures, test pieces containing cellular structures were tested for stress testing: flexure, traction and DMA. These test pieces were designed using CATIA and SolidWorks design applications and their structure was inspired by nature. When a certain landmark is inspired by nature, we can talk about the concept of "Biomimetics". Biomimetics is the application of existing biological methods and systems in nature to the design of engineering systems and modern technologies and is the way to solve technical problems through models, systems, or elements in nature [15].

For the mechanical dynamic analysis (DMA) pieces, its dimensions can be seen in Figure 7, respectively 66.8 mm long, 8.8 mm wide and 3 mm high and the thickness of the coating layers (the one that forms the sandwich) is 0.4 mm. The flexure test pieces has a length of 150 mm, a width of 20 mm and a height of 15 mm with a thickness of the coating layers identical to the DMA test pieces (Figure 8).

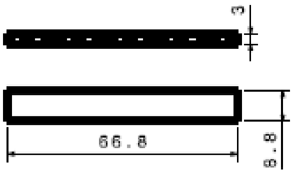


Fig. 7. DMA test piece

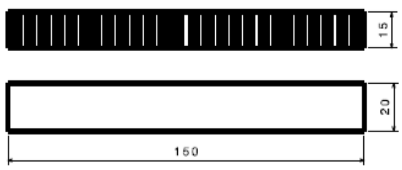


Fig. 8. Flexure test piece

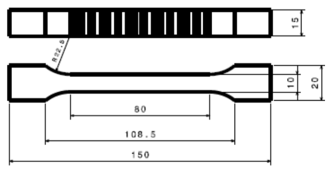
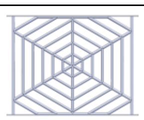
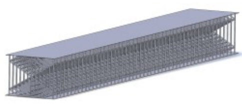
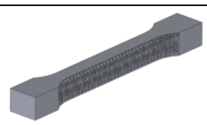
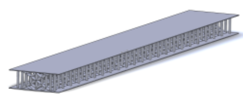
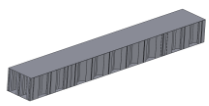
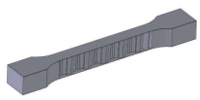
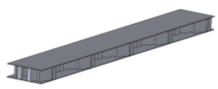
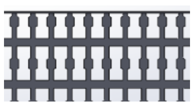
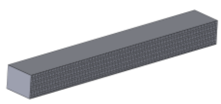
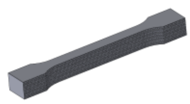
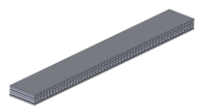


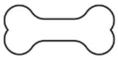
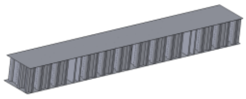
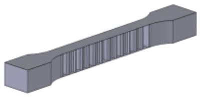
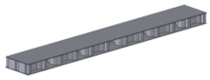
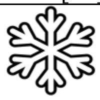
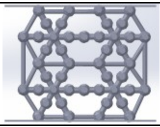
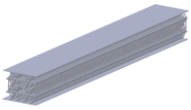
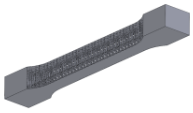
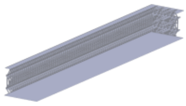
Fig. 9. Traction test piece

For traction, the test piece has the following dimensions: length 150 mm, width 20 mm and height 15 mm, with the observation that it is smaller in the center, having a width of 10 mm, the transition from 10 to 20 mm is done with the help of a radius of 22.5 mm (see figure 9). Like the other two test pieces, it has a thickness of 0.4 mm sandwich layers.

For this research, 30 test pieces were printed, 15 of them on the MAGNA printer using Daylight High Tensile material and the other 15 on the MARKFORGED printer. Classifying them according to the type of test, 10 test pieces were made for flexure, 10 for traction and 10 for mechanical dynamic analysis (5 of them were made of Onyx material and 5 of Daylight High Tensile). Each of these test pieces was designed based on a biomimetic model, namely: spiderweb, water drop, bone and snowflake. All designed test pieces can be seen in Table 2 where their enlarged structure is also found.

Table 2. Test pieces

Biomimetic models	Structures	Flexure	Traction	DMA
 Spiderweb [18]				
 Drop [16]				
 Bone [17]				

 Bone [17]				
 Snowflake [19]				

Figures 10 and 11 show the test pieces on the table of the 3D printer machine.

Fig. 10. Test pieces on the table of MARKFORCED machine

Fig. 11. Test pieces on the table of MAGNA machine

Due to design errors and improper placement of test pieces on the machine table at the time of the g code for printers, not all test pieces were printed. Properly manufactured test pieces were coded for easy tracking during testing (Table 3).

Table 3. Test pieces codification

Cod	Test	Material	Name
L	Traction	Onyx	Drop
LRI	Flexure	Daylight High Tensile	Drop
O	Traction	Onyx	Horizontally bone
OI	Flexure	Onyx	Vertical bone
RFI	Flexure	Daylight High Tensile	Snowflake
RL	Traction	Daylight High Tensile	Drop
RO	Traction	Daylight High Tensile	Horizontally bone
ROI	Flexure	Daylight High Tensile	Horizontally bone
VRO	Traction	Daylight High Tensile	Vertical bone
VROI	Flexure	Daylight High Tensile	Vertical bone
RDO	DMA	Daylight High Tensile	Horizontally bone
VRDO	DMA	Daylight High Tensile	Vertical bone
DL	DMA	Onyx	Drop
DO	DMA	Onyx	Horizontally bone
RDL	DMA	Daylight High Tensile	Drop

6. Testing of test pieces

The testing of the test pieces was performed on the INSTRON DX equipment, in figure 12 flexure testing can be observed.

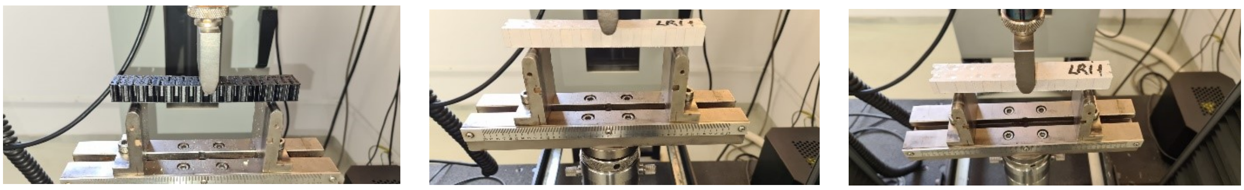


Fig. 12. Flexure testing

Following the samples taken and the results obtained, comparison graphs were made between various parameters of the test pieces but also of the materials from which they were designed. In figure 13 the variation of the deformation of the test pieces depending on the tensile stress is represented and in figure 14 the variation of the deformation depending on the flexure stress.

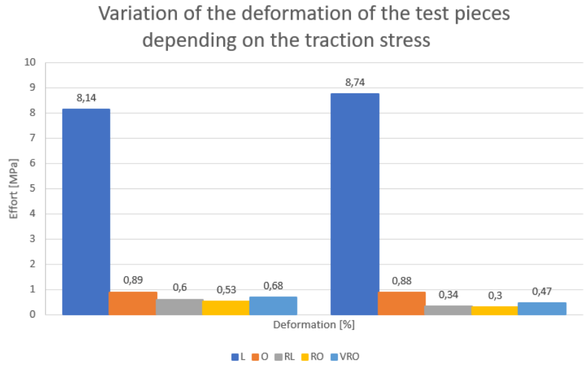


Fig. 13. Variation of the deformation of the test pieces depending on the traction stress

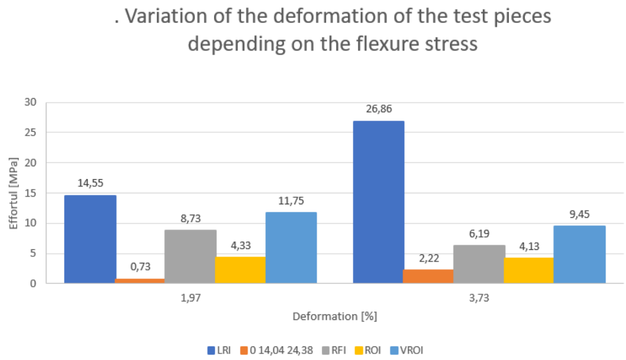


Fig. 14. Variation of the deformation of the test pieces depending on the flexure stress

In figure 15 the comparison of the traction test pieces according to the deformation, the modulus of elasticity and the force is represented. The same comparison is made in the case of flexure according to Figure 16.

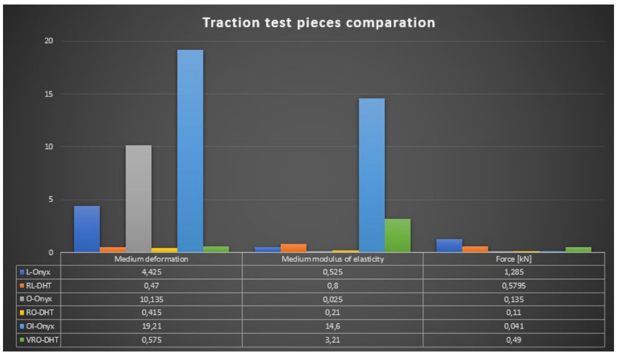


Fig. 15. Traction test pieces comparation

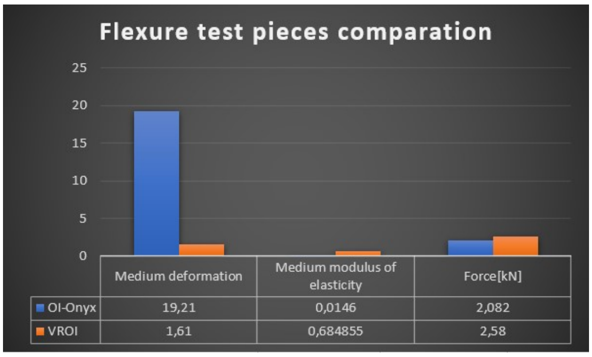


Fig. 16. Flexure test pieces comparation

Figures 17 and 18 represent the overall behavior during testing of tensile and flexure test pieces, with deformation on the x-axis and force on the y-axis.

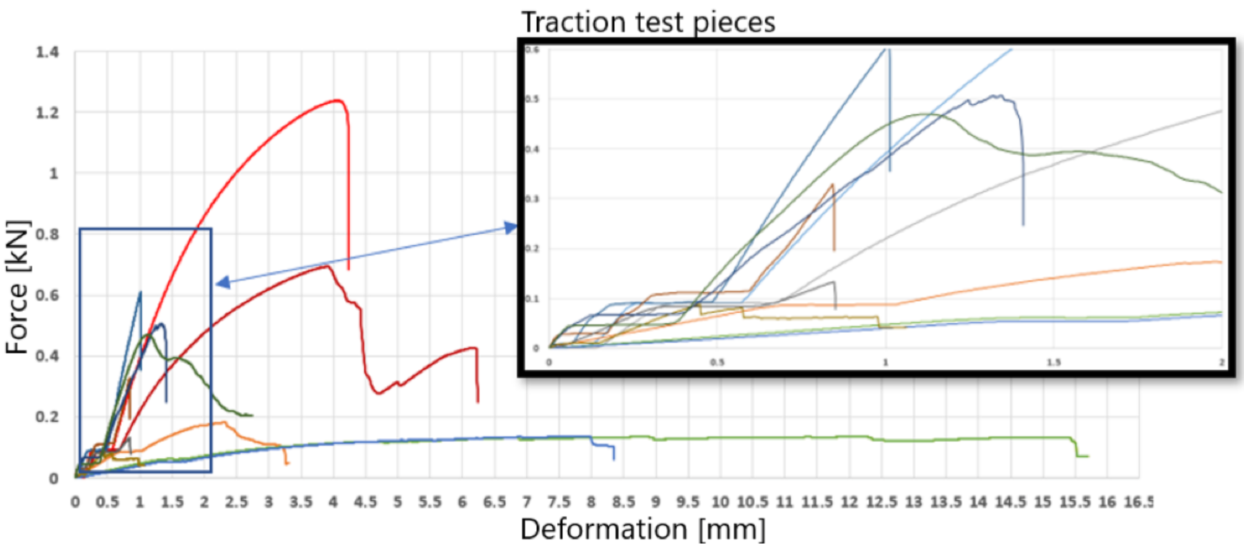


Fig. 17. Global traction behavior

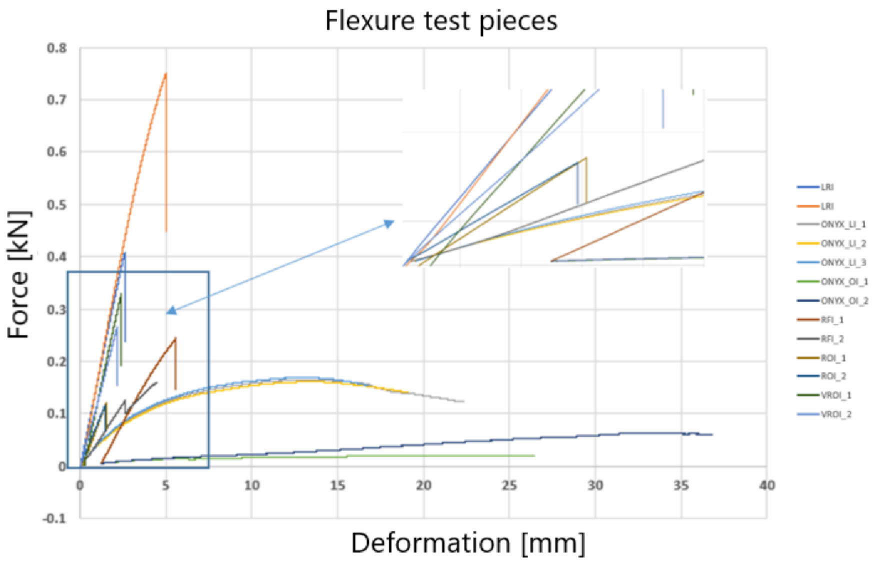


Fig. 18. Global flexure behavior

7. Conclusions

Numerous manufacturing problems have been identified in the early stages of cell development in this research paper. For some concepts it was possible to change the geometry by thickening the plates that supported the sandwich structures to improve the quality of the additive manufacturing process. However, there are still issues that require close attention in order to obtain the optimal structures in terms of current additive manufacturing capabilities.

A similar behavior is observed from the tests tested on traction in the case of all concepts in the first stages of testing. These can be seen in Figure 17 being represented by the thresholds that show the propagation of defects, gradual, which appears in the cellular structures until the moment of breaking the test pieces.

The best results were obtained in the case of structures called "drop". The L1 and L4 test pieces were subjected to modifications in the area of the connection between the cell chains and the tank clamps which were shown to increase the strength of the test pieces twice compared to the L2 and L3 test pieces.

In the case of the flexure test pieces, 2 distinct behaviors were observed, namely a linear behavior until breaking, at which point it occurs suddenly when the maximum force is reached and another type of behavior, ductile which does not show a breaking point of the test pieces. and continues to deform with a decrease in applied force. These two behaviors are given strictly by the material used due to the elastic capacity of the onyx to deform without breaking, thus in the case of resin additive test pieces, the LR concept showing the best resistance to flexure while in the case of test pieces made of onyx additive LI showing the best flexure strength. It can be concluded that the concept that integrates drop geometries has a high resistance compared to other concepts, both flexure and traction.

However, the use of other concepts in the future will not be ruled out, as the aim of the paper was to take the first steps in identifying the behavior for different sandwich structures that can be integrated later in reinforced polymer composite structures, serving several applications where wants both the reduction of the final mass of the component and its final resistance to different types of loads.

What was observed in the previous mechanical tests is also supported by the results obtained from the mechanical-dynamic tests that followed the isolated behavior of the cells investigated in this paper by deforming the samples up to 5 mm. Thus, it could be concluded that in the case of geometric structures with "bones" their modified version could pass the test without breaking.

8. Development directions

The cells can be used as sandwich structures as part of parts made of reinforced polymeric composite materials such as turbine blades or other components of their structure such as those shown in Figure 1. Thus, by determining the cellular structures of interest, the following research will aim at the “customized” production of sandwich structures such as those found on the market, honeycomb structures such as aluminum and nomex, by using the additive manufacturing technology offered by MARKFORGED, which allows to obtain these structures by depositing continuous reinforcement with wire: carbon, kevlar, fiberglass.

The aim is to develop a code in a programming language that copies the cellular structures from images obtained under microscopy for the geometric optimization of future cells used in sandwich structures.

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