TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue II, June, 2021

IMPACT BEHAVIOUR OF EXPANDED POLYSTIRENE BY EXPERIMENTAL AND NUMERICAL METHODS

Cristian VILĂU, Mircea Cristian DUDESCU

Abstract: *Today, expanded polystyrene is used in almost all areas. It is very used in the field of constructions, for the insulation of building facades due to the very good thermal characteristics. The polystyrene used for insulation of facades is subjected to various loads such as compressive, bending or impact due to natural phenomena, the impact of windborne debris on building envelopes being a major cause of their damage and a starting point for future damage mechanisms produced by wind power . The paper presents the results obtained experimentally after an impact tests of expanded polystyrene with different densities, but also the results obtained by similar numerical analyzes performed with the ANSYS Explicit Dynamics software. For impact tests and numerical analyzes of the samples polystyrene foam type EPS 50, EPS 80, EPS 100 and EPS 120 were used. The results obtained by these investigations revealed good convergence and validate the analysis methodologies.*

Key words: *expanded polystyrene, impact tests, finite element analysis, explicit dynamics.*

1. INTRODUCTION

Polystyrene (PS) is a polymeric material (synthetic hydrocarbon) thermal processing (thermoplastic), obtained from styrene monomer. Polystyrene is of two types: expanded polystyrene (EPS) and extruded polystyrene (XPS). [1] Expanded polystyrene (EPS) is a closed cell foam that is produced by "expanding" the polymer, and extruded polystyrene (XPS) is a rigid foam, which is formed by "extruding" the polymer.

Expanded polystyrene can be used in a wide range of applications, such as: protective housings for products, panels for shock attenuation, can be used for panels with sandwich structure [2, 4, 5]. It is lasting, solid and can be used as insulated panel systems for roofs, facades and floors in buildings, as a flotation material in the construction of pontoons and ports and as a light filler in the construction of roads and railways [3, 6, 7].

The post storm investigations revealed that the windborne and their impact is a major cause of damage to building envelope including the thermal insulation realized with EPS panels.

During severe storms or hurricanes the windborne debris might penetrate the building envelope and creates an opening that cause increasing of internal pressures which results in imminent and in most cases severe damage to the building. The debris impact produce a vulnerability with respect to internal pressurization creating additional loads in suction zone and a temporally evolution in a form of a “chain reaction”. Results of the analysis performed on composite structural insulated panel with expanded polystyrene core against windborne debris impacts are presented in [4]. Due to numerous cases when the EPS is used as façade isolation and its surface is impacted by various object, the study of impact results having practical relevance.

The paper is structured in two main parts. First part presents the experimental set-up to impact the EPS samples with different densities. In the second part, based on similar loading conditions, an explicit numerical analysis was

Received: 12.04.21; **Similarities**: 23.05.21: **Reviewed**: 02.06.21: **Accepted**:17.06.21

done to investigate the impact behavior of EPS. The obtained results are discussed at each part and the paper ends with the conclusions.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Materials

Experimental impact tests were performed on the commercially available EPS specimens. The material used was expanded polystyrene with the following codes and densities: EPS 50 (density 11 Kg/m^3), EPS 80 (density 15 Kg/m^3), EPS 100 (density 20 Kg/m^3) and EPS 120 with a density of 25 Kg/m^3. For experimental impact tests were considered samples having the dimensions (*L x l x h*): 200x200x30mm cut from above-described types of EPS.

2.2 Experimental set-up

To validate the values of the deformations obtained from the simulations, an experimental set-up presented in Figure 1 was designed in a similar way like a gravitational pendulum. The metallic ball with a diameter of 120 mm and a mass of 9 kg will strike after a free falling the surface of the polystyrene specimens. The arm length of the pendulum can be adjusted to reach different impact speeds. In our study the ball was considered at a height of 0.5 m and this will produce according to gravitational pendulum formulas an impact speed of 3344.2 mm/s.

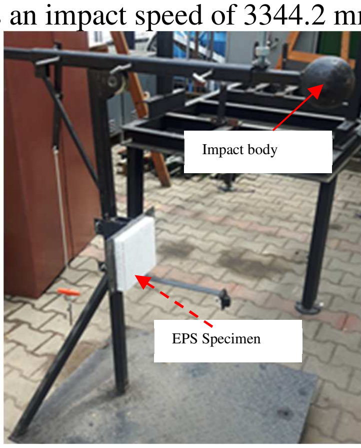


Fig.1. Experimental set-up including a gravitational pendulum and EPS specimen.

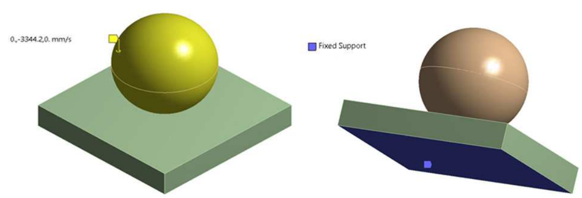
In Figure 1 is also shown the position of the specimen during the experiment. The types of polystyrene mentioned above were impacted with the same impact speed and respectively mass position. After performing the impact test, the trace by the ball left on the surface of the sample was measured. The surface of the specimen was hit with the ball only once. Figure 2 shows the measured value of the trace left by the ball on the surface of the sample (maximum depth with respect to the sample surface).

Fig.2. Depth of calotte resulted in the specimen after impact

3. NUMERICAL SIMULATION

3.1. Simulation parameters

The software used for the explicit dynamic analyses was ANSYS Workbench 2019R2. In order to perform the dynamic simulation loading conditions for the ball consist of initial speed (equal with the calculated impact speed of the pendulum 3344.2 mm/s) and fixed support for the lower side for the EPS specimen (Fig. 3). The impact mass (metallic ball) was considered as a rigid body in the numerical simulation.



a) b)

Fig.3. Boundary conditions a) initial speed of the impact body; b) fixed lower surface for EPS specimen.

After establishing the loading and supporting conditions the mesh of finite elements was created. For the contact areas (between the ball surface and the surface of the EPS sample) was carried out a fine mesh, the value of the element length being 1mm (Fig. 4).

Material model and mechanical characteristics of the polystyrene used in the dynamic analysis were determined experimentally in [8] and imported as experimental data in the Engineering Data module of the simulation software. In [8] is analyzed the mechanical behavior of the EPS compressed at different speeds. Best mechanical strength in compression has EPS-120, the higher density of EPS develops higher compressive strength [8].

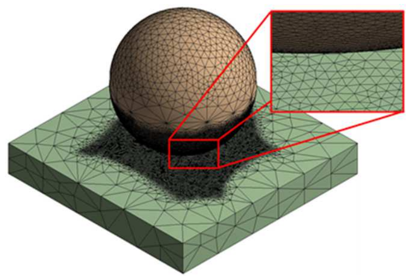


Fig.4. Mesh density of the samples in the contact areas

3.2. Simulation results

After performing the analysis were obtained values of deformations and absorbed energies for samples made of EPS with different densities. In figure 5 are shown the values of the total deformations obtained from explicit dynamic analysis of the impact. A maximum value of 6.097 mm is identified for EPS-50.

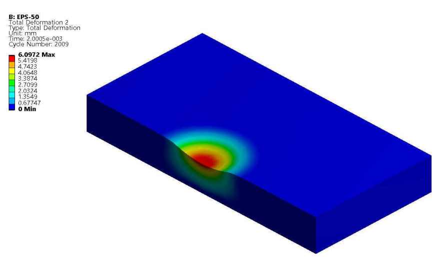


Fig.5. Numerical displacements of EPS 50 after impact

Figure 6 shows the value of absorbed energy (mJ) of EPS 120 versus time (s) obtained from explicit dynamic analysis.

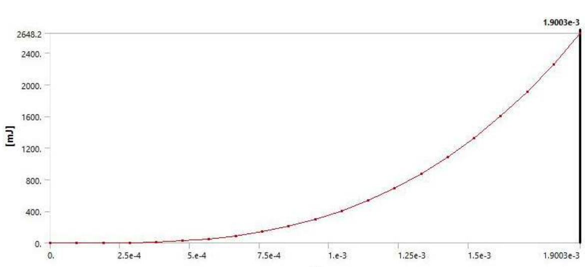


Fig.6. Internal energy variation of EPS 120 under impact.

5. RESULTS & CONCLUSION

The values of total deformations and internal energy obtained resulted from numerical analysis of impact and deformations obtained from experimental tests, are presented in the Table 1.

Table 1

Displacements and internal energy

EPS	Displacement (experimental) [mm]	Displacement (numerical) [mm]	Internal energy [mJ]
50	5.9933	6.0972	418.33
80	5.7790	5.8655	828.32
100	5.7711	5.7645	2159.1
120	5.7560	5.7552	2648.3

For a better visualization and comparison of the results presented in Table 1, a graphical representation of the numerical and experimental displacements is presented in figure 7. Relative deviations between the results are under 3%.

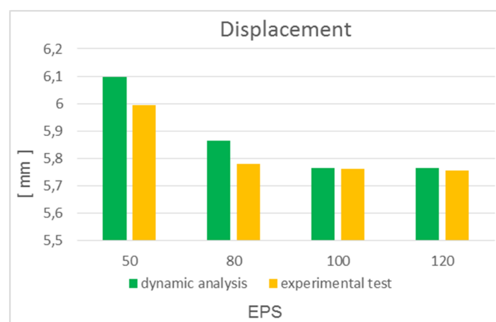


Fig.7. Comparative numerical and experimental displacement data.

Because the specimen has an elastic return, to the remanent measured value of the trace left by the ball will be added the elastic deformation calculated based on the stress-strain curve of the material obtained after experimental compression test [8].

Thus, for example for EPS 80 the total deformation during impact will be: 4.53 mm + 1.249 mm = 5.779 mm. In this expression 4.53 mm represents the value of the trace depth after impact (permanent deformation) and 1.249 mm is the elastic deformation (spring-back) of EPS 80 resulting a total of 5.779 mm. This value was considered the experimental value of the deformation during the impact and compared with the numerical simulation results.

In this work was analyzed the impact behavior of polystyrene, a phenomenon often encountered in constructions when the facade is hit with various objects. To understand the mechanical behavior under impact were carried both numerical and experimental investigations. The experimental impact tests performed on various densities EPS specimens was compared with the numerical modeling using explicit dynamic analysis under similar boundary conditions. The material model used in the simulation was also experimentally validated by compression test at different testing speeds. The obtained results by the two methods are in good convergence with a relative deviation between the results are under 3%, which certifies their validity and applied research methodology.

5. ACKNOWLEDGMENT

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0391 within PNCDI III.

6. REFERENCES

[1] https://www.chemicalsafetyfacts.org/polystyrene/

[2] Wensu Chen, Hong Hao, Dylan Hughes, Yanchao Shi, Jian Cui, Zhong-Xian Li, *Static and dynamic mechanical properties of expanded polystyrene*, Materials & Design, Volume 69, 2015, pp. 170-180.

[3] https://omnexus.specialchem.com/selection-guide/expanded-polystyrene-eps-foam-insulation

[4] Wensu Chen, Hong Hao, *Experimental and numerical study of composite lightweight structural insulated panel with expanded polystyrene core against windborne debris impacts,* Materials and Design 60 (2014) 409–423.

[5] Yiping Liu, Dongpeng Ma, Zhenyu Jiang, Fan Xiao, Xinxiong Huang, Zejia Liu, Liqun Tang, *Dynamic response of expanded polystyrene concrete during low speed impact,* Construction and Building Materials 122 (2016) 72–80.

[6] Umut Caliskan, M Kemal Apalak, *Bending impact behaviour of sandwich beams with expanded polystyrene foam core: Analysis,* Journal of Sandwich Structures and Materials 2019, Vo l. 21(1) 230–259.

[7] U. Caliskan, M. K. Apalak, *FEM analyses of low velocity impact behaviour of sandwich panels with eps foam core,* Journal of Thermal Engineering, Vol. 3, No. 6, Special Issue 6, pp. 1544-1552, December, 2017

[8] Cristian Vilau, Mircea Cristian Dudescu, *Investigation of mechanical behaviour of expanded polystyrene under compressive and bending loadings,* Materiale Plastice (Mater. Plast.), 2020, Volume 57, Issue 2, pp. 199-207.

COMPORTAREA POLISTIRENULUI EXPANDAT LA IMPACT PRIN METODE EXPERIMENTALE ȘI NUMERICE

Astăzi, polistirenul expandat este utilizat în aproape toate domeniile. Este foarte utilizat în domeniul construcțiilor, pentru izolarea fațadelor clădirilor datorită caracteristicilor termice foarte bune. Polistirenul utilizat pentru izolarea fațadelor este supus la diverse solicitări, cum ar fi sarcini de îndoire, sarcini dinamice și solicitări prin șoc. Lucrarea prezintă rezultatele obținute la testele de impact dinamic ale polistirenului expandat, dar și rezultatele obținute la analizele de impact dinamic efectuate cu software-ul de analiză ANSYS. Pentru teste dinamice și analize ale probelor s-au folosit spumă de polistiren tip EPS 50, EPS 80, EPS 100 și EPS 120.

Cristian VILAU, Dr. Asist. Eng., Technical University of Cluj-Napoca, Department of Mechanical Engineering, email: vilau_cristian@yahoo.com, B-dul Muncii no. 103-105, Cluj-Napoca, Romania.

Mircea Cristian DUDESCU, Prof. Dr. Ing., Technical University of Cluj-Napoca, Department of Mechanical Engineering, email: mircea.dudescu@rezi.utcluj.ro, B-dul Muncii no. 103-105, Cluj-Napoca, Romania.