BLAST LOADING ON ALUMINUM FOAM MICROSTRUCTURE

Danuta Miedzińska, Robert Panowicz

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 6839849, fax: +48 22 6839355
e-mail: kmiis@wat.edu.pl

Abstract

One of the possible options as a material for protective layers is aluminum foams which become also very popular due to their lightweight and excellent plastic energy absorbing properties. Such characteristics have been appreciated by the automotive industry with continued research to further understand foam pr operties. Compressed f oaming materials exhibit extensive plastic response, while the initial elastic region is limited in tension by a tensile brittle-failure stress. Aluminum foams have become also an attractive material as blast protective layers due to t heir desirable compressive properties. With different material engineering techniques (as, for example double-layer foam cladding) they can be customized to achieve the most desirable pr operties. Energy absorption capacity of foams microstructures under blast load was analytically confirmed based on a rigid-perfectly plastic-locking foam model. Initial research indicates that energy absorbed by the cladding is much larger than that under quasi-static conditions due to strain rate effect. In this paper a numerical model of a closed cell aluminum foam idealistic microstructure was presented. The quasi static c ompression tests were carrie d out with the use of LS Dyna computer code. Then the sample was numerically loaded with the blast wave from detonation of explosives and its behavior was analyzed. The results of both analyses were compared.

Keywords: microstructure, aluminium foam, strain rate effect

1. Introduction

Closed-cell aluminium foam offers a unique combination of properties such as low density, high stiffness, strength and energy absorption that can be tailored through design of the microstructure. During ballistic impact the foam exhibits significant nonlinear deformation and stress wave attenuation [1].

In recent years, aluminium foams of high porosity have attracted much attention of researchers on materials due to their unique compression behaviour that undergoes a large deformation at nearly constant nominal stress, and great potential for application in absorbing energy from impact. This application therefore requires the knowledge on the shock compression behaviour of the aluminium foam under various impact conditions.

In the paper the closed-cell aluminium foam microstructure model was analyzed under both quasi-static and blast loading. The model was developed with the use of Kelvin unit cell geometry. The numerical analyses were carried out with the use of LS Dyna computer code. Both numerical experiments were compared due to the model deformations, stress and pressure distributions.

2. Numerical model of closed-cell aluminium foam microstructure

The numerical model, presented in Fig. 1, was developed with the use of the Kelvin unit cell geometry. The undeformed Kelvin cell (Fig. 2) is a tetrakaidecahedron with six flat quadrilateral faces and eight nonplanar hexagonal faces with zero mean curvature. All of the curved edges have the same shape. A Kelvin foam is composed of Kelvin cells with the same orientation. In the reference orientation, each quadrilateral face is perpendicular to a coordinate axis [2].
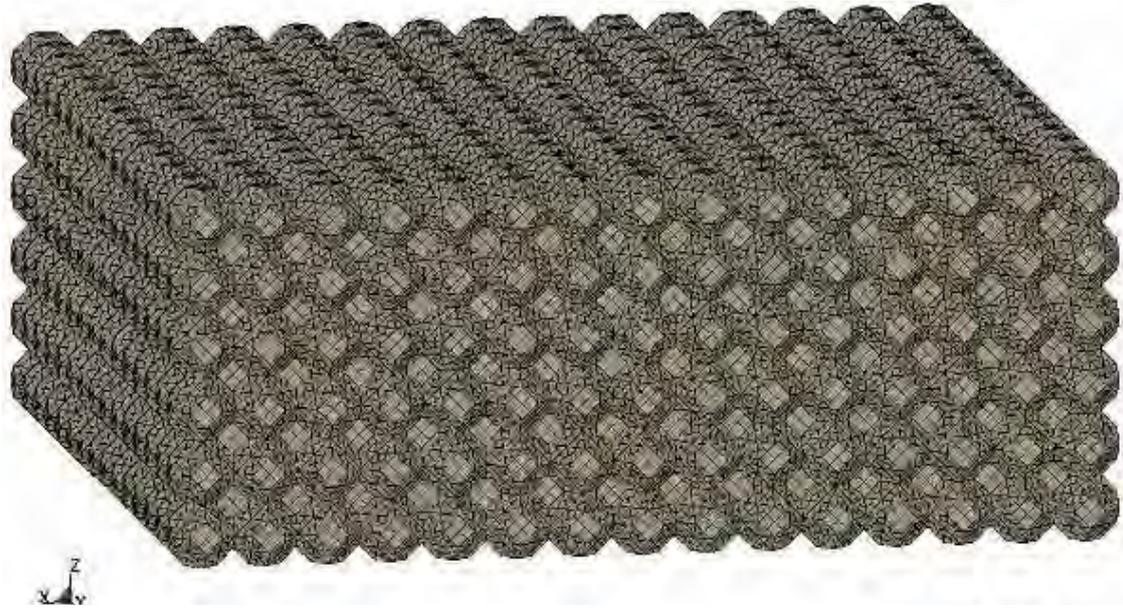
Fig. 1. Numerical model of closed-cell aluminium foam microstructure
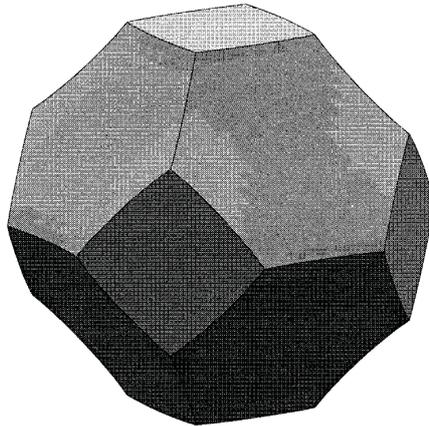

Fig. 2. Kelvin foam unit cell

The numerical model was built of the Kelvin unit cells of the dimension of 4 mm each. The total dimension of the model was 15×15×6 unit cells (60×60×24 mm). The porosity of the model was 85%.

A piecewise linear plastic material model [3] was used for aluminium (Young modulus E = 71000 MPa, Poisson ratio ν = 0.33, yield stress R_e = 250 MPa).

3. Numerical compression analysis

A dynamic numerical analysis was carried out with the FEM implemented in LS Dyna computer code. A compression was performed with two rigid plates - stationary and moving (v = 1 m/s) one. The results are presented in Fig. 3 as deformations, in Fig. 4 as effective stress distribution and in Fig. 5 as pressure distribution.

Analysing the pictures 3-5, it can be concluded that the developed numerical model demonstrated strong auxetic behaviour. It is strictly visible that the external walls of the sample collapsed into the model.

The stress and pressure distribution are almost uniform. Some concentrations appeared in the vicinity of the right plates (top and bottom of the sample). Those facts lead to the conclusion that the closed-cell foam microstructure works homogeneously in the whole volume.
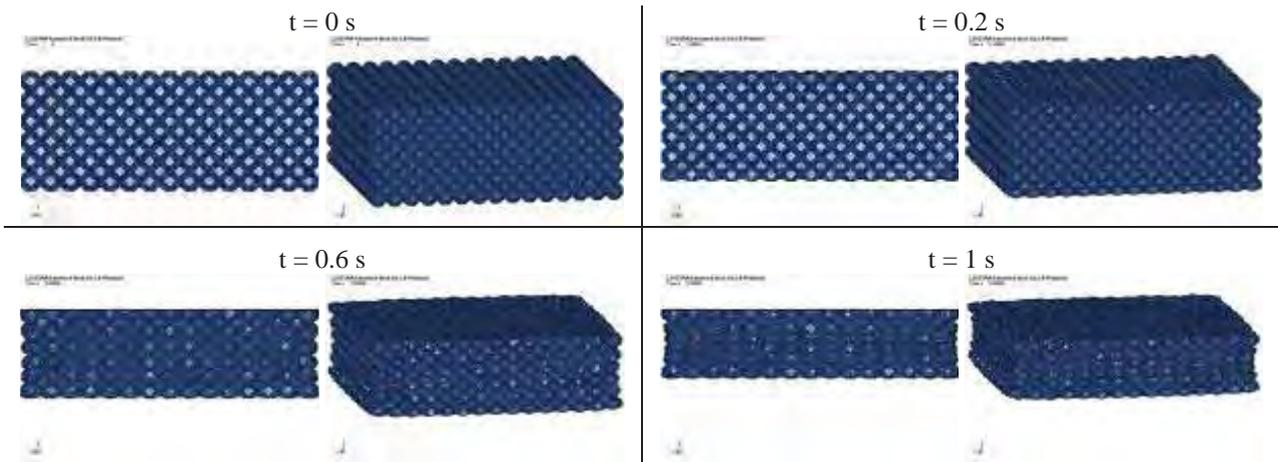
t = 0 s   t = 0.2 s

t = 0.6 s   t = 1 s

Fig. 3. Deformations for compression test of aluminium foam microstructure FE model

t = 0 s   t = 0.2 s

t = 0.6 s   t = 1 s
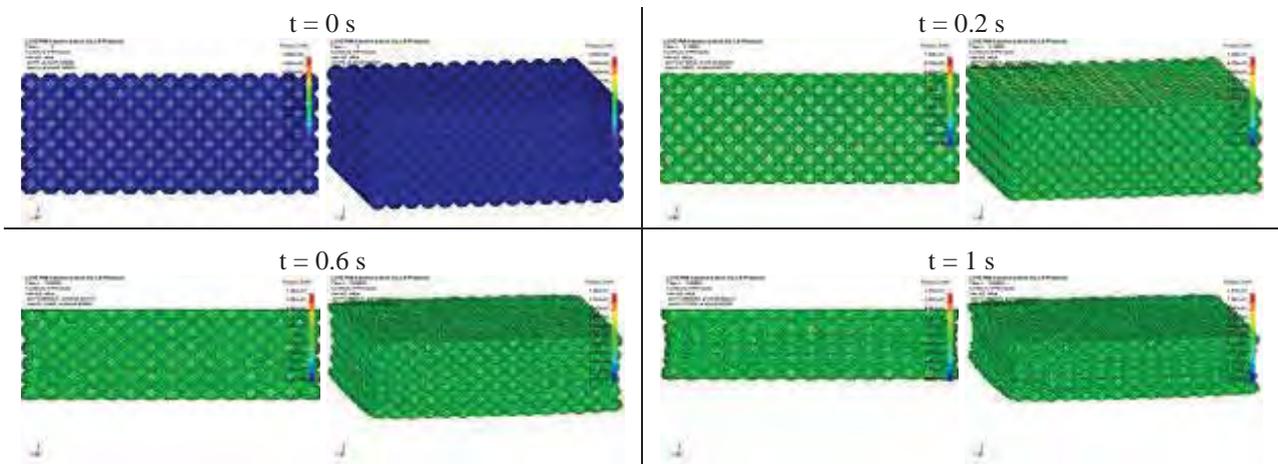
Fig. 4. Pressure distribution for compression test of aluminium foam microstructure FE model

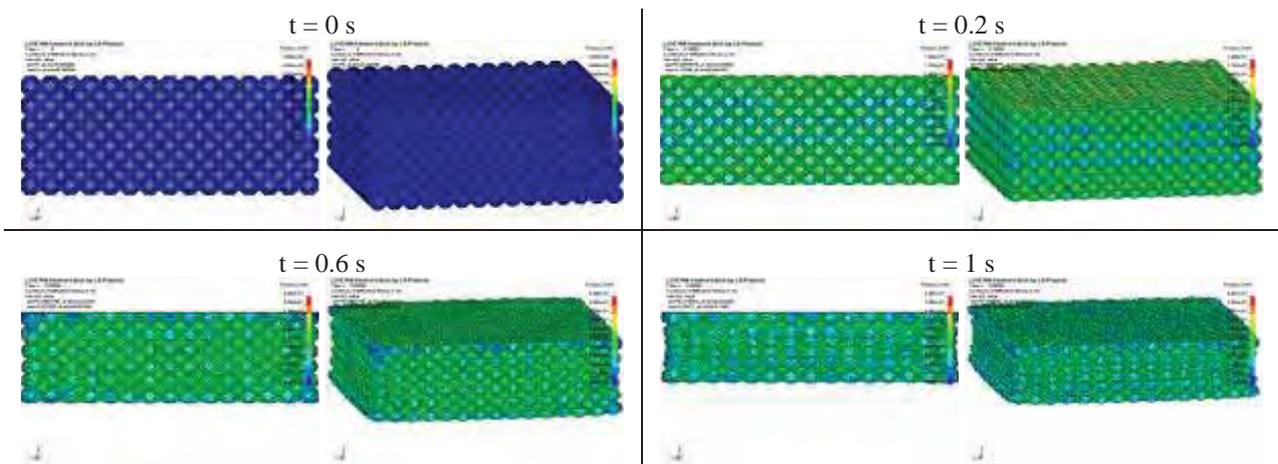t = 0 s   t = 0.2 s

t = 0.6 s   t = 1 s

Fig. 5. Effective stress distribution for compression test of aluminium foam microstructure FE model

4. Numerical blast load analysis

Blast waves generated by the explosions of high explosive charges can damage or destroy structures. Numerical models are used to study these phenomena to precisely evaluate the blast propagation in the space around the structure and the structure response, FE models have to be used. Using a fluid structure interaction method (which exists in LS-Dyna: *ALE, *CONSTRAINED_

LAGRANGE_IN_SOLID) is possible. Nevertheless, this generates big models (fine 3D mesh, to define air from explosive to structure). Another possibility (also available in LS Dyna: *LOAD_BLAST), that was applied to the model, is to use an empirical model to compute the load on the structure. This solution is far less expensive in CPU and memory usage.

When a high explosive detonates, a pressure front propagates into surrounding atmosphere. This strong incident shock called the blast wave is characterized by an instantaneous increase from ambient pressure to peak incident pressure. Generally this shock is characterized by use of a Friedlander formulation (positive phase) [4]:

$$P_s(t) = P_{so}\left(1 - \frac{t - t_A}{t_o}\right)\exp\left(-\beta\frac{t - t_A}{t_o}\right),$$ (1)

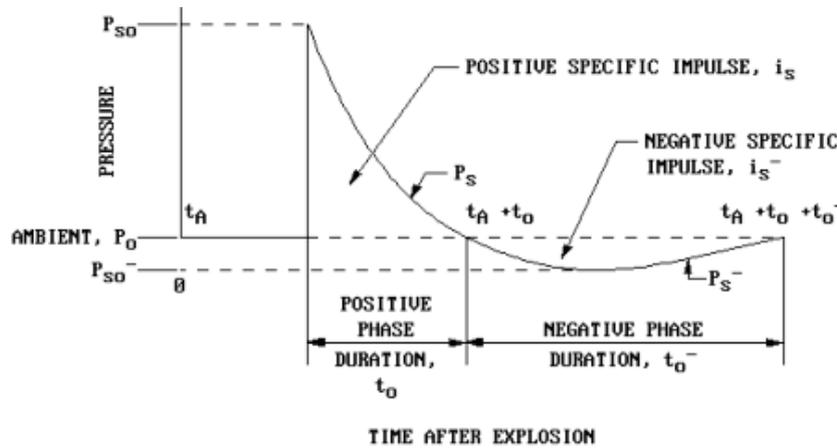The values in the equation are described in Fig. 6.

Fig. 6. Pressure-time evolution during blast load

The ConWep blast pressure function with LS Dyna was used to provide the blast loading exerted on the model surfaces. The inputs include equivalent TNT mass, type of blast (surface or air), detonation location, and surface identification for which the pressure is applied. From this information, ConWep calculates the appropriate reflected pressure values and applies them to the designated surfaces by taking into account the angle of incidence of the blast wave. It is important to note that ConWep, adopted within LS-DYNA, updates the angle of incidence incrementally, and thus, accounts for the effect of surface rotation on the pressure load during a blast event [5].

ConWep function was developed by the US Army in 1991. In this function, pressure is calculated based on the following equation [6]:

$$P(t) = P_r\cos^2\theta + P_i(1 + \cos^2\theta - 2\cos\theta),$$ (2)

where θ is an angle of incidence, P_r is reflected pressure and P_i is incident pressure. In the paper, ConWep air blast function was used to apply blast loading.

An equivalent mass of TNT 0.1 kg was placed 0.4 m above the symmetric centre of the analyzed structure placed on the rigid wall. In accordance to the previous chapter, the results are presented in Fig. 7 as deformations, in Fig. 8 as effective stress distribution and in Fig. 9 as pressure distribution.

Looking at deformations it can be noticed that the destruction of the sample begins and is the largest at the top cells. The bottom cells collapsed. Analyzing the pressure distribution in the foam microstructure we can see that it becomes quite uniform at the end of the analysis. Taking the stress distribution into consideration, it can be seen that the increase in the effective stress value begins at the top surface of the sample (it is round, because the blast is spherical), then the stress wave penetrate the sample and at the time t = 0.00021 s spreads across whole sample. At the end of the analysis the stress value decreases.
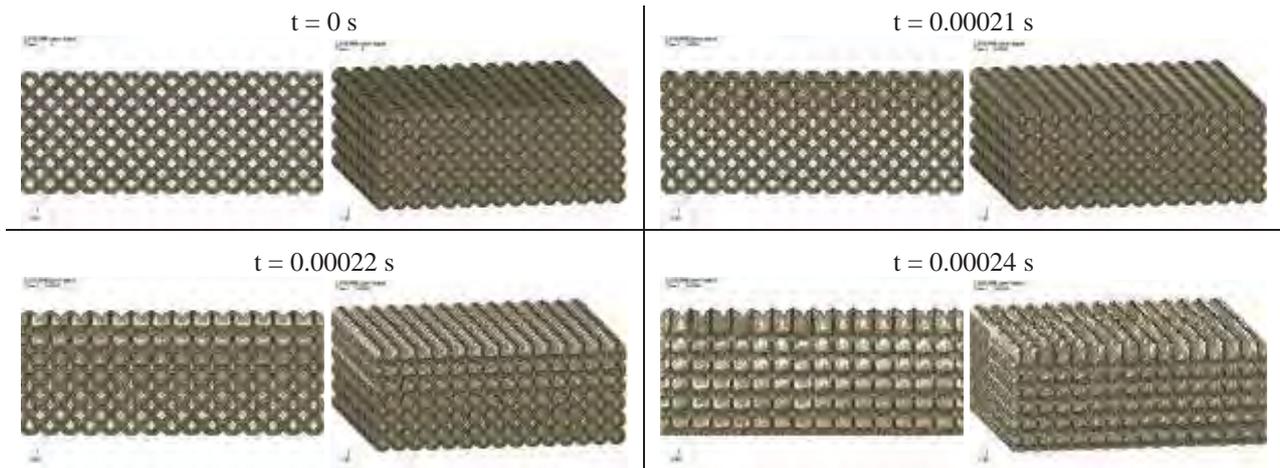
t = 0 s	t = 0.00021 s

t = 0.00022 s	t = 0.00024 s

Fig. 7. Deformations for blast loading of aluminium foam microstructure FE model
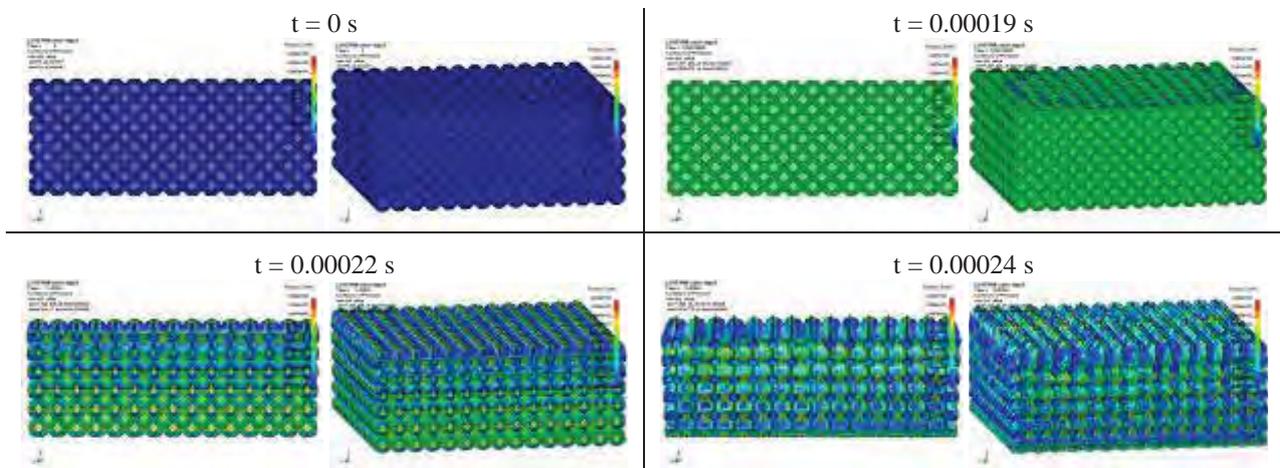
t = 0 s	t = 0.00019 s

t = 0.00022 s	t = 0.00024 s

Fig. 8. Pressure distribution for blast loading of aluminium foam microstructure FE model

t = 0 ms	t = 19 ms

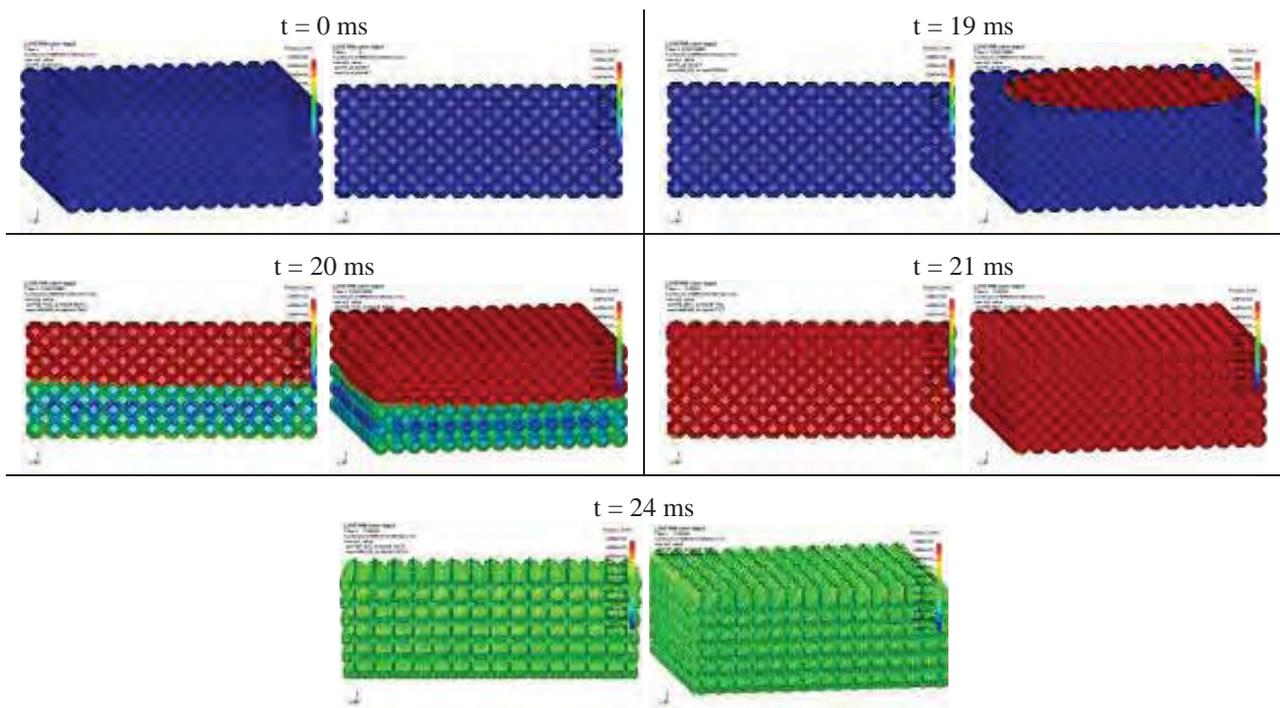| t = 20 ms	t = 21 ms

t = 24 ms

Fig. 8. Effective stress distribution for blast loading of aluminium foam microstructure FE model

5. Conclusions

In the paper the numerical analyses of the closed-cell aluminium foam microstructure FE model were presented. The model was loaded both with quasi-static and blast load. The significant differences appeared in the results of both calculations. The deformations, pressure and effective stress distributions are completely different in both cases. It can be concluded that the behaviour of the foam microstructure strongly depends on applied load what should be taken into consideration during the design process of constructions protected against the blast wave.

Acknowledgements

References

[1] Hanssen, A. G., Enstock, L., Langseth, M., *Close-range blast loading of aluminum foam panels*, International Journal of Impact Engineering, Vol. 27, Iss. 6, pp. 593-618, 2002.
[2] Kraynik, A. L., *Linear Elastic Behaviour of Dry Soap Foams* , Journal of Colloid and Interface Science, Vol. 181, pp. 511-520, 1996.
[3] Hallquist, J. O., *LS-Dyna. Theoretical manual* , California Livermore Software Technology Corporation, 1998.
[4] Le Blanc, G., Adourn, M., Lapoujade, V., *External Blast Load on Structures – Empirical Approach*, 5th European LS-Dyna Users Conference, UK 2005.
[5] Mrityunjaya, R. Y., Trivikram, N. L., Vasanth, S., Ramesh, V., *Simulation of Explosions in Train and Bridge Applications*, 3rd ANSA & μETA International Conference, Greece 2009.
[6] Ergonenc, C., *Development and Design of Closed- Cell Aluminum Foam- Based Lightweight Sandwich Structures for Blast Protection*, Doctor's Thesis, Turkey 2008.