# COMPRESSION TEST EVALUATION METHOD FOR ALUMINIUM FOAM PARTS OF DIFFERENT ALLOYS AND DENSITIES

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***Abstract***
*In general, the stress-strain curves of aluminium foam obtained from uniaxial compression tests are not smooth and the expected plateau is missing. Moreover, the curve often exhibits lot of peaks with locally dropping stress instead of slowly increasing stress before final densification. The paper is therefore aimed to describe and explain these effects and is based on the experimental compression testing of several hundred samples. It has been shown how the structural non-uniformities in foam structure affect the stress strain curve in compression, i.e. collapse stress, densification stress, corresponding strains, and finally the potential of foam in crash energy absorption. Moreover, a way for objective evaluation of the tests was suggested.*
***Keywords: aluminium foam, uniaxial compression, evaluation method***

## INTRODUCTION

The most common test method for aluminium foams is the uniaxial compression test. The stress-strain curves obtained from tests consist of three parts: 1. quasi-elastic region, 2. plateau region and 3. densification region. The quasi-elastic region is defined up to the yielding of the weakest pore layer, usually called collapse stress. The plateau region is characterized by high energy absorption efficiency, where almost the entire deformation energy is absorbed at constant force level. The densification region is characterized by rapid force increase at almost constant strain.

However, the regions on stress-strain curves are different due to variability of the aluminium alloy composition, structural defects, porosity, etc. and therefore a typical stress-strain curve of aluminium foam does not exist. In this paper, the problems occurring during the evaluation of the compression testing and objective evaluation method are introduced.

## EXPERIMENTAL

The specimens for experimental study were manufactured according to Alulight® process from brittle (AlSi10, AlSi12Mg0.6) and ductile (AlMg0.4, AlMg1Si0.6) alloys with variable porosity. Compression tests were also performed on samples made according to Alporas® process. The experimentally measured values of compression force F [N] and deformation L [mm] were evaluated as follows:

- the collapse stress σ was calculated from the force F [N] using an apparent cross-sectional area A [$mm^2$] of the specimen:

$$\sigma = \frac{F}{A}[MPa]$$

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- strain ε [%] was calculated from the deflection L [mm] and initial height h [mm] of the specimen:

$$\varepsilon = \frac{L}{h} \cdot 100[\%]$$

- energy W [J] needed for deformation up to L:

$$W = \int_0^L F(L)dL$$

- Efficiency eff [%] of the energy absorption was calculated as the ratio of actually absorbed energy W at the deflection of L to the ideal absorption, where $F_{max}$ is the maximum force obtained until the deflection L was attained.

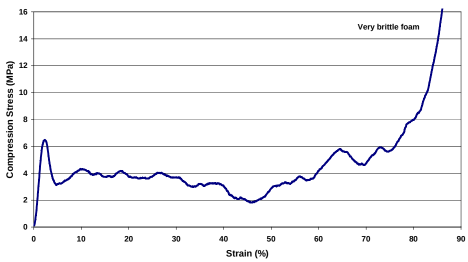
$$eff = \frac{W}{F_{\max} \cdot L}$$

## RESULTS AND DISCUSSION

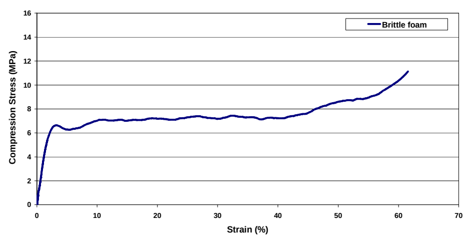
### Typical approach for evaluation of the uniaxial compression test

Based on all compression tests on various aluminium foams which were performed in the last 15 years at IMMM SAS, aluminium foams can be sorted out with regard to deformation behaviour during compression loading into the following four groups:

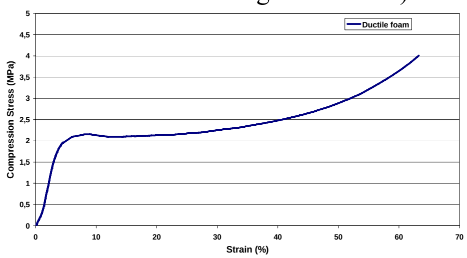
1. Very brittle foams with significant disintegration.
2. Brittle foams without significant disintegration.
3. Ductile foams with clear plateau stress or collapse stress.
4. Ductile foams without clear plateau stress or collapse stress.



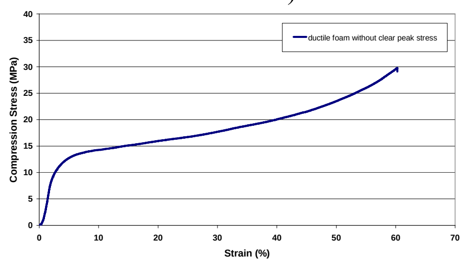

1. Very brittle foams or thin walled parts made of brittle foams. Disintegration can occur (cell wall fractures during deformation).




2. Brittle foams – without significant disintegration (cell wall fractures during deformation).




3. Ductile foams with clear plateau stress or compression strength. (Bending of cell walls during deformation – densification of the foam).




4. Ductile foams without clear plateau stress or compression strength. (Bending of cell walls during deformation – densification of the foam).

Fig.1. Types of deformation behavior for different aluminum foams.

It is suggested that the correct evaluation of the uniaxial compression stress-strain curves should be done according following steps:
a. Recording the stress-strain curve

***First and second derivation of the stress-strain curve***

First local maximum on the curve is defined as collapse stress. In this case, the first derivation equals zero and second derivation is negative. The second zero point with a positive second derivation corresponds to the first force minimum. This determination is precise and works very well for the typical stress-strain curves 1, 2 and 3. If there is no clear local maximum (the curve continuously rises), the plateau force and the collapse stress can be determined as the first local minimum of the first derivation of the stress-strain curve.
b. Calculating the absorbed deformation energy $E$ ($J$) for all points on the curve.
c. Calculating the energy absorption efficiency $E_{ff}$ (%) for all points on the curve.
d. Creating the energy absorption efficiency-strain curve.

***First derivation of the energy absorption efficiency-strain curve***

The last local maximum of the energy absorption efficiency-strain curve is the end of the plateau region. In this case, the first derivation equals zero; this point represents actually a deformation level beyond which no increase of energy absorption efficiency can occur. The energy absorption efficiency continuously decreases and no subsequent increase is possible.

**Characterization of the typical stress-strain curves**

The typical curves are presented in Fig.2 and in Fig.3. A significant difference between brittle and ductile foam can be seen. The reason is that brittle cell walls crack during deformation because of partial sample disintegration, the compressed cross-section is reduced. This effect is responsible for the sudden stress drops in the stress-strain curve. Ductile cell walls deform plastically, the prevailing deformation mechanism is bending of the cell walls and almost no disintegration of the foam occurs.

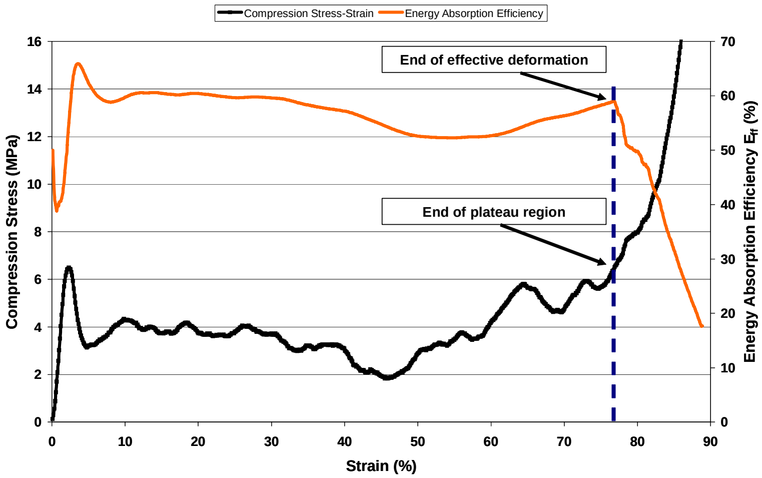



Fig.2a. Stress-strain and energy absorption efficiency-strain curves of very brittle foam; cylinder D20x30 mm made of AlSi12 foam with 85% porosity.

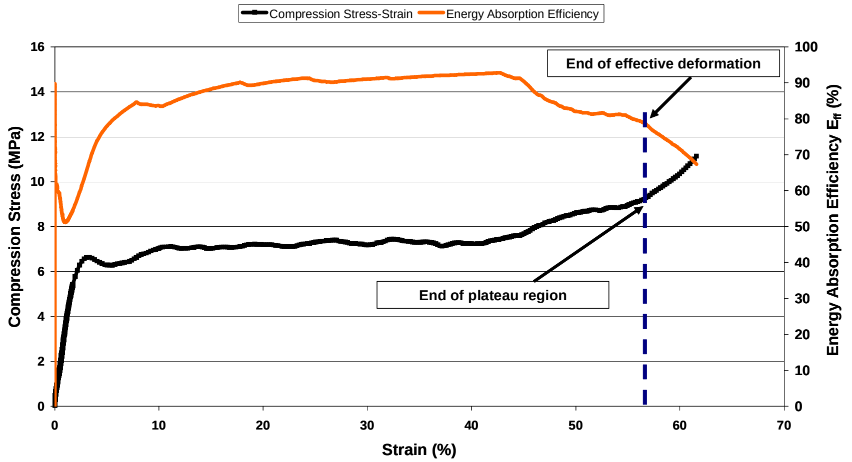



Fig.2b. Stress-strain and energy absorption efficiency-strain curves of brittle foam; 50 mm cube made of AlSi10 foam with 81% porosity.

In the case of very brittle foams, the evaluation was performed on the stress-strain curve obtained for cylindrical sample D20x30 mm made of AlSi12 foam with 85% porosity. Generally, the very brittle foams are characterized by the first stress peak followed by a strong drop. This drop can occur either instantly after the first stress peak or after the certain deformation (Fig.2a). The strong drops of compression stress always lead to a reduction of energy absorption efficiency. The disintegration of material occurs accidentally, and hence it is undesirable. Therefore, the reproducibility of foam parts with this stress-strain characteristic is very poor. In cases of very strong and long stress drops, there is no plateau region. The stress-strain curve of brittle foam obtained for the 50 mm cube made of AlSi10 foam with 81% porosity (Fig.2b) does not exhibit strong stress peaks and drops. The energy absorption efficiency is high because of plateau formation. It is also possible to reach very good reproducibility of stress-strain curves for these foams.

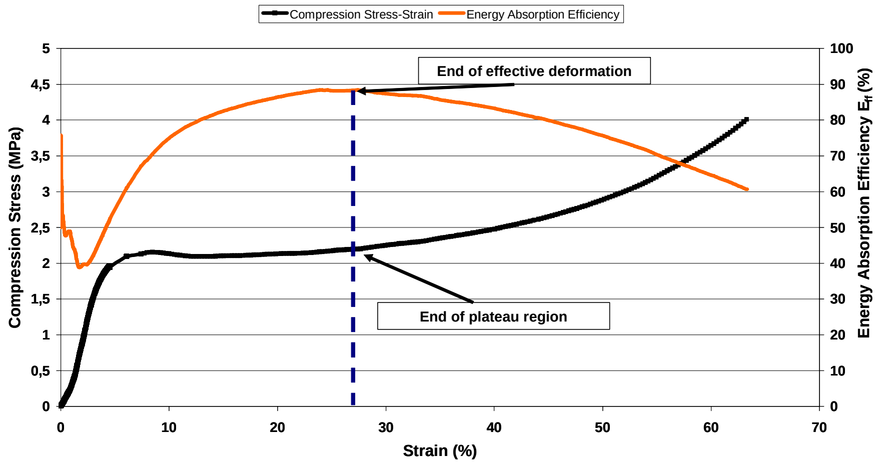



Fig.3a. Stress-strain and energy absorption efficiency-strain curves of ductile foam with clear collapse stress peak; Alporas (Al+1.5wt.% Ca), cube 45 mm, 88% porosity.

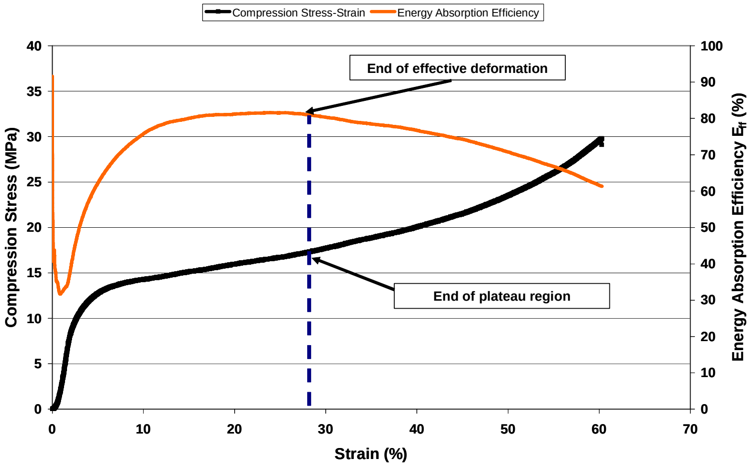



Fig.3b. Stress-strain and energy absorption efficiency-strain curves of ductile foam with unclear collapse stress peak; AlMgSi0.6-foam, dimensions 49x55x35 mm, 77% porosity.

Ductile foams exhibit a continuous stress-strain curve without disintegration of material. However; the end of the effective deformation length is significantly shorter in comparison with brittle foams. The effective deformation length is less than 30% strain in this case. The reason for the shorter effective deformation is almost no disintegration of material. Moreover, the cell walls are successively bent and compressed during the deformation. The curves on Fig.3 were obtained for a 45 mm cube made of Alporas® foam with 88% porosity (Fig.3a). The curve with unclear collapse stress was obtained for a 45 mm cube of Alulight®-AlMgSi0.6 foam with 77% porosity (Fig.3b).

## CONCLUSIONS

Evaluation of the typical stress-strain curves showed that the method presented can be used for characterization of the deformation behaviour of aluminium foams. An estimation of the effective deformation length is necessary for calculation of the maximal amount of deformation energy which can be effectively absorbed during the crash. The evaluation standard must be able to provide reliable values which can already be utilized in the early stages of designing crash absorption units.

## Acknowledgements

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