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Original Research Article

Global stability of an aluminum foam stand-alone energy absorber

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ABSTRACT

Aluminum alloy foam is the commonly used material in energy absorber design due to its excellent ability to dissipate energy in relation to density. This paper investigates the behavior of standalone absorber made of ALPORAS aluminum foam. The limiting parameters in the aforementioned application are the stability of absorber column and the risk of global buckling. Specimens with different slenderness ratio were crushed in order to find the transition point between local collapse of the cell walls and global buckling of the entire column. The ability of the aluminum foam energy absorber to work even after partial global buckling was presented.

1. Aluminum foam as energy absorber

Energy absorbing materials are important in many applications connected with the risk of impact [1]. Aluminum foam is the commonly used material in energy absorber design due to its excellent ability to dissipate energy in relation to density (Specific Energy Absorption) [2,3]. This parameter is responsible for the total mass of the designed energy absorber, but in some applications other parameters characterizing energy absorbers are more important. One such parameter is the stroke efficiency δ_{eff}, which describes the fraction of total length usable for crushing, defined as:

$$\delta_{eff} = \frac{\delta_f}{L} \tag{1}$$

where δ_f is the maximum usable length of absorber and L is the initial length of absorber.

Aluminum foam is usually an additional component in energy absorption devices, especially for filling metal tubes, or cladding material in sandwich structures. When applied in axially compressed metal tubes, foam increases the mass efficiency of the structure.

In metal tube absorbers the basic energy absorption mechanism consists in local buckling followed by local plastic deformation [4,5,12]. In the case of aluminum foam, the local buckling is related to the stability of the foam cell walls, which progressively buckle and are plastically deformed [6,7].

When aluminum foam is used independently as an axially compressed energy absorber, it offers the unique ability to maintain a perfectly stable compression force (plateau stress), which is a great advantage in comparison with metal tube absorbers, where progressive folding results in significant force variation.

Stroke efficiency is limited by various mechanisms, which depend on the type of absorber. For metallic tube absorbers, the maximum stroke efficiency is limited on the one hand by absorber slenderness (causing global buckling) and on the other hand by the total length of absorber at the end of progressive folding (bottom-up).

In the case of absorbers based on stand-alone aluminum foam, the effective stroke efficiency is limited in a similar

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manner by the same two mechanisms—the slenderness of the aluminum foam column and the compaction of the foam to a density which is similar to the density of the foam base material.

The desired average crushing force can be achieved in two ways:

- by selecting cross section area and
- by selecting the relative density of the foam.

The dependency between relative density and plateau stress is shown in Fig. 1.

Both of these parameters are restricted. Relative density is limited to commercially available grades of foam, whereas the cross-section area can be limited by available space.

In some applications, where relatively low force and long stroke is desired, the use of absorber with high slenderness ratio *L/D* is necessary, where *L* is the initial absorber length and *D* is the width of absorber base. In the paper [11] the slenderness dependent behavior of high density closed-cell aluminum foam (510 kg/m^3) was reported. The slender column fractured under compression load, the global bucking behavior was not observed (Fig. 2).

While the influence of some parameters, such as foam cell size or relative density, on the compression characteristics was widely investigated [3,6,9], the resistance of the standalone aluminum foam column to global buckling has not been researched in the available literature.

2. Experiment

The goal of the experiment was to check the resistance of a standalone foam absorber to global buckling, which can cause the loss of its energy absorption ability. In order to check the global stability, specimens with various slenderness *L/D* ratio were prepared, where *L* is the initial length of the specimen and *D* is the width of the specimen base. Specimens were made of ALPORAS closed-cell aluminum foam. Foam density was equal to 250 kg/m^3. For each specimen, uniaxial compression test was carried out. In order to avoid bending, the faces of specimens which were in contact with compressing plates were machined using face milling. The electromechanical Zwick-Roell machine equipped with crushing plates was used for tests.

All tests were carried out as quasi static compression with a compression rate of 1 mm/min. Slow deformation causes the absence of stabilizing effects of inertia, which in the case of dynamic crushing can inhibit the global buckling of the absorber column.

The average cell size *d* in aluminum foam influences the plateau stress and Young's modulus. Of high importance is the cell size to specimen base ratio $D/d<6$ [9]. To avoid the influence of the cell size effect, the specimens with the base size of $D=50$ mm were used. For the average Alporas foam cell size of 4.5 mm, the ratio of base of specimen *D* to cell size *d* is greater than 10.

Specimens with an *L/D* slenderness ratio of 1.0–5.0 were investigated and the results of the buckling test for each specimen are presented in Table 1.

Selected photographs of compressed specimens are presented in Figs. 3–5. In the case of specimens S1 and S2, characterized by low slenderness up to 2, global buckling was not observed. Samples were progressively compressed until they reached the densification phase (Fig. 3).

The S3 specimen with slenderness 2.4 exhibited a transition between stable compression and global buckling. The deformed specimen compressed up to 55% is shown in Fig. 4.

The S4–S6 specimens with higher slenderness undergo global buckling. S4 specimen with *L/D* ratio 3.6 was partially able to absorb energy, but the absorption was unstable. The deformed S4 specimen after global buckling is shown in Fig. 5.

Fig. 6 presents the stress–strain characteristics of specimen compression. Nominal stress and nominal strain were calculated with equations:

$$\sigma_{nom} = F/A_0 \tag{2}$$

$$\varepsilon_{nom} = \Delta l/l_0 \tag{3}$$

where A_0 and l_0 are the initial cross section area and length of the specimen respectively.

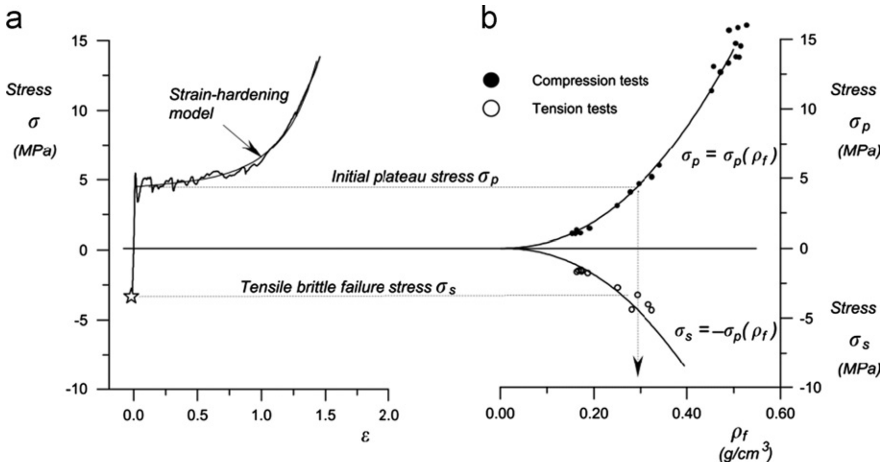

Fig. 1 – Dependency between relative density and plateau stress for closed-cell aluminum foam [11]: (a) typical stress–strain curve and (b) power law relationship.