Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066 – 8570 Volume **6**, Number **2**/**2014**

IMPACT BEHAVIOUR AND RESIDUAL STRENGTH OF HONEYCOMB STRUCTURES

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Rezumat. *Scopul acestui articol este studiul comportării în timpul impactului și după acesta a unei structuri stratificate cu miez de tip fagure. Pentru aceasta a fost creat și apoi aplicat un program de testare. Acesta constă în solicitarea la impact cu energii multiple a stratificatului, urmând ca, după aceea, epruvetele impactate să fie supuse la un test de compresiune pentru a determina capacitatea portantă după impact. Rezultatele obținute sunt centralizate la finalul lucrării într-un grafic care evidenţiază capacitatea portantă a stratificatului în funcție de energia de impact.*

Abstract. *The goal of this article is to study the behavior of sandwich structures with honeycomb core during and after an impact. In this purpose, a test program was created and afterwards was applied. It consists in the application of multiple impact energies over the multi-layered structure. Impacted specimens are subjected to a compression test in order to determine the load capacity after impact. The results are summarized at the end of the paper in a graph that shows the loading capacity of multi-layer structure depending on the impact energy.*

Keywords: multi-layer structure, honeycomb, impact, residual stress and residual strength

1. Introduction

Impact resistance is one of the most important properties for component designers to consider, as well as the most difficult to quantify. Impact resistance is a critical measure of service life and more importantly these days, it involves a complicated problem of product safety and liability.

Impact software and data acquisition system allows the engineer to “see” all types of information that was previously unknown, including incipient damage points and ductile-brittle transition zones. With instrumentation, the load on the specimen is continuously recorded as a function of time and/or specimen deflection prior to fracture. This gives a more complete representation of an impact than a single calculated value because failures originate at the weakest point and propagate from there. Samples don’t have to shatter to be considered failures. Failure can be defined by deformation, crack initiation, or complete fracture, depending on the requirements [1] and [5].

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Honeycomb structures are natural or man-made structures that have the geometry of a honeycomb to allow the minimization of the amount of used material to reach minimal weight and minimal material cost.

A honeycomb composite structure (figure 1) is composed by two glass reinforced polymer (GRP) layers separated by a honeycomb core. GRP is a lightweight, strong material with very many uses, including boats, automobiles, water tanks, roofing, pipes and cladding [8].

The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density.

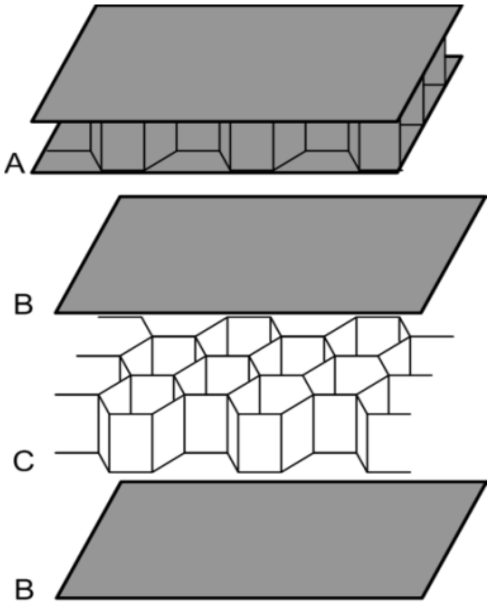


Fig. 1. Representation of an assembled composite sandwich (A), and its constituent face sheets or skins (B) and honeycomb core (C).

Residual stresses occur after the original cause of the stresses (external forces, heat gradient) has been removed. They remain along a cross section of the component, even without the external cause. Residual stresses occur for a variety of reasons, including inelastic deformations and heat treatment. Heat from welding may cause localized expansion, which is taken up during welding by either the molten metal or the placement of parts being welded. When the finished weld cools, some areas cool and contract more than others, leaving residual stresses.

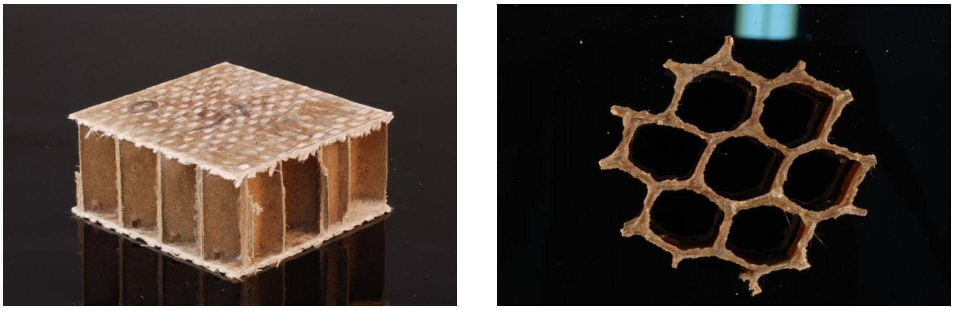
In this area the residual strength can be defined as the load or force (usually mechanical) that a damaged object or material can still carry without failing.

2. Specimen description

Due to the interest of this research, the paper will only cover a small part of the sandwich structures manufactured from glass-reinforced resin and paper honeycomb.

Figure 2 presents a specimen of the sandwich used for impact, with a core thickness of 22 mm and outer shells made from two layered polyester resin–glass fiber fabric. The skins plates are 1 mm thin each, with the overall dimensions of 60 mm × 60 mm.

For each core there were used two shells one made from two layered polyester resin – glass fiber fabric and one made from one layered polyester resin–glass fiber fabric. After the initial tests it was considered that the one layer specimen was not strong enough, so only the two layered specimen were used [2] and [3].



a) **b)**

Fig. 2. a) specimen and **b)** core.

3. Impact and compression tests

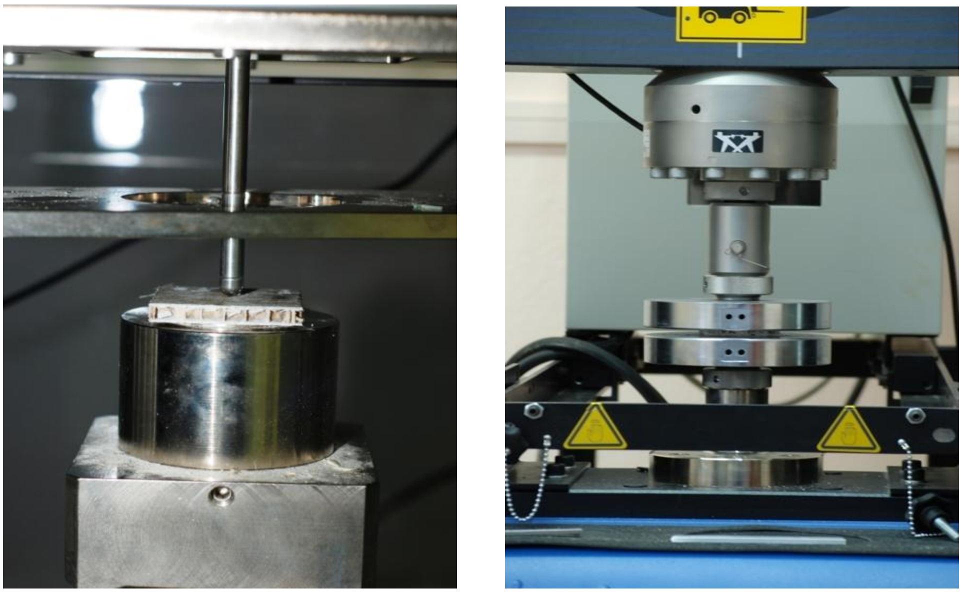
The impact analyses were made on the INSTRON CEAST 9340 tower. The CEAST 9340 is a floor standing system designed to deliver 0.30 - 405 J (0.22 - 299 ft-lb) of energy. The standard model includes basic instrumentation and a conveniently mounted machine controller that enables the operator to run the tower and collect basic data. For more in-depth data, the CEAST impact software and data acquisition system can be added [4], [6] and [7].

The CEAST 9340 is suitable for a range of impact applications including tensile impact, penetration tests on plates and films lms, Izod, and Charpy tests.

An experimental program consisting of impact tests in a set of specimens was performed. The energy of the impact was set to values starting from to 2 Joules up to 10 Joules. The figure 3.a) details the method of impact.

For the needs of the present study the compressive strength (figure 3.b)) was determined by subjecting specimens of the above mentioned structure to compression tests to determine their maximum load capabilities.

After the impact tests the damaged specimens were subjected to static loading in order to determine their new maximum loading capabilities regarding compression.



a) b)

Fig. 3. a) Impact test and **b)** compressive test.

In total there have been made five compression tests prior to the impact for each sandwich specimen and for the impact tests there were selected three energies of impact at 5 J, 7.5 J and 10 J. For each energy of impact there were also made five tests per specimen. After the impact tests all the specimens were subjected to compression tests.

4. Results

Experimental results consist of raw text file data which can be plotted as charts. These charts are created for the average values of the data. Such a result is presented in figure 4, which plots the variation of force versus time in a 5 J impact for a 22 mm core specimen with outer shells made of two layered fabric. As it can be seen from the following chart on the X axis is displayed the time and on the Y axis the force generated during the impact. In the interval 0-1.1 ms there is a linear increase of force from 0 to ~900 N. The same linear variation is presented in the deformation (from 0 to ~2 mm), energy (from 0 to ~1.2 J) and velocity (from 1.5 to ~1.4 m/s) charts. In the next interval from 1.1 to ~1.3 ms there is a small decrease in force form 900 N to 800 N, but there is no deviation from the linearity of the deformation, potential energy of deformation and velocity charts. This small drop in force corresponds to the initial crack in the matrix of the outer shell of the sandwich.

In the interval 1.3-2 ms the force increases from 800 N to almost 1200 N with no variation in the other three charts. The deformation increases to 2.5 mm, the energy to 2 J and the velocity drops to 1.2 m/s.

The next part of the chart is the most important. The following interval (from 2 to 2.5 ms) presents the failure of the honeycomb beneath the impact area. The force drops from ~1200 N to ~500 N. During these 0.5 ms all the slopes remain unchanged, the deformation increases form 2.5 mm to 3 mm, the energy to 2.3 J and the speed drops to 1.1 m/s.

The final interval, form 2.5 to 5 ms presents only small variations in force corresponding to the vibration of the specimen. The increases of deformation and energy are less fast, reaching 5.5 mm and 4 Joules. The velocity drops from 1.1 m/s to 0.8 m/s.

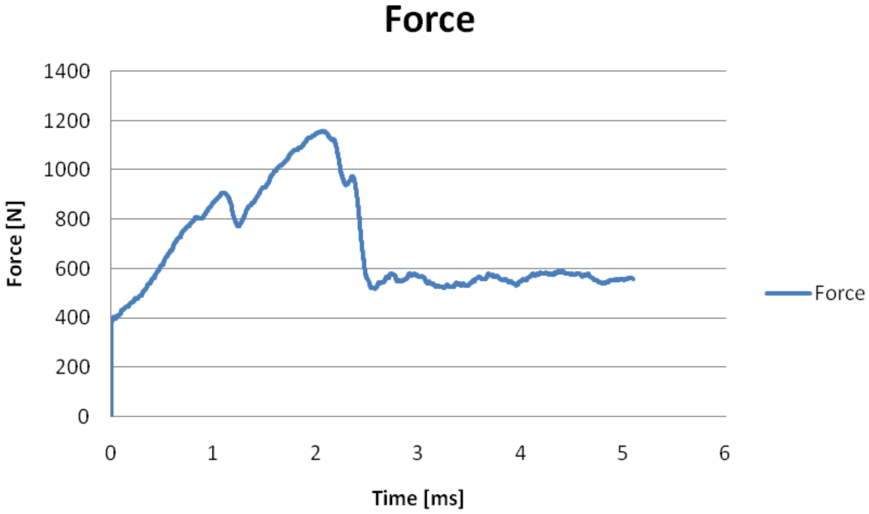


Fig. 4. Force variation over time for a 5 J impact.

Figure 5 presents the force variation over time, for a 7.5 Joules impact. The initial speed of the impact was set to 2.1 m/s.

Compared to the previous charts the behaviour of the specimen regarding force, deformation, energy and velocity is similar in the first two milliseconds. The difference in behaviour appears in the interval 2-2.8 ms where a mild decrease of force from ~1200 N to 1000 N can be seen. This decrease in force can be associated to the penetration of the outer shell of the honeycomb sandwich. During this period of time the deformation and energy reach 3.5 mm and 2.7 Joules. The velocity drops to 1.1 m/s.

After this point in time the destruction of the honeycomb occurs and the force drops to 600-700 N. The behaviour of the specimen after this point is the same as the previous model.

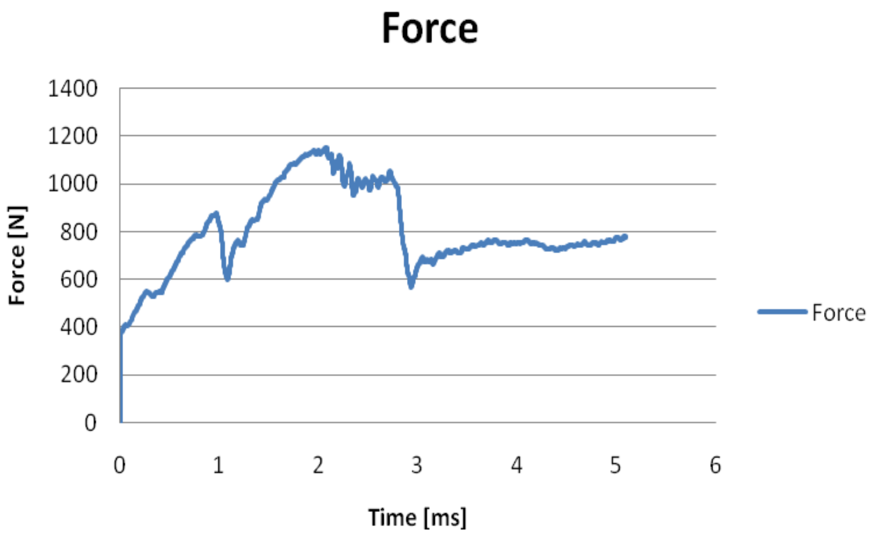


Fig. 5. Force variation over time for a 7.5 J impact.

Figure 6 represents the force variation over time for a 10 Joules impact. It can be seen that the same kind of thresholds appears but with different maximum and minimum values for force (1000 N and 300 N).

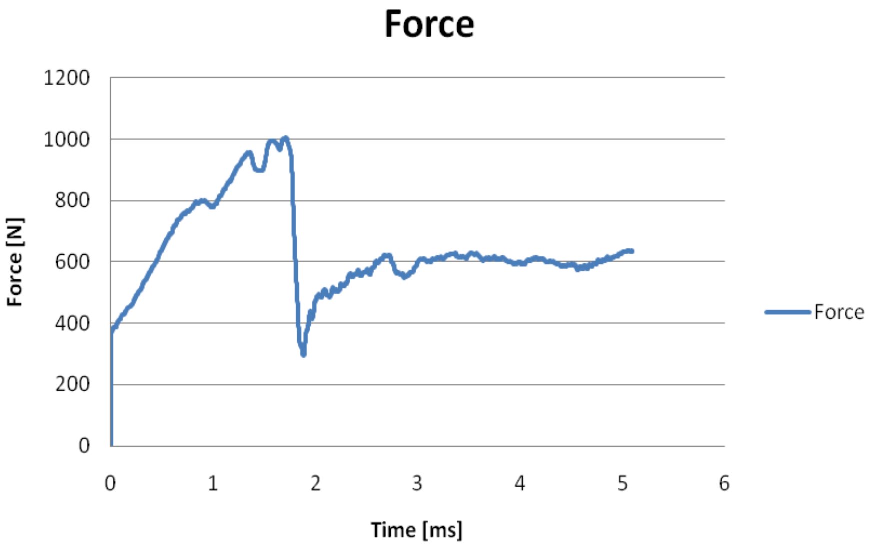


Fig. 6. Force variation over time for a 10 J impact.

Figure 7 presents the Strain-Stress curve prior to the impact of the 22 mm honeycomb specimen.

Figures 8, 9 and 10 show the Strain-Stress curves for impacts at 5 Joules, 7.5 Joules and 10 Joules.

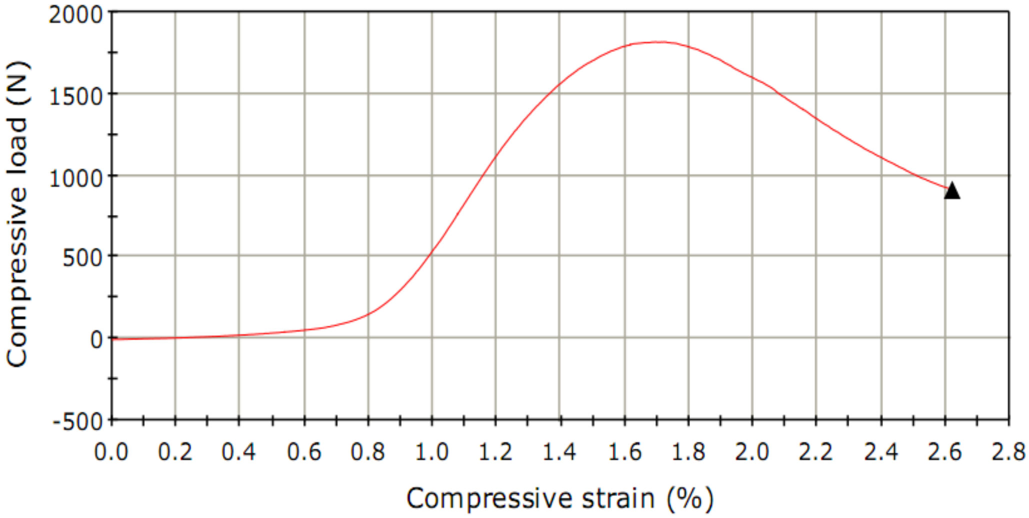


Fig. 7. Strain-Stress curve before impact.

As it is shown in the previous charts the variation of the compressive load over compressive strain has the same shape but with different maximum values.

The initial load capability was situated above 1500 N and after a 5 Joule impact it drops down to 1000 N.

The 7.5 Joule impact creates a very small damage compared to the 5 J impact so the maximum load is decreased only to 800 N.

After the 10 Joule impact, full penetration in the upper shell of the specimen appears and the maximum load capability drops down to 200 N.

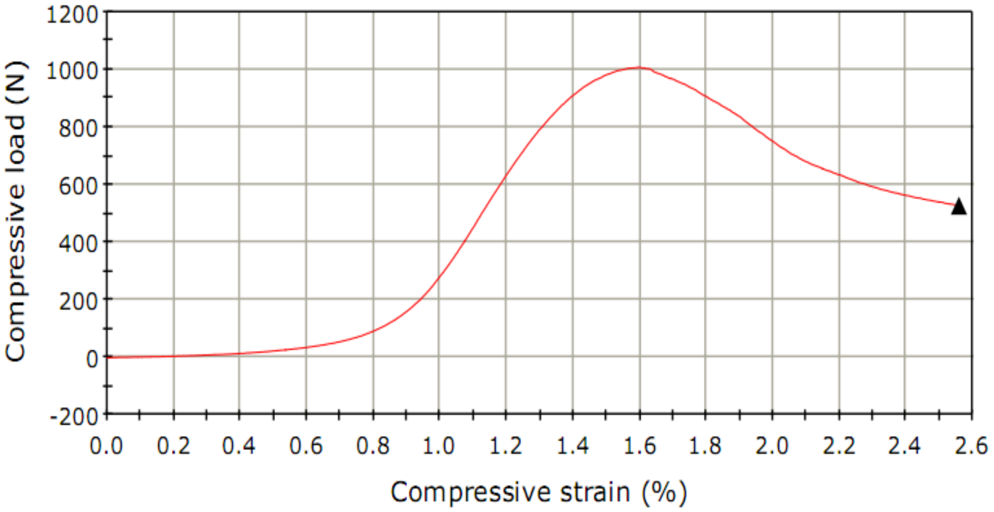


Fig.8. Strain-Stress curve after the impact at 5 Joules.

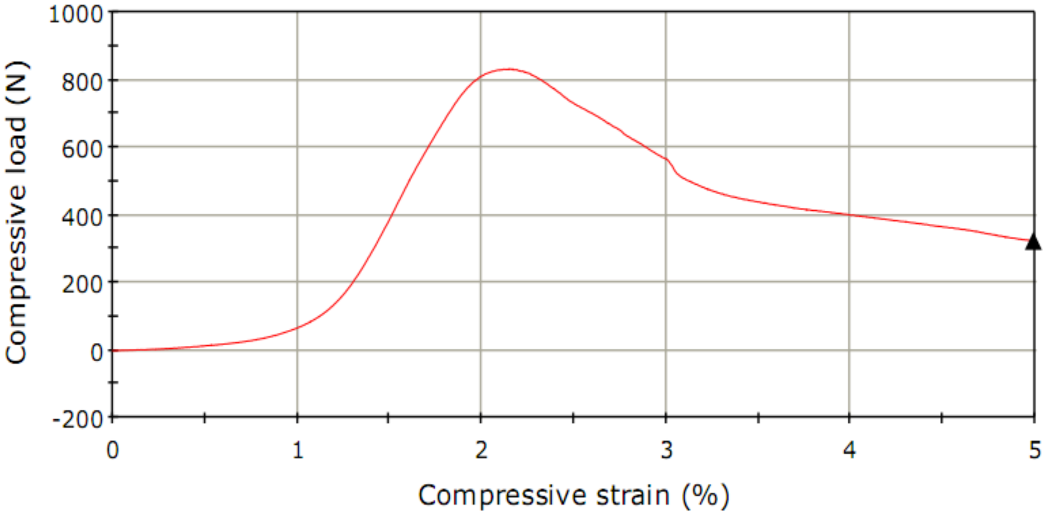


Fig. 9. Strain-Stress curve after the impact at 7.5 Joules.

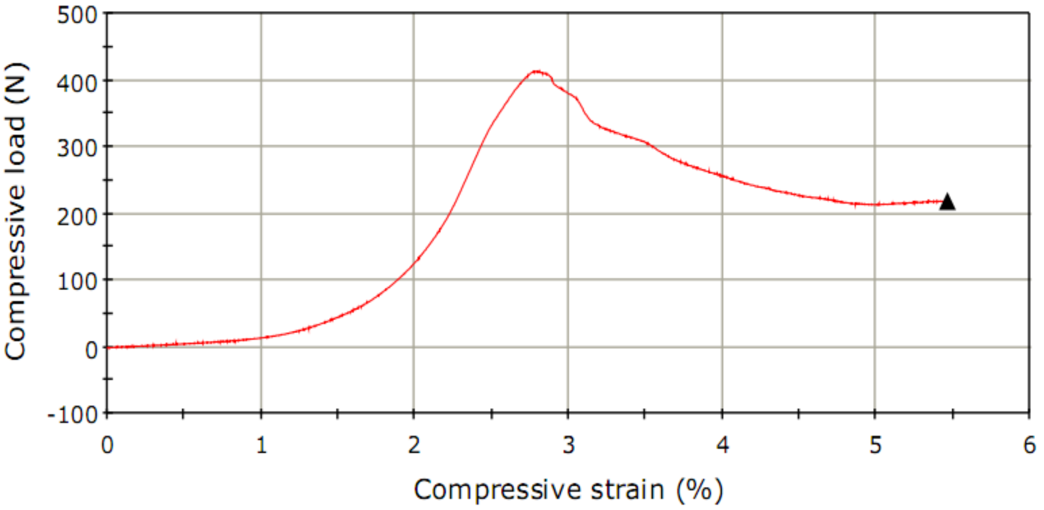


Fig. 10. Strain-Stress curve after the impact at 10 Joules.

5. Data interpretation

All data for the previous examples can be inserted into a chart as compressive strength in function of impact energy as it is seen in figure 11 the specimen has a mild slope with very small variations.

As we approach the 7.5 Joules of impact energy the slope has a small change in angle, but thirds the 10 Joules impact it regains its former shape.

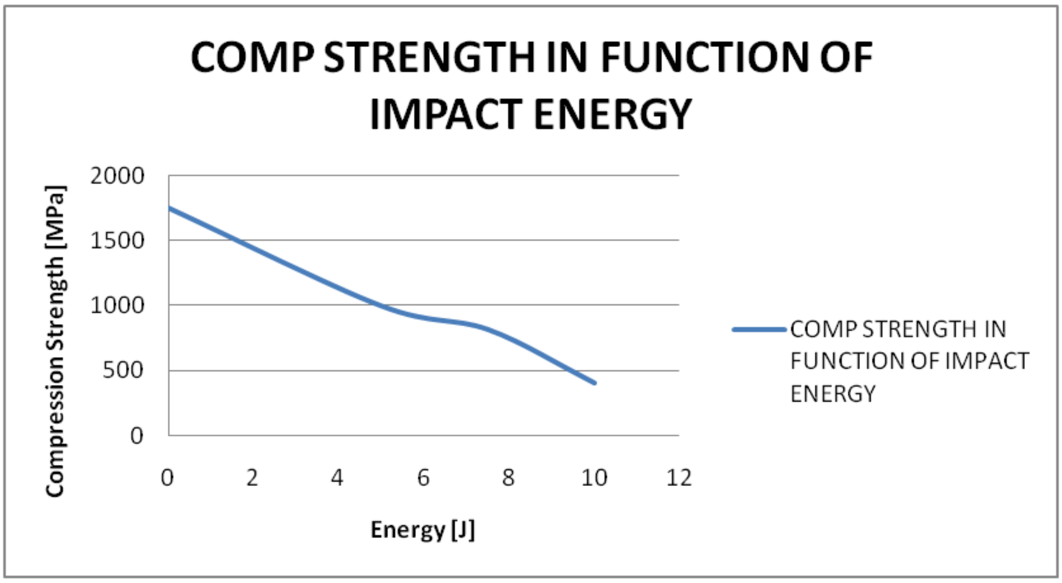


Fig.11. Compressive strength in function of impact energy.

It also notes that the proposed solution successfully meets all the requirements of release conditions, both in terms of the vibrational behaviour and in terms of resistance to gravitational accelerations.

Of course, to fully validate the model space applications are required analyses the thermal behaviour and the behaviour of the radiation. Furthermore, all analyses should be coupled finite element analysis definite experimental validation of the proposed model.

6. Conclusions

The results summarized at the end of the paper in a graph, show the loading capacity of multi-layer structure depending on the impact energy.

A discontinuity in the graphics slope's trend can be observed only for the 7.5 Joules impact energy.

The difference of loading capacity ads up to a value of 1800 N between an unimpacted specimen and a 10 Joules impacted specimen.

Further determinations will be necessary to determine the entire behaviour of such specimens during impact. Independent honeycomb cell destruction and how it affects the entire honeycomb should be investigated using finite element modelling, by this establishing how one bad cell can break the structural chain of the entire specimen.

These results could be used to create new structures with a higher capability to absorb kinetic energy in areas where simple structures are used.

REFERENCES

[1] A. Burr, J.B. Cheatham, Mechanical Analysis and Design, Prentice-Hall, New Jersey, USA, **1995**.

[2] D. Rosu, *Contribuții teoretice și experimentale la structuri din materiale compozite noi*, PhD thesis Bucharest, Romania, **2010**.

[3] H.A. Petrescu, Contribuţii la studiul comportării plăcilor stratificate, cu miez de tip fagure, solicitate static şi dinamic, PhD thesis Bucharest, Romania, **2011**.

[4] H.A. Petrescu, Hadar A., *Influence of Load Position on a Honeycomb Sandwich Using Nonlinear Analsys*, Mat. Plast. Magazine, vol. 48, nr. 2, pp. 202-207, **2011**.

[5] H.M. Lankarni, *Contact/Impact dynamics applied to crash analysis*, Proceedings of the NATO-ASI on Crashworthiness of Transportation Systems Structural Impact and Occupant Protection, Troia, Portugal, July 7-19 **1996**.

[6] Inston CEAST *User guide*.

[7] J.R. Vinson, The Behavior of Sandwich Structures of Isotropic and Composite Materials, Taylor & Francis Routledge, **1999**.

[8] L.J. Gibson, M. F. Ashby, Cellular Solids Structure and Properties-Second Edition, **1988**, USA.