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Dynamic compressive behaviour of aluminium foams fabricated from rejected precursor materials

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Abstract

The work aims to study the deformation and failure mechanisms of rectangular aluminium foam blocks prepared from rejected precursors using dynamic uniaxial compressive tests supported by middle-wave infrared thermography. The dynamic compressive behavior of these foams was compared to the behavior of the foam blocks prepared from a traditional single precursor. The results indicate that the foams from rejected precursors begin to deform at lower strain with local deformation dispersed at the foam surface leading to the formation of many deformation bands, while the reference samples (fabricated from a single precursor) present only few deformation bands which are mainly located at their lower and upper ends. The bands occur at the weakest points of the samples, which in case of the samples made of rejected precursors correspond to the joining regions formed within the foam by the different precursors used during the foaming process. In these joining regions imperfections and structural defects are developed, i.e. micro-pores promoting a stress concentration for crack initiation. The results also indicate that the plateau region of the compressive stress-strain curves (the stress gradually increases with increasing strain) is much more inclined in case of the foams from rejected precursor pieces compared to the reference ones.

Keywords: aluminium foams; uniaxial compression behavior; deformation mechanisms.

1. Introduction

The powder metallurgy [1] is an eco-efficient process to produce metal foams. Simple or complex near net shape parts of aluminium foams with considerable large dimensions can be obtained using rejected precursor pieces (clipped materials) in the cutting intermediate stage, which is the step used to cut the usual single precursors with dimensions and geometry of the required foam component from large extruded panels [2]. Few research works have been conducted to explore the fabrication of the foam parts using various small precursor pieces instead of a single precursor [3-5]. The considerable precursor losses in the cutting step, as well as the difficulty to prepare large components were the main motivation of this research since both lead to an increase of the production cost. For example, the fabrication of large precursors is technically more problematic than to make smaller ones using the conventional compaction techniques (e.g. hot extrusion). X-ray radioscopy showed that the smaller rejected precursors should be placed randomly (preferentially perpendicular to each other) [5] inside the closed mould without further compaction. Although a slight increase of the foaming temperature is required, no additional precursor is needed [2]. X-ray

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tomography showed that the high local densities in joining regions and in areas of delayed pore nucleation are formed in the internal structure of these foams prepared by expanding smaller rejected precursors [5]. These foam products result from a rather eco-efficient process where the rejected sub-systems enable the formation of an integral-skin foam exhibiting a slightly lower compressive properties [2]. It has been demonstrated that high quality foam parts, including the foam filled profiles [6] can be fabricated using rejected precursor pieces, for use as fillers in multifunctional construction elements for energy and sound absorption, and vibration damping. Herein, the work aims to study the deformation and failure mechanisms of rectangular foam blocks prepared from rejected precursors using uniaxial dynamic compressive tests supported by middle-wave infrared (IR) thermography. The IR has been proved to be an effective method to observe the deformation modes and collapse of different types of structures based on cellular materials (e.g. open-cell metal foams, closed-cell foams and foam filled tubes) [6-12]. The IR thermography during the compression tests is enabled to locate initial plastification and the densification zones in which the energy is transformed into plastic deformations and heat [11].

2. Experimental

2.1. Preparation of specimens

Rectangular blocks of closed-cell 6061 foams (50 x 50 x 80 mm) were prepared using an extruded panel of foamable precursor material of 6061 (Al1Mg1SiCu) with a rectangular cross-section of 160 x 20 mm (A, Fig. 1a). This panel was prepared in two steps. Firstly, a cylindrical billet was prepared by cold isostatic pressing of a powder mix (~50 kg) of 6061 alloy and titanium hydride (0.5 wt.%). Secondly, this cylindrical billet previously preheated (350 ºC) was extruded to rectangular panels using a horizontal 25MN direct extrusion machine, as described in detail in [1]. A closed rectangular steel mould (50 x 50 x 80 mm) was constructed to be used in this research. Rectangular foam blocks (Fig. 1b) were prepared using approx. 128 g of rejected precursors from the panel (no defined geometry, C, Fig. 1a) which was introduced randomly into a closed mould without further packing (no compaction). To compare the mechanical behaviour (including the deformation modes) of these foams with behaviour of the conventional foams prepared using a single traditional precursor, rectangular foam blocks were prepared using only one single piece of precursor (50 x 50 x 20 mm, B, Fig. 1a) with the same amount of precursor (approx. 128g). Foams were fabricated by placing the mould containing a single precursor piece or rejected precursors into a pre-heated furnace at 740ºC and 760ºC, respectively. The density of the foam blocks was determined by dividing their mass by their volume.

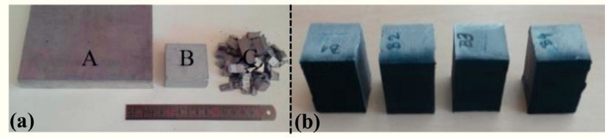

Fig. 1. (a) Panel (A) and single precursor (B), and small rejected precursors (C). (b) Rectangular foam blocks (50 x 50 x 80 mm).

2.2 Mechanical characterization

The foam block specimens were subjected to uniaxial compression tests using a servo-hydraulic INSTRON 8801 under dynamic loading condition (loading rate: 284 mm/s). The deformation and failure modes were additionally studied using a high speed cooled middle-wave IR thermal camera Flir SC 5000 [11-12].

3. Results

Fig. 2a and Fig. 2b show IR thermography image sequences recorded during the compression of foam block specimens prepared by rejected precursors and by a single traditional single precursor, respectively.

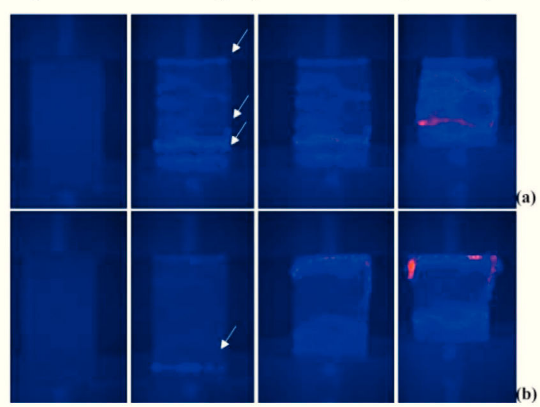

Fig. 2. Dynamic compression of foam blocks prepared (a) from rejected precursors and from a single precursor (b).

The bands occur at the weakest points of the samples. In the foam blocks from rejected precursors, these bands are localised in the different joining regions formed during their formation. X-ray tomography and X-ray radiography showed that many imperfections and structural defects (e.g. micropores) are developed during the formation of a foam resulting in stress concentrations where the cracks initiate [5]. Clearly, the foams from rejected precursors have a premature failure, due to the strong variation in their cellular structure. IR thermography also revealed that few additional bands are formed in the undeformed region. As the compressive loading proceeds the deformation progresses in other weaker regions, through the undeformed region in a layer-wise deformation mode. The failure subsequently develops along the clusters of defects. After the cell wall material becomes completely pressed together, it finally results in total collapse (densification region). Clearly, the inhomogeneous density distribution leads to localisation in several deformation bands. The irregularities in these foams can represent the difficulty in prediction of their mechanical behaviour. With the increase of compression load these deformation bands (Fig. 2a) converge to a single one, normal to the loading direction, as observed in the reference ones (Fig. 2b). The deformation modes of these foams are identical to the other closed-cell metal foams [7]. Figs. 3 and 4 show dynamic compressive curves of rectangular foam block specimens from rejected precursors (0.48-0.55 g/cm^3) and a single traditional precursor (0.47-0.49 g/cm^3), respectively.

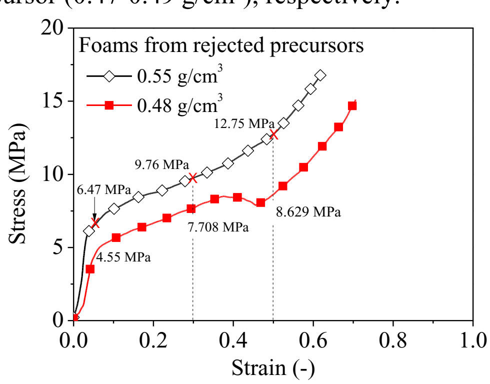

Fig. 3. Dynamic compressive stress-strain curves of the foams prepared by rejected precursors.

Both type of foams show typical shapes of compressive curves of the closed-cell aluminium foams that are divided into three regions (linear-elastic, plateau and densification) [7]. Nonetheless, the shape of the compressive curves clearly depends on the origin of the foams (from rejected precursors or traditional single precursor), in particular in the plateau region and the densification strain. The plateau region of the compressive stress–strain curves (the stress gradually increases with increasing displacement) is much more inclined in case of the foams from rejected precursors (Fig. 3) compared to the reference ones (Fig. 4). The plateau region of the compressive stress–strain curves is well defined for the foam blocks from a single precursor piece. Nonetheless, the oscillation (fluctuation) of stress in the plateau region is observed for these foams (Fig. 4). The densification of the foams from rejected precursors (above of 0.45 strain, Fig. 3) occurs much later than in case of foams fabricated from a single precursor (above of 0.6 strain, Fig.4).

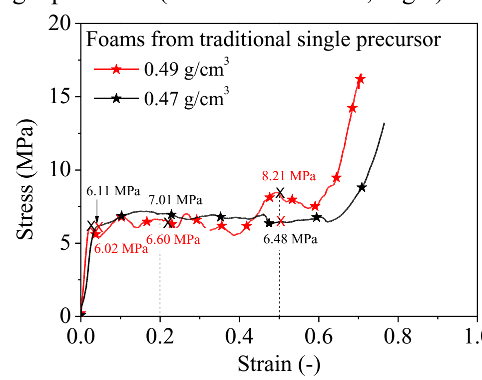

Fig. 4. Dynamic compressive stress-strain curves of the foams prepared by a single precursor piece (50 x 50 x 80 mm).

As it is well known, an efficient energy-absorbing material should have high yield stress, a long flat plateau and high initial densification strain [13]. Depending on the cellular structure and the properties of the base material, the plateau region of the compressive curve may not be flat, but inclined or oscillated, as it was the case for both types of the foams studied. The plateau region of the compressive curves of foam blocks from rejected precursors is inclined (Fig. 3). This is due to the formation of a non-uniform foam structures with areas of remarkably different pore sizes and shapes and different density [5]. Although, foam blocks from single precursor exhibit an oscillation of the stress in the plateau region, it is much more flat (Fig. 4). The results, also demonstrate that the curves and the mechanical properties of the foams increase mainly with the foam density, independently of their origin. For example, the yield strength of a foam block from rejected precursors with a density of 0.55 g/cm^3 is 6.47 MPa (Fig. 3), while the foam from single precursor with a density of 0.49 g/cm^3 is 6.11 MPa (Fig. 4). Nevertheless, a non-uniform cell size distribution, including the presence of structural imperfections could reduce the yield strength of these foams. For example, the yield strength of a foam block from rejected precursors having 0.48 g/cm^3 is 4.55 MPa (Fig. 3), while the foam from single precursor having 0.47 g/cm^3 is 6.02 MPa (Fig. 4). The shape of the compressive curves strongly depends on the origin of foams (from rejected or from single precursor). The compressive behaviour of the foams is directly related to their capacity to absorb energy during an impact. To analyse this, energy absorption curves are calculated by integrating the area under the experimental stress–strain curves for a given testing specimen, as shown in Fig. 5.

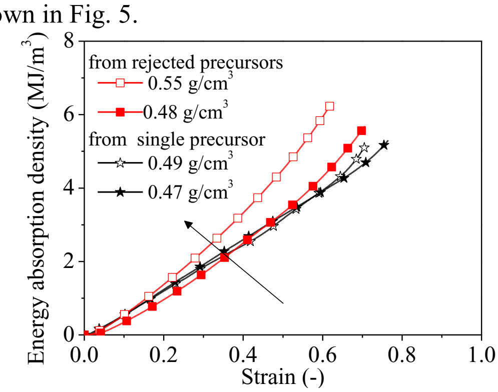

Fig. 5. Energy absorption density curves of foam block prepared by rejected precursors and a single traditional precursor.

The results demonstrate that the foams from smaller rejected precursors present promising results when compared to the foams made from a single precursor. The problem is that the foams from rejected precursors lead to a high scatter of values in terms of density and the variation of the cellular structure. These foams are characterised with non-uniform cellular structure with areas of remarkably different pore sizes and shapes and different densities. The global behaviour could be compared to conventional foams. The results even indicate that foams with identical densities have the same energy absorption efficiency, independently of the origin of the foams (Fig. 5). For example, a foam block from rejected precursors with 0.48 g/cm^3 absorbs 3.33 MJ/m^3 (0.5 of strain) under quasi-static compression which is similar to the foams with 0.47 and 0.49 g/cm^3 prepared by expanding a single precursor. As for structural applications of closed-cell aluminium foams, where the mode how the structures deform is not of crucial importance, but the global amount of absorbed energy, these foams are suitable to be used in the industry, replacing the conventional foam.

4. Conclusions

The dynamic compressive behaviour of the foams prepared by expanding rejected precursors was compared to the behavior of the foam blocks prepared from a traditional single precursor. The results presented and discussed along this work enable the following conclusions to be draw:

The foams fabricated from rejected precursors begin to deform at lower strain showing local deformation dispersed on the foam surface leading to the formation of several deformation bands that correspond to different interface regions formed [5] during the foaming process.

The plateau region of the compressive curves of foam blocks from rejected precursors is inclined, while they are almost constant in the case of foam blocks made from a single precursor piece. This is due to the formation of a non-uniform foam structure with areas of remarkably different pore sizes and shapes and different densities.

Identical energy absorption efficiency can be achieved by foams fabricated from different number of precursors.

Acknowledgements

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