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Poster Session

ENERGY ABSORPTION OF ALUMINUM FOAM-FILLED TUBES UNDER QUASI-STATIC AXIAL LOADING

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Abstract

Closed aluminum foams fitted thin-walled circular tubes was investigated for its energy absorption characteristics. Compression test was carried out to obtain the representative quasi-static stress-strain curves. The deformation characteristic (foam, tube and their combination) was analyzed. The results indicated that the deformation mode of aluminum foam and tube changed after combine. Foam–tube configuration absorbed more energy than the sum of foam and tube due to the interaction between tube and filler which contains friction, extrusion, crack formation and growth. In addition, the energy absorption of foam–tube configuration was 6 times of aluminum foams. The experiment results reflected that the foam–tube configuration was a potential energy absorber candidate for car industry and transportation cask.

1. Introduction

Metallic foams are excellent energy absorber as they can convert impact energy into deformation energy [1,2].The energy absorption abilities of aluminum foams have been investigated in recent years due to their potential application [3-5]. There is an increased interest in aluminum foams with composite structure such as aluminum foam sandwich and aluminum foams as fillers inside thin-walled metallic tube [6-7]. The bending strength of aluminum foam sandwich was increased by sandwich composition [8]. When aluminum foams as fillers inside thin-walled metallic tubes, energy is absorbed as the foam cell walls bend plastically, buckler fracture with the stress limited by a long, flat plateau on the stress-strain curve [9]. Hanssen et al. [10] performed a comprehensive experimental study on filling thin-walled columns with aluminum foam. They found a significant increase in crushing force from the compressive strength of the foam and the interaction between the foam and the wall column. The foam-wall interface decreased the folding length and hence increases the crushing force. L. Mirfendereski and M. Salimi [6] discussed the deformed shapes, load–displacement, fold length and specific energy absorptions of empty and foam-filled thin-walled tubes by numerical analysis; Teixeira-Dias [7] investigate the role of the plastic deformation of metal foams on the dynamic behavior of aluminum foam-filled columns with respect to their energy absorbing capabilities by finite element modeling.

In this paper, we present an experimental study on the static axial crush performance of both unfilled and aluminum foam-filled tubes. Compression test was carried out to obtain the representative quasi-static stress-strain curves. The deformation characteristic (foam, tube and their combination) was analyzed.

2. Experimental

The tubes were 6063 Al alloy with outside diameter of 30mm and wall thickness of 1mm, giving a diameter to thickness ratio of 30. Closed-cell aluminum foams were prepared by molten body transitional foaming process in Northeastern University with the porosity of 80%. The raw materials for preparing foams were Al-Si alloy (6.5-7.5wt.%Si, 0.25-0.45wt.% Mg), high purity Ca and TiH_2 power. Ca about 3wt.% was used as thickening agent. TiH_2 power in the size range of 40~50μm of about 1.5wt.% was used as foaming agent. Al-Si alloy was used as virgin alloy. The method involves four steps: (1) Al-Si alloy and Ca were melted to 850℃ in crucible furnace, (2) the TiH_2 foaming agent was added into the melt at 680℃, with a stirring rate of 2000 rpm, (3) after holding for a certain period at 660℃, the crucible was taken out of the furnace, (4) the melt was cooled to room temperature in air [11].

There were three types of compression test specimens: aluminum foam with the dimension of Φ28mm*40mm, Al tubes with the dimension of Φ30mm*40mm and their composition (aluminum foam filled tube). Quasi-static compression test were conducted in mechanical testing machine of CMT5105 with a rate of 2mm/min until 70% deformation was achieved. The strain rate of specimens was $8.33{*}e^{-4}$.

3. Results and Discussion

3.1 Compression behavior

The images of different stages in compression were shown in Fig.1. The cells are not spherical initial due to the gravity in the foaming phase. The deformation process of aluminum foam contains three steps: linear elastic deformation, plastic deformation and collapse. The cells begin to collapse after the linear elasticity stage. The initial deformation cells were A-D and not concentrated in lager cells or spherical cells. This can be attributed to the lower concentration of defects in region with lager and spherical cells. In Fig.1b, cell walls of A-D failed via plastic bulking and forming hinges. Due to the interaction of contiguous cells, the deformation band formed along A-D under future compression (Fig.1c). The deformation was shear failure as a whole with the band angle approximately 45° (Fig.1c).

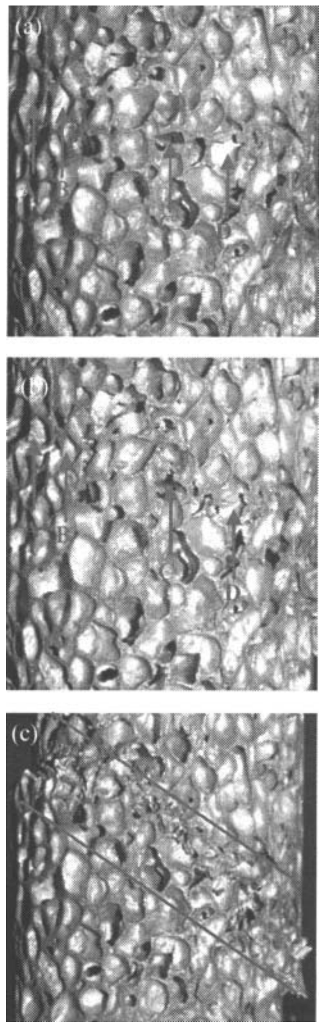

Fig.1 Deformation of cells: (a) before compression test (ε=0) (b) ε=0.05 (c) ε=0.175

Fig.2 shows the different stages in compression of foam-filled tube. The deformation tended to be axisymmetric (Fig.2a) in the initial stage until the form of the first crack A (Fig.2b). A few new cracks (B, C) (Fig.2b) formed and growth along the further compression due to the stress concentration in crack tips. The tube started to curl and ductile tearing that is different to the fold reported before [11,12]. Due to the extrusion of tube outside, the deformation mode of aluminum foam changed from shear failure to gradient, with enhancement deformation from center to periphery. The deformation mode of foam-filled tube was splaying progressive crushing that was shown in Fig.2c.

Stress-strain curves of the specimens were shown in the same figure (Fig.3) for comparison. F represents aluminum foam, T represents tube, TF represents foam-filled tube and T+F means the sum of foam and tube. Three of them (T, F, TF) were experimental data and one (T+F) was by calculate. According to Fig.3, the stress-strain curve of aluminum foam contains three regions: linear elastic region, plateau region and densification region. The curve exhibited a fluctuant plateau region as the collapse of cells while the stress-strain curve of tube exhibited a marked fluctuant serration which was related to the formation and growth of cracks. According to Fig.3, the foam-filled curve exist a marked valley at the strain of 0.13. The valley corresponded to the form of first crack in the experiment. Fig.3 with the area said indicated the interaction effect. Foam–tube configuration absorbed more energy than the sum of foam and tube due to the interaction between tube and filler which contains friction, extrusion, crack formation and growth. Furthermore, the densification strain (ε_D) of foam-filled tube reduces.

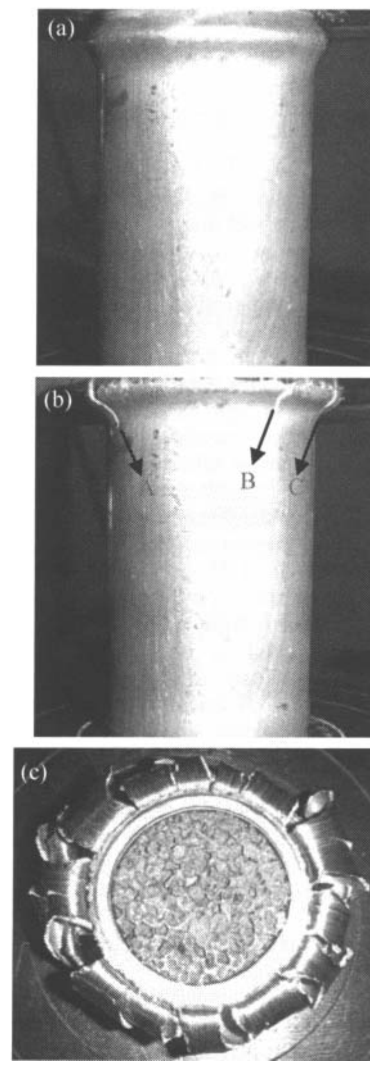

Fig.2 Deformation of foam-filled tube: (a) ε=0.1 (b) ε=0.2 (c) ε=0.7

3.2 Energy absorption

The average crushing loads of tube and plateau load P_f are shown by transverse line in Fig.3. The strengthening coefficient C can be expressed as function of P_f by the following equation:

$$C = \frac{P_{af} - P_{ae}}{P_f} \tag{1}$$

Where P_{af}, P_{ae} are the average crush load of foam-filled and empty tubes. Linear interpolation to the date in this figure gives C of 2.7. The foam-filled structure enhances the energy absorption ability.

The energy absorption per unit volume W_V for a specimen, up to a strain ε_m, can be evaluated by integrating the area under the stress–strain curve

$$W_V = \int_0^{\varepsilon_m} \sigma d\varepsilon \tag{2}$$

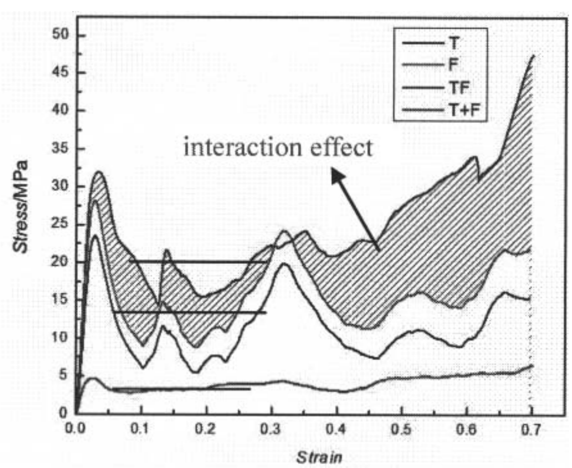

Fig.3 Stress-strain curves of specimens

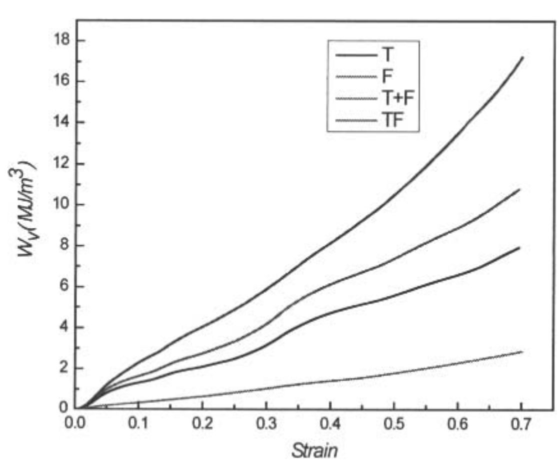

Fig.4 Stress-strain curves of specimens

Fig.4 shows the absorption energy capacities per unit volume of different species. Foam–tube configuration absorbed more energy than the sum of foam and tube (Fig.3, 4) under any step. W_V of TF was higher than that of T+F with strain increases. The density of foam increases with compression, which enhances the transverse extrusion. W_V of foam-filled tube (W_V =17.26) is about 6 times of foam alone (W_V =2.9) at the strain of 0.7. The results suggest that the aluminum foam filled tube was a potential energy absorber.

4. Conclusions

The deformation mode of closed cell Al foams is shear failure which is different from foam-filled tube that is spaying progressive crushing. The compressive tests results show that foam–tube configuration absorbed more energy than the sum of foam and tube due to the interaction between tube and filler which contains friction, extrusion, crack formation and growth. The energy absorption per unit volume of foam-filled tube was about 6 times of foam alone at the strain of 0.7.

Acknowledgements

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