Finite Element Analysis of the Multilayered Honeycomb Composite Material Subjected to Impact Loading

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The main purpose of this paper is the study the behavior of four multilayered composite material configurations subjected to different levels of low velocity impacts, in the linear elastc domain of the materials, using experimental testing and finite element simulation. The experimental results obtained after testing, are used to validate the finite element models of the four composite multilayered honeycomb structures, which makes possible the study, using only the finite element method, of these composite materials for a give application.

Keywords: multilayered honeycomb composite materials, low velocity impac testingt, experimental study, finite element simulation

The continuous development of materials used in engineering applications, has allowed the improvement of traditional mechanical engineering areas and the development of new ones.

The appearance and usage of composite materials in mechanical engineering has resulted in many improvements of industry leading domains [1]. In [2], the non-homogenous nature of a honeycomb sandwich panel that significantly affects the structural performance during hypervelocity impact with space debris is presented. C.L. Wu and C.T. Sun evaluate the low velocity impact in composite sandwich beams, concluding that major modes of damage included matrix cracking and delamination in the face laminate and yielding in the core [3]. Sandwich composite structures with honeycomb core are extensively used in many performance demanding areas of mechanical engineering, such as: aerospace, naval and astronautics industry. The major factor which makes the sandwich structures extensively used is their high strength and low weight.

The ongoing development of sandwich structures has resulted in many new materials with different mechanical properties. Such developments have been achieved by the usage of nonconventional honeycomb cores [4].

Studying the behavior of honeycomb structures subjected to impact loading represents a strategic domain. As applications in this area, the outer hall of spacecraft structures can be mentioned, which is subjected to impact loading by meteorites which are traveling in space with high speed. In [5], high energy impact tests were carried out on E-glass phenolic impregnated sandwich structures in order to obtain a finite element procedure thus calibrating the basic properties for the adopted material model to take into account the main damage mechanisms occurring during the impact tests. Ping Liu Yan Liu Xiong Zhang propose in [6] an improved shielding structure with double honeycomb cores for hyper-velocity impact.

The impact load has been classified by many criteria, the most used is by the impact speed [7-10]. Impact loading on composite structures represents a strategic research domain especially for low velocity impact.

Low velocity impact (LVI) is considered when the impact speed is not higher than 20 m/s, [7]. During LVI, the main loading, for composite sandwich structure is bending. G. Reyes [11] revealed that low velocity impact behaviour of the sandwich systems investigated using an instrumented impact exhibit excellent energy absorbing characteristics under dynamic loading conditions. Thus for a for a composite sandwich structure, which undergoes LVI, it has been established the main failure modes width the increase of impact energy. These failure modes are: local indentation, delamination, and buckling of the honeycomb core followed by penetration of the composite structure [12, 13].

Throw many experimental analysis it has been determined that the behavior of sandwich structures subjected to impact loading is influenced on the honeycomb core configuration used for the composite material [14-16] but in [17] it was shown that the partition of the incident energy depends strongly on the geometry of the impacting projectile.

In the case of low velocity impact it has been determined that the core has an important role in the distribution of the impact energy throughout the entire composite structure. At beginning of the LVI domain, the most loaded component of the honeycomb structures is the contact sheet of the sandwich structure, accumulating over 70 % of the impact energy. As the impact speed increases, towards the end of the LVI, the absorbed energy is distributed between the contact area and the lower sheet of the sandwich structure [14].

The main purpose of this article is to validate the finite element models of four multilayered honeycomb composite materials subjected to impact loading. The finite element model is made using the Ansys finite element software. The geometrical model of the multilayered honeycomb composite material is made using Solidworks software.

Multilayered honeycomb composite material description

The multilayered honeycomb composite materials are made out of five layers. Two external layers are made of double layered woven laminated composites impregnated in polyester resin and two honeycomb layers separated by a single layer of woven laminated composite. The honeycomb cores used for the multilayered composite materials, are of two types, paper honeycomb and impregnated paper honeycomb in polyester resign, thus resulting four multilayer honeycomb composite material

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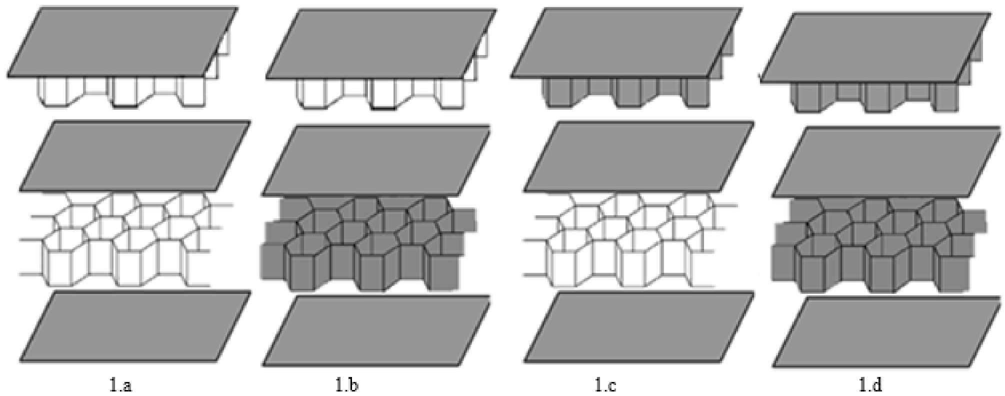


Fig. 1. Multilayered honeycomb composite materials configurations

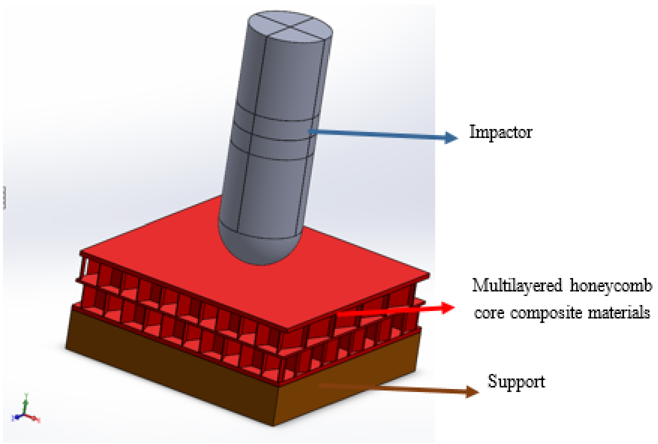
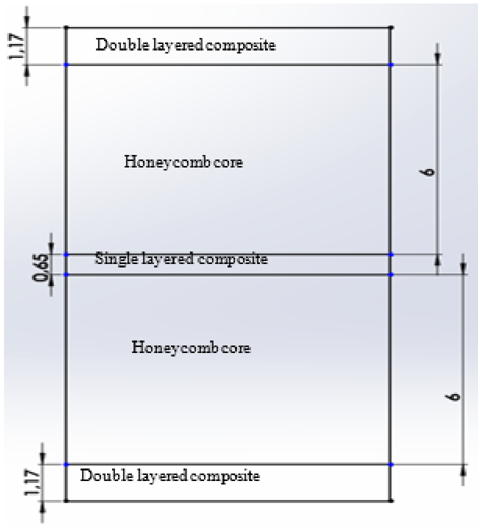


Fig.2. Finite element model



configurations. The four configuration of multilayered composite material, are different from one another, by the two honeycomb cores types, used in their structure. The first type of multilayered honeycomb core composite material has both honeycomb cores made of paper, figure 1.a, the second one has the first honeycomb core made of paper and the second core made of impregnated paper, figure 1.b, the third multilayered honeycomb composite material has the first layer made of impregnated paper, and the second layer from paper, figure 1.c and the last multilayered honeycomb composite material has both honeycomb layers made of impregnated paper, (fig. 1d).

Finite element and geometrical models

The geometry of the model contains three main parts: the support on which the multilayered honeycomb composite material is placed, the multilayered honeycomb composite material and the impactor. The support has the dimensions 60x60 mm and has a hole in the center of 40 mm in diameter. The impactor has a semispherical head with a diameter of 20 mm, (fig. 2).

The geometry of the honeycomb core is presented in figure 3.

The wall thicknesses are different for paper core honeycomb and impregnated paper core honeycomb. For paper core honeycomb the wall thickness is 0.23 mm and for impregnated paper core 0.55 mm.

Because the position of the two honeycomb cores related to each other are unknown, four geometrical models have been made, considering four extreme positions of the two honeycomb cores related to each other.

The first configuration has both honeycomb cores overlapped (fig. 4).

The second geometrical configuration has a 3.53 mm distance between the two cores on the X axis direction, (fig. 5).

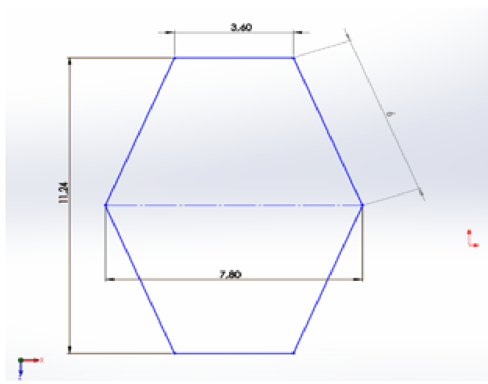


Fig. 3. Honeycomb core geometry

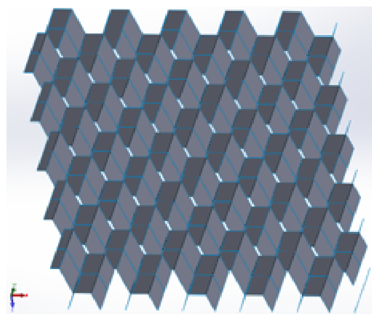


Fig. 4. First multilayered honeycomb composite material configuration

The third geometrical configuration has a distance of 5.62 mm on the Z axis direction between the two cores, figure 6.

The fourth geometrical configuration is made from the displacements of the two honeycomb cores in the second and third geometrical models (fig. 7).

Material mechanical properties

The mechanical properties of the materials used in the analysis are presented in the table 1.

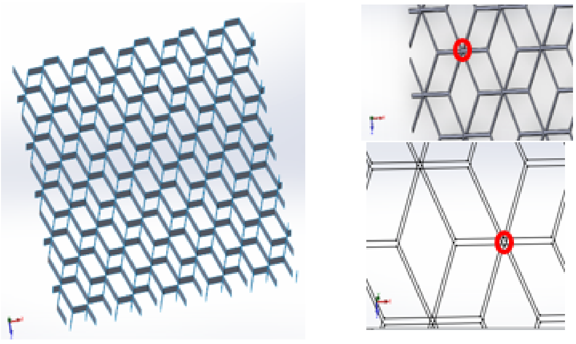


Fig. 5. Second geometrical configuration for the multilayered honeycomb composite material

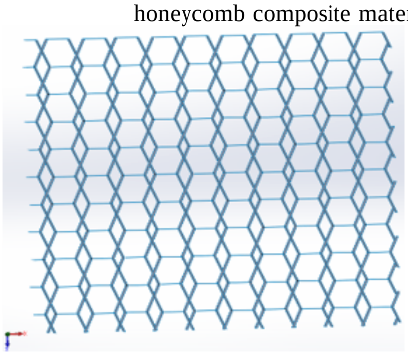


Fig. 6. Third geometrical configuration for the multilayered honeycomb composite material

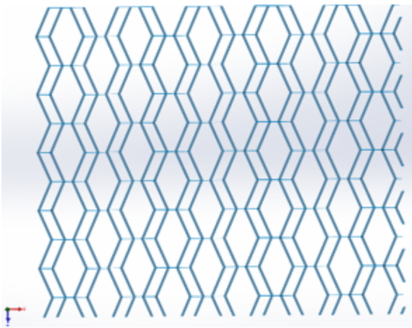


Fig. 7. Fourth geometrical configuration for multilayered honeycomb composite material

The mass of the impactor was taken into account by modifying the steel density to the value of 379700 kg/m^3, which corresponds to a mass of 6.76 kg, for the finite element model. The support is made from the same steel material. The steel used for both the impactor and the support has standard mechanical properties.

Experimental device

To make the impact tests on the multilayered honeycomb composite materials, a drop tower was designed in the University Politehnica of Bucharest, figure 8. The drop tower is made of impactor region with a mass of 6.76 kg, an accelerometer and the impactor head.

Table 1
MECHANICAL PROPERTIES OF MATERIALS

Material name	Young Modulus (MPa)	Poisson Ratio
Composite	15819	0.33
Paper	11511	0.2
Impregnated Paper	16357	0.35

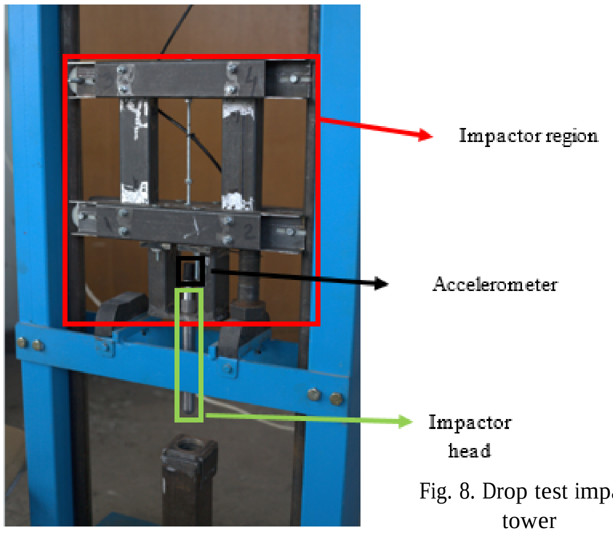


Fig. 8. Drop test impact tower

Test conditions

The multilayered honeycomb composite materials are tested for three energy levels: 5 J, 10 J and 15 J. The energy level control is made by adjusting the distance between the multilayered honeycomb composite material and the impactor head. The test parameters are presented in table 2. The impact speed is determined using the mechanical energy conservation theory.

Experimental testing

To determine the behavior of the multilayered honeycomb composite material configurations to impact loading, on the three specified energy levels, in the linear elastic domain of the materials, three tests were performed for each composite material type. For each test case the acceleration was determined and a medium value was computed from the three results. On the following tables the experimental results are presented for each multi-layered honeycomb composite material on each energy level. In the next tables the maximum acceleration values are given for each test case.

Table 2
IMPACT TEST PARAMETERS

Test case	Energy level (J)	Impact speed (mm/s)	Impact distance (mm)
1	5	1216	75.4
2	10	1720	150.8
3	15	2107	226.2

Table 3
EXPERIMENTAL RESULTS FOR THE FIRST ENERGY LEVEL ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=1216 (mm/s)		Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Test 1		1783.19	1982.24	1956.00	1649.42
Test 2		1730.71	1214.20	856.42	1831.19
Test 3		1109.23	1410.05	1713.42	1513.73
Experimental Medium Value		1541.04	1535.50	1508.61	1664.78

V=1720 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Test 1	1066.99	1873.43	1304.44	1187.32
Test 2	768.73	1502.85	1344.76	2878.29
Test 3	1625.74	1861.27	1459.33	2180.65
Experimental Medium Value	1153.82	1745.85	1369.51	2082.09

Table 4
EXPERIMENTAL RESULTS FOR THE SECOND ENERGY LEVEL ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=2107 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Test 1	3269.99	4537.90	2013.60	1133.55
Test 2	5039.05	1368.45	1541.89	2474.43
Test 3	6087.43	3899.79	2186.41	1747.35
Experimental Medium Value	4798.83	3268.71	1913.97	1785.11

Table 5
EXPERIMENTAL RESULTS FOR THE THIRD ENERGY LEVEL ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

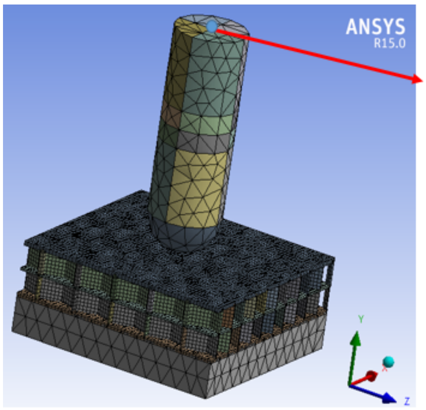


Fig. 9. Finite element simulation results extraction point position

After completing the experimental analysis a medium value for the impact test duration was determined, 3 ms. This value is approximated to the value of 3.5 ms, value which is used for the finite element simulation.

Finite element simulation results

The finite element simulation is carried out using Ansys software, Explicit Dynamics module. The impact duration for each analysis is considered 3.5 ms, duration obtained from the experimental results. The acceleration values for each multilayered honeycomb composite materials configuration is taken from the center of the upper circular section of the impactor (fig. 9). The position of this point

V=1216 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Model 1	1163	1253.00	955.00	1545.00
Model 2	1057.00	1627.00	993.00	861.00
Model 3	901.00	1512.00	1017.00	1675.00
Model 4	1035.00	1379.00	1236.00	1754.00
Finite Element Medium Value	1039	1442.75	1052.75	1458.75

Table 6
FINITE ELEMENT RESULTS FOR THE FIRST TEST CASE ON EACH MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=1720 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Model 1	2063.00	1715.00	1887.00	1951.00
Model 2	1272.00	1779.00	1061.00	1592.00
Model 3	2534.00	1832.00	1551.00	2149.00
Model 4	1605.00	1860.00	1662.00	2583.00
Finite Element Medium Value	1868.50	1796.50	1540.25	2068.75

Table 7
FINITE ELEMENT RESULTS FOR THE SECOND TEST CASE ON EACH MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

Table 8
FINITE ELEMENT RESULTS FOR THE THIRD TEST CASE ON EACH MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=2107 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Model 1	2332.00	1930.00	3065.00	2262.00
Model 2	1713.00	2858.00	1840.00	2243.00
Model 3	2468.00	2891.00	1767.00	2960.00
Model 4	1717.00	2400.00	2257.00	3363.00
Finite Element Medium Value	2062.00	2519.75	2232.25	2707.00

Table 9
COMPARATIVE RESULTS FOR THE FIRST TEST CASE ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=1216 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Experimental Medium Value	1541.04	1535.50	1508.61	1664.78
Finite Element Medium Value	1039.00	1442.75	1052.75	1458.75
Error (%)	32.58	6.04	30.22	12.38

Table 10
COMPARATIVE RESULTS FOR THE SECOND TEST CASE ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=1720 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper -Impregnated Paper (m/s^2)
Experimental Medium Value	1153.82	1745.85	1369.51	2082.09
Finite Element Medium Value	1868.50	1796.00	1540.25	2068.75
Error (%)	61.94	2.90	12.47	0.64

Table 11
COMPARATIVE RESULTS FOR THE THIRD TEST CASE ON ALL MULTILAYERED HONEYCOMB COMPOSITE MATERIALS

V=2107 (mm/s)	Acceleration Paper - Paper (m/s^2)	Acceleration Paper - Impregnated Paper (m/s^2)	Acceleration Impregnated Paper - Paper (m/s^2)	Acceleration Impregnated Paper - Impregnated Paper (m/s^2)
Experimental Medium Value	4798.83	3268.71	1913.97	1785.11
Finite Element Medium Value	2062.00	2519.75	2232.25	2707.00
Error (%)	57.03	22.91	16.63	51.64

takes into account the position of the accelerometer from the impact tower.

The finite element results for each test case on each geometrical model of the multilayered honeycomb composite materials, are given in the following tables. For each multilayered honeycomb composite material configuration on each test case a medium value is computed.

Comparative results

After completing the experimental and finite element analysis, the medium values were obtained for the impact accelerations on each multilayered honeycomb composite materials on the three energy levels. These results are presented in the tables from paragraphs 1.7 and 1.8. To make a comparative analysis between the experimental results in the finite element simulation, the results for the medium values are presented for each multilayered honeycomb composite material configuration on each load case in the following tables.

The error is computed using formula 1:

$$Error = \left| \frac{EMV - FEMV}{EMV} \right| \quad (1)$$

EMV - experimental medium value;

FEMV - finite element medium value.

Explanation:

Paper - Impregnated Paper - multilayered honeycomb composite material with impact on impregnated paper honeycomb layer;

Impregnated Paper - Paper - multilayered honeycomb composite material with impact on paper honeycomb layer.

Conclusions

The multilayered honeycomb composite materials on the first two test cases are tested in the linear elastic domain of the component materials.

The lowest errors were obtained for the impact on impregnated paper honeycomb layer.

For the third energy case the errors are significantly higher between the experimental and finite element analysis. In this case the component materials are no longer in the linear elastic domain, delamination and nonlinear deformations appear on the multilayered honeycomb composite materials.

The high error values for the multilayered honeycomb composite materials with impact on the paper layer, appear because in the finite element models, paper material was considered homogeneous material. This assumption was made because the difficulty of considering the natural mechanical properties of the paper material.

The finite element models used in the analysis, can be considered validated on the linear elastic domain of the multilayered honeycomb composite materials.

To make the experimental analysis on the multilayered honeycomb composite materials an impact tower was designed in the University Politehnica of Bucharest.

The finite element models of the multilayered honeycomb composite materials can be successfully used to determine the impact behavior of these materials, in the linear elastic domain.

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