International Conference “ADVANCED METALLIC MATERIALS”
5 – 7 November, 2003, Smolenice, Slovakia

CELLULAR ALUMINIUM FOAM PANELS UNDER TENSILE LOADING

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Abstract – The cellular materials are useful for passive safety components. Foamed powder compacted aluminium is characterised by X-ray tomography (XCT), of which local mass density data are derived to transform the cellular structure into a continuum. The mass density distribution and the skin of the panels influence the E-modulus, tensile strength and engineering strain to failure.

Keywords: cellular aluminium, tensile behaviour, density map

1. INTRODUCTION

Cellular materials are especially good in absorbing kinetic energy by conversion into plastic deformation when compressed. For the design of components all mechanical properties have to be known. In literature many data on compression behaviour are published [1,2], but hardly any data on tensile behaviour, which are needed for a successful design of load bearing structural elements.

In general tensile behaviour showed that the deformation is concentrated in weak regions of the cellular metal [3]. Deformation bands are formed in the stage of final failure. In ductile cellular metals such as foamed aluminium cracking of cell walls and cell edges can also be observed before a main crack starts to propagate. With increasing deformation, a damage zone starts to develop in which the whole deformation is concentrated. In closed-cell metals, several cell walls rupture inside this damage zone. Further deformation leads to the development and propagation of a main crack along the weakest path in the cellular structure. Only the strongest cell edges remain intact and hold the two foam parts together [2]. In the paper of Motz et. al [3] a relaxation in tensile loading of foam core material can be seen when crack growth was found, this was followed by hardening of the foam. The stiffness module was unaffected by damage till maximum stress was reached.

Falahati et. al. [4] characterized AlMg1Si0.6 foams, with an average density of the plates of 0.5 g/cm^3. Foam cores and tensile samples with skin typical for powder compact foam were tested. Fig. 1 depicts the tensile curves, with loading and unloading loops. The different behaviour between foam core material and samples with skin can be seen. The strength and the stiffness module is higher in samples with skin, but the ductility is remarkable lower than for foam core material. The skin has a reinforcing effect on the sample. Comparing the evolution of stiffness modules as function of elongation gives a continuous stiffness drop in skin reinforced sample, while stiffness module of foam core material remains constant with elongation. Objective of this paper is the investigation of metallic foam samples with skin loaded under tension, so that the effect of reinforcement by the skin can be understood better. The experimental behaviour is analysed and a model for interpretation is presented.

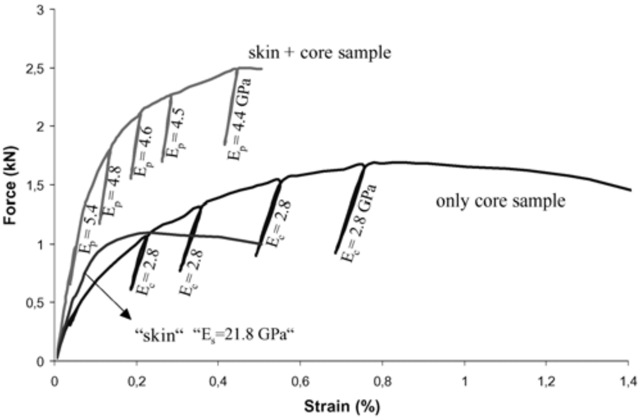

Fig. 1[4]. Force-strain curve of tensile sample made of AlMg1Si0.6 foam; the curve for the “skin” was estimated according to the model introduced in this paper.

2. MATERIAL AND DENSITY DISTRIBUTION

The powder compacted foam AlSi10 alloy from Slovak Academy of Science [5] was investigated by medical computed tomography providing a voxel size of 0.4 × 0.4 × 3 mm^3. Density mappings of each sample were calculated by the procedure described in [6] using averaging volumes of 8.91mm × 9.00mm × 15.80mm for samples with skin and of 8.91mm × 9.00mm × 12.80mm for the foam core. The average density of the whole plate was $\rho = 0.40$ g/cm^3.

Powder compact foamed samples have a skin of metal, oxide and compressed pores at the surfaces. Structural analysis revealed that the skin layer is followed by very small cells. Gradually the size of cells is increasing till the centre. A significant interface from skin to foam core can not be defined [5].

The density distributions of the samples with skin and the foam core show that the density distribution is dominated by the core material, whereas the skin does not change the variations in the density distribution fig. 2, which means its mass is relatively uniform.

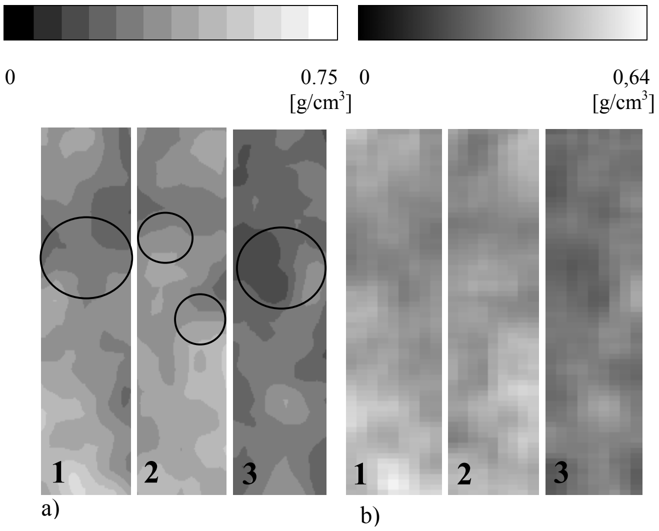

Fig. 2. a) density mapping of investigated sample with critical areas b) density mapping without skin (1.5 mm of face was cut off)

3. TENSILE TEST

Dog-bone specimens with thickness of 15.8 mm, width of 25.4 mm, length of 250 mm and a gauge length of 100 mm, were cut from powder compact foam plates. Average density of each sample was about 0.4 g/cm^3. All specimens were reinforced in the gripping head zone with thin steel sheets, which were attached with epoxy resin. The tensile tests were performed at room temperature using the universal test machine Zwick equipped with a 50 kN loading cell. The displacement rate was 0.5 mm/min. Loads and displacements were recorded simultaneously during all mechanical testing. Stiffness of specimens was calculated from the slope of the unloading load-loops taken at 0.1, 0.2, 0.3, and 0.4% nominal strain.

4. RESULT OF TENSILE TEST

The stress strain curves of fig. 3 show the typical behaviour of investigated samples. The crack initiation, which was visually observed on the skin is also marked in the diagrams. In case of fig. 3a the sample showed macroscopic ideal plastic behaviour after cracking. In case of fig. 3b and 3c, hardening of the sample occured, after crack initiation. For all the samples it can be stated that they do not fracture immediately when cracks on the skin were detected.

In general, the trend was found that the stiffness module was moderately reduced with increasing elongation, but when crack initiation was observed a significant drop in stiffness module was measured, while the strength of the samples still increased.

Usually a crack was formed only on one side of the sample, sometimes the crack stopped, when loading proceeded. The crack paths at 0.6% strain are shown in fig. 4. In sample 3 having the stress-strain curve depicted in fig 3c, a rather straight crack front was found. All other samples show cracks having a step like shape. Correlating these crack paths to the density distribution shows, that the cracks are located in low density regions of the samples marked in fig. 2a.

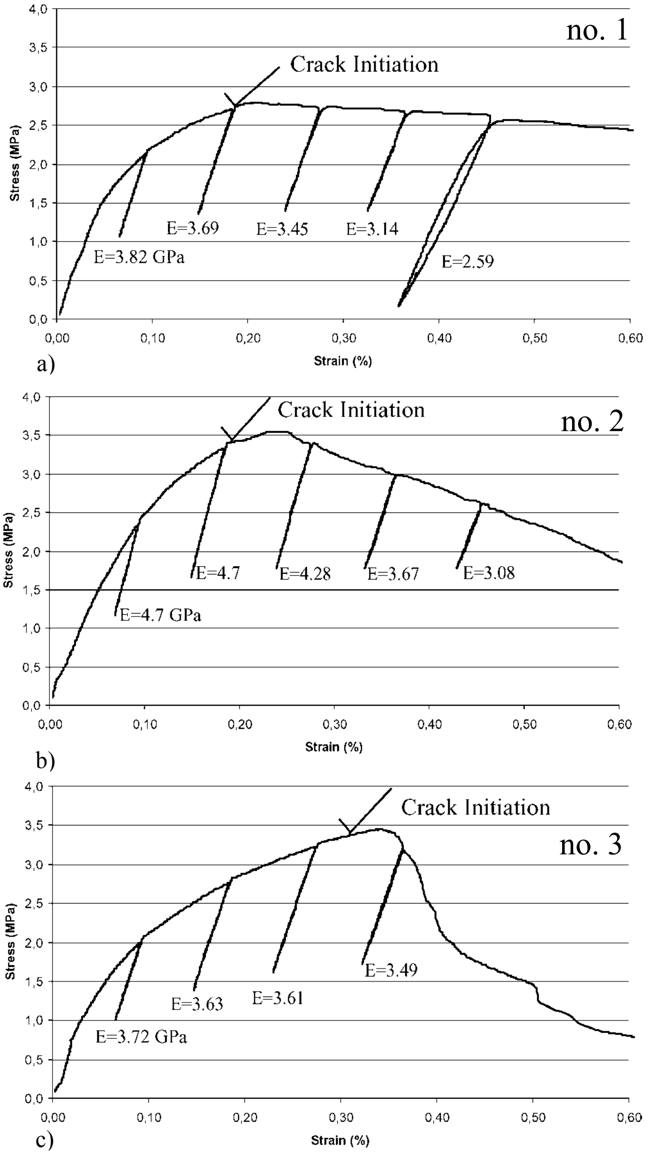

Fig. 3a-c. Stress-strain curve of investigated samples, showing the E-modulus of loading/unloading loop, and the observed start of cracks in the surface skin.

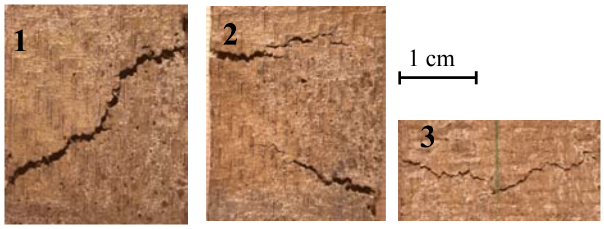

Fig. 4. Cracks of the skin on the tensile test specimens after failure; cracks are located in areas of low density marked in fig. 2a. (numbers refer to the samples shown in fig. 3 and 2)

5. MODEL OF BEHAVIOUR AND DISCUSSION

In principle wrought alloy foam type [4] shows the same behaviour found in the present work. Of course the stiffness and stress level are not the same due to the different ductility and density of the two materials. From that result it can be stated that, the skin has a reinforcing effect. Results of both investigations are taken to describe the behaviour by a model.

The following mechanisms seem to determine the behaviour of the skin reinforced sample. Caused by the combination of skin and foam core, the stiffness of the sample with skin is increased. This assumption is reasonable for the present samples considering the results of Falahati [4] (fig. 1), who measured modules of foam cores and samples with skin.

Loading the sample gradually leads to the damage of the skin first which lowers stiffness, while the foam core is still intact and does not show reduction in stiffness when further strained. So it is assumed that the stiffness of samples with skin is constrained by the skin. When cracking of a skin occurs, a drastic loss in stiffness module of skin reinforced sample is observed, but an increase of strength is still found. On first sight this experimental result leads to the model that the foam core has the capability to compensate the loss of strength by hardening, like wrought alloys do (fig.1). Whether this mechanism works, depends on the thickness, properties of skin layer and the hardening coefficient of foam core material.

In the present experiments the skin on either side of one sample cracked at different strains. So a modified mechanism, than that discussed before seems to be more likely for the investigated material. From XCT result, it is shown that skin and core material have non uniform density, which lead to different stress-strain response of each component. If one skin starts cracking, the second skin, having less defects, still hardens. As long as the intact skin and the foam core can compensate the loss of strength because of the damaged skin, the overall stress level of the sample still increases. As soon as both skins are damaged or the second skin and the foam core cannot compensate the loss of strength of the other skin, the stress level of the whole sample is reduced. Depending on the local density of the sample and the skin, the properties of skins and foam core are determined, which consequently determines the behaviour of the overall sample.

An estimation of the properties of the skins in fig. 1 can be derived by mechanical properties of foam core and sample with skin applying the rule of mixture. The stiffness module of the panel with skin E_p can be estimated by:

$$E_p t_p = E_{core} t_c + E_{skin}(t_p - t_c) \qquad (1)$$

when t_p is the thickness of the panel and t_c the thickness of the core without skin. The samples measured in [4] have E_{skin} = 21.8 MPa assuming a thickness of 1mm on each side, thus corresponding to an average density of about 1.4 g/cm^3. Fig. 1 clearly indicates that the skin passes its maximum strength when the stiffness of the panel drops significantly.

Depending on the thickness of skin, it can be shown that the model quantitatively explains the experiment, but further investigation on foam core material and reinforced material have to be carried out to clarify, the effects quantitatively.

6. CONCLUSION

The powder compacted aluminium cast alloy foam AlSi10 with skin was investigated under tensile loading. The mechanical behaviour like tensile strength, tension strain to failure and stiffness modulus were investigated. Characterisation of the stress curve and evidence in literature, let assume that the skin has reinforcing effect on foam core. Using a superposition model of properties of skin and foam core, described by the rule of mixture, helps to explain the skin reinforced sample. Thus the observation of decreasing stiffness of tensile loaded cellular aluminium plates with cracking skin while still strengthened can be explained by the low ductility of the skin material compared with the core. This drop in stiffness can be used as damage indicator for foamed components overloaded in service before rupture occurs.

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