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NOVEL IMPACT ATTENUATOR

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***Abstract*:** *The capacity of materials and structures to dissipate the impact energy generated by impulse forces (collisions, explosions, etc.) raises great interest in applications from vehicle industry – terrestrial, nautical or spatial – for increasing security of passengers and goods, as well as in applications from civil engineering – for protection of high security buildings. This paper presents a novel impact attenuator made of a multi-layered cellular structure - ExpaAsym. The analysis regards the main conditions an attenuator should fulfill in order to be efficient: the damage curve – which should be relatively constant during the deformation; the distance to compaction – which is expected to be higher, preferably more than 80% of the initial height; maximum initial load force – which should be as close as possible to the value of the average load force; the dissipated energy, respectively the area beyond the force-displacement curve – which is expected to be as large as possible. The results of the numerical analysis prove the feasibility of the novel proposed system.*
Keywords: *cellular structure, energy absorption, numerical analysis*

1. INTRODUCTION

An efficient impact attenuator is the one that meets the following conditions, related to Figure 1: the crushing curve keeps itself constant during the whole process of deformation (> 80% from the initial height of the impact attenuator), the maximum initial peak load is as close as possible to the value of the average load, the quantity of the dissipated energy, respectively the area under the Force – Displacement curve, has to be as large as possible.

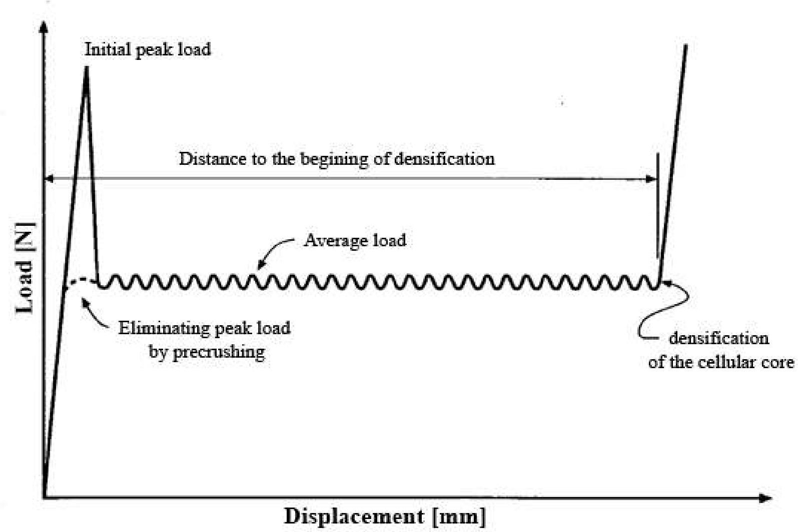

Figure 1: The behaviour description of the ideal impact attenuator [1]

Research in this field has demonstrated that the periodic cellular structures have a high potential to satisfy the above described conditions. Thus, several types of cellular structures used for attenuating the impact energy are known, such as: honeycomb structures, [2], [3], [4], single or multi-layered formed structures, [5], [6], or multi-layered corrugated structures, [7]. These cellular structures have several disadvantages: their construction implies high material consumption in order to dissipate a large quantity of energy; they have high relative density due to the material distribution in space; the plastic deformation takes place in shocks due to the buckling of the cells' walls; they possess a low number of variables that can be modified for the optimization of the absorption capacity; the manufacturing methods are relatively expensive, with a reduced degree of flexibility.

2. NOVEL IMPACT ATTENUATOR

According to the aspects mentioned in the previous section, it was considered the realisation of an impact attenuator by a simple process, having a low relative density, which should allow the dissipation of large quantity of energy as a result of an impact force. In order to uniform the reaction force, the plastic deformation of the constitutive elements should occur with low intensity shocks.
Due to the advantages that the expanded cellular structure ExpaAsym implies, [8], [9], its use for attenuating the impact energy may eliminate the disadvantages mentioned in paragraph 1 as follows: a multi-layered cellular structure **2** is constructed, Figure 2, consisting of two or more successive layers of ExpaAsym cellular structure rotated in plane from one layer to the other by 180°; this multi-layered structure is covered by two exterior face sheets **1** and **3.**

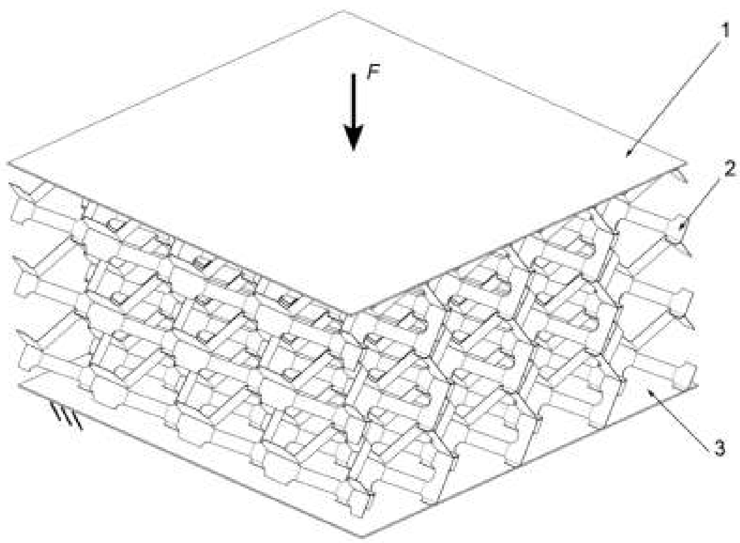

Figure 2: Impact attenuator containing ExpaAsym multi-layered cellular structure

3. NUMERICAL SIMULATIONS

Several quantitative criteria exist for the evaluation of the impact energy absorption capacity, [10], [11]. One of the most used refers to the determination of the volume specific impact energy absorption capacity (the absorbed energy at a unit volume). Thus, volume specific impact energy absorption capacity E_v [J/m^3] of the impact attenuator obtained using the multi-layered cellular structure is calculated as the ratio between the absorbed energy E_{abs} and the initial volume V of the attenuator, Equation (1).

$$E_v = \frac{E_{abs}}{V} \tag{1}$$

A preliminary numerical simulation was performed using Abaqus/Explicit in order to calculate the value of E_v, considering the geometric case when the internal angle has a value of 60°, the *l/c* ratio is 1.4 and the width *b* has a value of 10 mm, according to the notations made in **Error! Reference source not found.**.
The material properties introduced in the FE model correspond to a steel E = 210000 MPa, ρ=7870 Kg/m^3, σ_{yield} = 200 MPa for ε_p = 0% and σ_{yield} = 480 MPa for ε_p= 0.18%. The impact attenuator consists of 6 layers of

ExpaAsym cellular structure with the base material thickness of 0.5 mm, and one exterior face sheet with a thickness of 0.5 mm; this results in a total weight of 1,426 Kg (1,13 Kg - the weight of the cellular structure and 0.296 Kg - the weight of the exterior face sheet). The dimensions of the analysed attenuator are: width w = 317,3 mm, length t = 236,8 mm, height h = 203,9 mm.

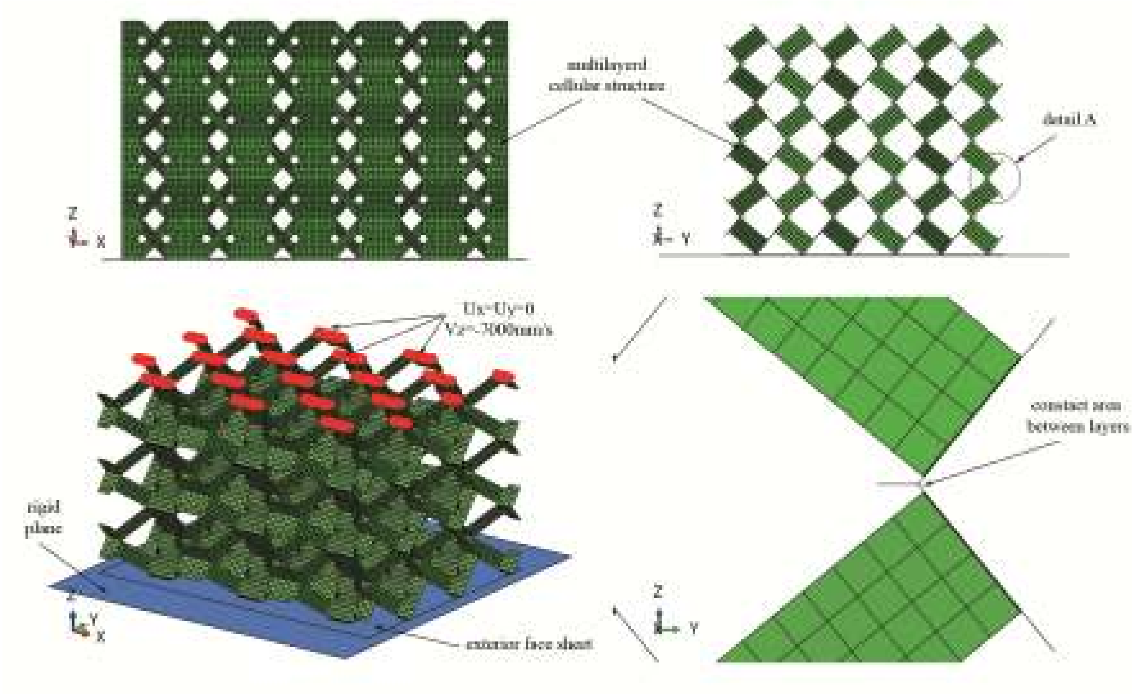

Figure 3: The FE model of the impact attenuator and the imposed boundary conditions

A concentrated mass of 300 Kg has been defined in a "master" node, positioned at 1000 mm along the Z direction, from the surface of the exterior face sheet that is in contact with the rigid wall. The superior nodes of the attenuator (marked with red in Figure 3), named "slave" nodes, are connected at the „master" node. An initial velocity of 7000 mm/s, Figure 3, was imposed to the master node which was implicitly transmitted to the "slave" nodes.

A great influence on the impact behaviour of cellular structures belongs to the deformation rate [10] $\dot{\varepsilon}$ which represents the rate of change of the specific deformation with respect to time. Its value can be calculated as the ratio between the impact speed v and cellular structure height h. According to the data presented in this analysis, the deformation rate has the value of 69.30/s. This value of the deformation rate, according to the classification of Ashby [10], is considered to be an *intermediate* value. As an order of size, the requirements of vehicles industry foresee the design of the elements required in impact considering deformation rates up to 40/s.

4. RESULTS AND CONCLUSIONS

The reaction force due to the impact is measured in the reference point that defines the position of the rigid plan, in terms of the distance of the nodes from the superior plane of the attenuator, and it is presented in Figure 4.

It can be observed that the value of the reaction force varies in lower limits around the value of 4000 N, Figure 4, allowing approximating that it is constant and thus fulfilling one of the conditions listed within section 1 for a high performance impact attenuator. Another requirement of an impact attenuator is also fulfilled, according to which the initial value of the impact force must be as close to the average load value.

The energy dissipated at a specific strain of 0.5, respectively when the impact attenuator height value is halved (100 mm), Figure 5, has a value of 323453 mJ. Thus, considering Equation (1), for a specific strain of 0.5 and at a deformation rate $\dot{\varepsilon}$ of 69.30/s, the energy absorbed per unit volume E_v has a value of 4.31 mJ/mm^3, respectively 4310000 J/m^3.

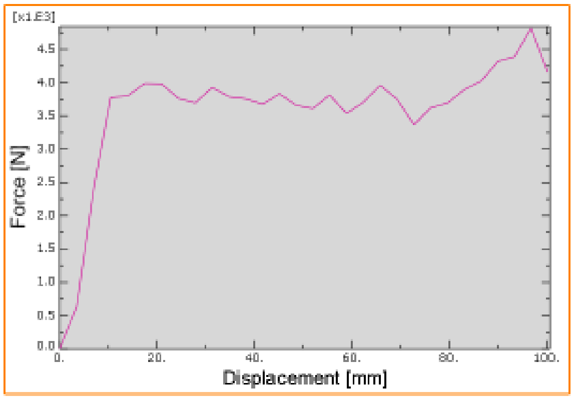

Figure 4: Reaction force registered at the deformation rate $\dot{\varepsilon}$ = 69.30/s

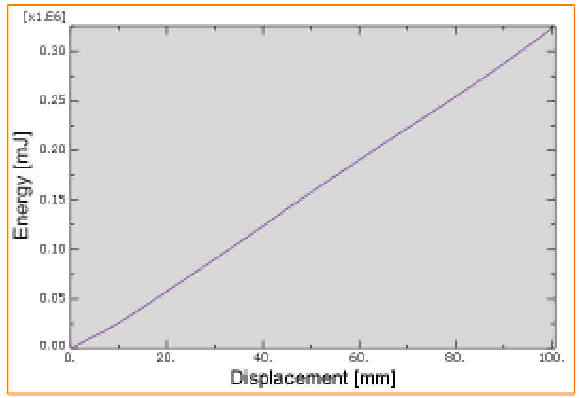

Figure 5: Dissipated energy by the plastic deformation of the cells' walls considering the deformation rate $\dot{\varepsilon}$ = 69.30/s.

Figure 6 illustrates the variation of deceleration up to a specific strain of 0.5, respectively when the height of the impact attenuator is halved (100 mm) being recorded a value of 15mm/s^2 (respectively 1.5g) at the beginning of the impact and then slightly increasing. This represents an important advantage in applications for passengers' transportation in order to increase their safety.

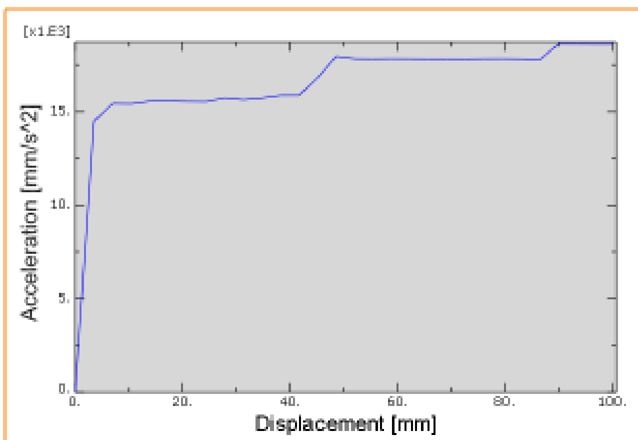

Figure 6: Variation of the deceleration within the impact scenario

Figure 7 shows the way in which the multi-layered cellular structure is deformed, and also the stress distribution in the material, expressed in MPa; it can be noticed the relatively constant distribution of stresses in the whole body of the cellular structure due to the impact loading.

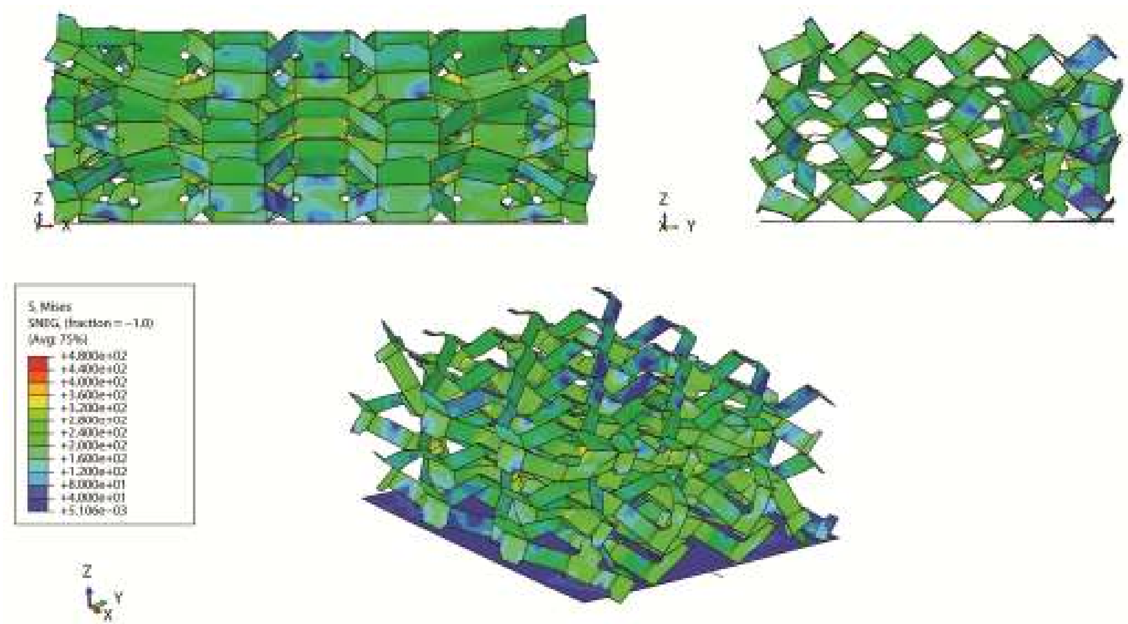

Figure 7: The deformations appeared in the structure at a strain of 0.5 and a deformation rate $\dot{\varepsilon}$ of 69.30/s

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