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A NUMERICAL AND EXPERIMENTAL STUDY OF THE ENERGY ABSORPTION CAPACITY OF AUXETIC STRUCTURES MANUFACTURED WITH ADDITIVE TECHNOLOGY

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ABSTRACT

The paper investigates the purposefulness of using 3D printed auxetic structures for energy absorbers. The influence of two different geometrical parameters of the structure was tested: cell size and cell convergence angle that corresponds to structures Poisson's ratio. All variants have been tested numerically, and then manufactured using the SLA method and tested experimentally.

Keywords: auxetics, dynamics, energy absorption, vision system, additive technologies.

INTRODUCTION

Auxetics are structures shaped in such a way that their structural Poisson ratio takes negative values. Therefore, they are characterized by many interesting features, among which the high ability to absorb mechanical energy can be mentioned [Kolken H., 2017]. Due to the extremely low specific mass of structures of this type, attempts to use them in flying vehicles seem to be natural while use of rapid prototyping methods, such as stereolithography, they can also be used in modeling (UAVs) [Alderson A., 2015], where vibrations and impacts are particularly common during emergency landing. It should be noted that due to the high degree of complexity of geometry, printed structures of this type are often subject of research, however, no studies similar to those has been found.

The study was performed on samples of honeycomb re-entrant structures with dimensions of approximately 40x20x15 mm (the exact dimension is individual for each sample) total number of cells must fit to different size for each sample made of photoelastic resin, which properties are indicated below (Table 1).

Table 1 - Uniaxial tension test results [Szykiedans K, 2016], [own research, not published yet]

Young's Modulus [MPa]	Poisson's ratio	Density [kg/m^3]	Yield stress [MPa]	Damping ratio
2460	0,41	1200	25	0,42

Samples with different geometrical parameters has been used: a cell size *a* equals 3, 5 and 7 mm, and an angle of convergence α from 40 to 90° (Figure 1). During the test, a steel indenter of mass m = 163 g (Figure 2) has been brought to collision with the structure sample at the relative velocity v = 4 m/s. The energy absorption capacity of the structure was determined based on a comparison of the mechanical energy of the system before and after the impact.

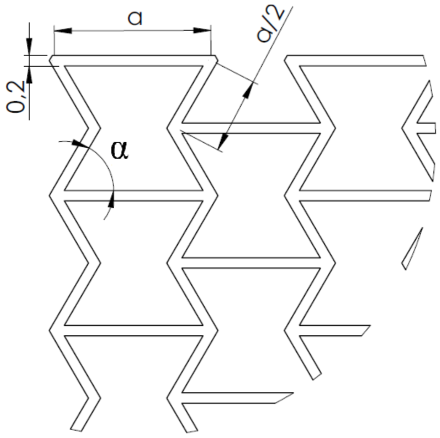

Fig. 1 - Structure dimensions

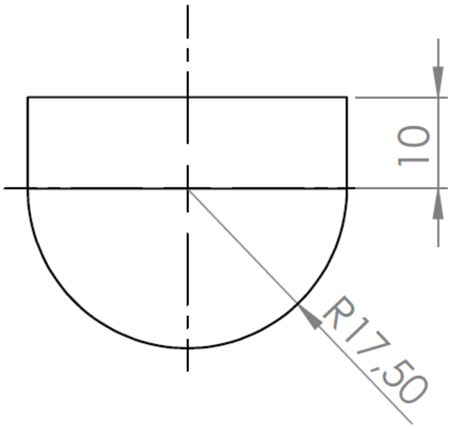

Fig. 2 - Indenter dimensions

STUDIES DISCRIPTION

The influence of each parameter on energy absorption was simulated in the Ansys using the LS-DYNA solver. A parametric 3D model was imported to the environment representing the quarter of the tested system: structure and indenter (Figure 3). The model allowed for a flexible change of the tested parameters in the above-mentioned scope. To so defined geometry a material properties has been assigned - to the indenter the default properties of steel, while for the sample - according to Table 1 - new material was defined. The reduction of the tested system to quadrant was dictated by the limitation of computational resources. This caused the necessity of defining the appropriate boundary conditions, ensuring the correct behavior of the system: zero displacements on the cutting planes in the normal direction. The remaining degrees of freedom of the structure has been taken by blocking vertical displacements of the lower plane of the structure and fixing one of its points lying in the plane of the intersection identical with the symmetry plane of the structure. In addition, frictionless contact between the indenter and the structure was made.

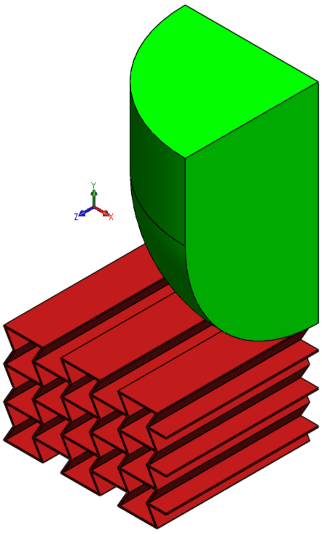

Fig. 3 - Tested system

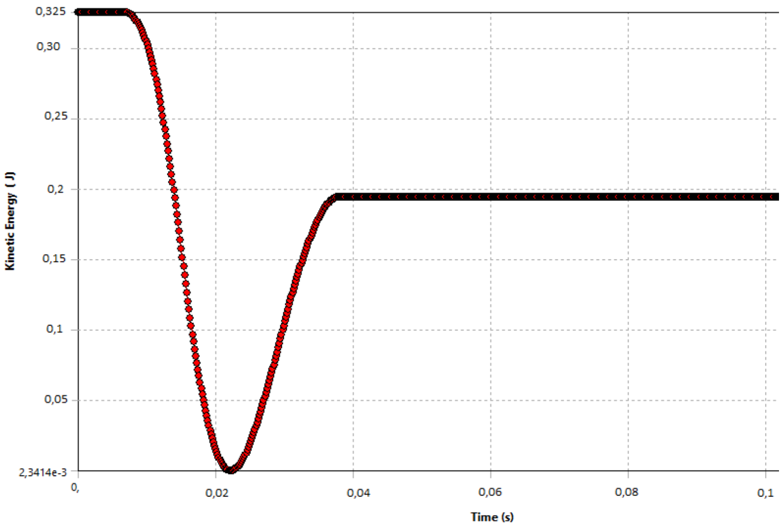

Fig. 4 - Indenter’s kinetic energy versus time graph for a=0.3mm, α=60˚

The excitation of the system was obtained by the initial condition in the form of the initial velocity of the indenter in the vertical direction v = -4 m/s. The model was divided into finite elements with a minimum element size of 0.05 mm using the Hex Dominant method. The calculations were carried out for the event time t = 0.1 s. An exemplary energy diagram of the system is shown in Figure 4. Experimental study was carried out on structures manufactured by stereolithography with the XYZ Nobel Printing machine [product manual]. The thickness of the solidified layers for each sample was equal w = 0.1 mm (Figure 5).

The overview diagram of the test stand is shown in Figure 6. A guide sleeve (6.1) is mounted above the sample (6.2) with a sight window (6.3). The indenter (6.4) placed in the sleeve has two degrees of freedom - movement along the vertical axis and rotation around it, but the influence of the rotational energy on the results can be ignored due to the small radial forces in the system. Under the influence of gravity, the indenter can fall freely and eventually hit the structure at velocity of 4 m/s. Camera (6.5) connected to a computer (6.6) equipped with the Pylon application records the collision and bounce of the indenter.

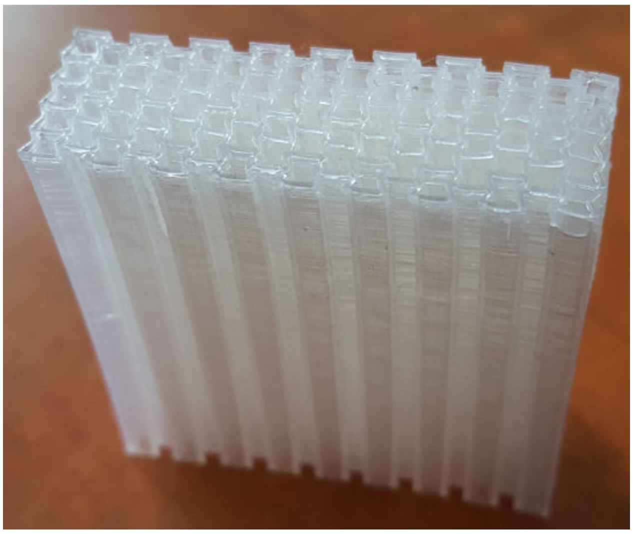

Fig. 5 - Printed structure

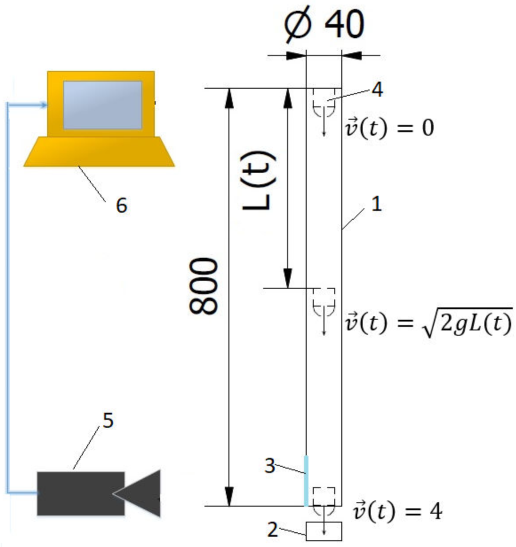

Fig. 6 - Test stand scheme

The recording is converted into a sequence of photos in .jpg format, exportable to LabVIEW Vision Assistant. In this program, the obtained images are processed to make them easier to segment and, as a result, to extract the indentation from the background. The position of the indenter is examined on successive frames, which is the basis for determining the function of indenter speed changes over time. Information about the velocity of the indenter at the moment of impact and immediately after the bounce is sufficient to determine the energy absorbed by the structure.

RESULTS AND CONCLUSIONS

As shown on Figure 7. Poisson's ratio has no direct influence on energy absorption ability of printed re - entrant honeycomb structure. Energy absorption is rather a result of plastic strain, not of energy dissipation. Due to relatively high material stiffness the structure could not perform enough elastic work and so dissipate the energy.

The results of the study of the influence of cell size (Figure 8) confirm the earlier thesis. The smaller cells are more rigid, so kinematic exclusion caused by the hammer causes greater plastic deformation and thus greater energy absorption.

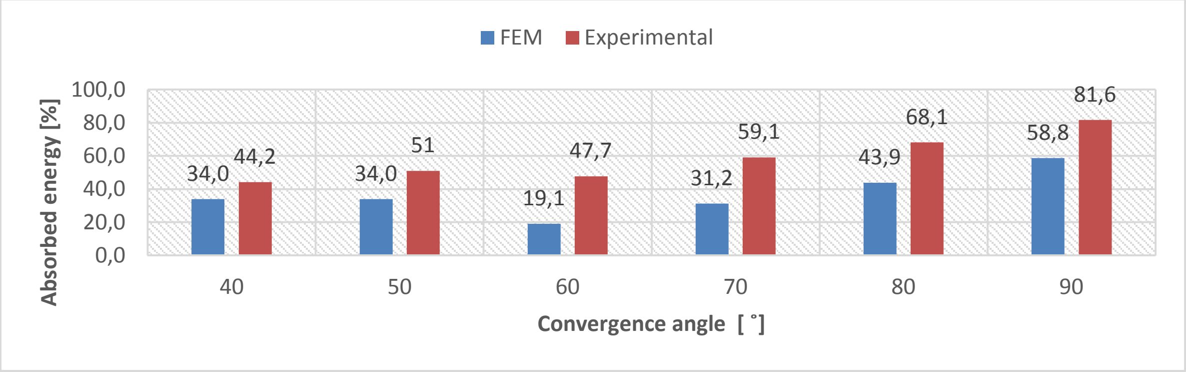

Fig. 7 - Influence of the coverage angle on energy absorption

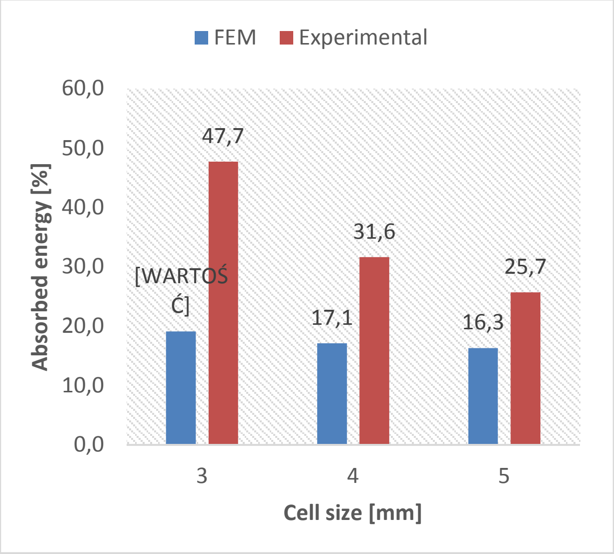

Fig. 8 - Influence of the cell size on energy absorption

The results obtained by both methods have similar characteristics but has significantly different values - results obtained by experimental method are greater by 130% to 250% from the values obtained by FEM. The reasons for this should be found in the fact that - for practical reasons - in the numerical simulation not all phenomena affecting the final result were taken into considered. Among them can be mentioned rotation of the indenter after impact or crumbling of the structure.

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