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Closed Cell Aluminium Composite Foam for Crashworthiness Applications

D P Mondal*, A N Ch Venkat & Sanjeev Saxena
CSIR-Advanced Materials and Processes Research Institute, Bhopal 462 026, India

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Closed cell aluminium foams with various densities have been made through stir casting technique. The crucible temperature and melt temperature have been controlled to control the foaming temperature for controlling foam cell size and foam densities. The foam made has been then characterized for their micro-architectural characteristics as well as deformation responses. The crash of vehicle takes place at very high speed and therefore, the foams have been tested both at quasi-static and dynamic conditions. It is noted that at dynamic conditions the foams exhibit much higher strength and energy absorption. Then the foams have been filled manually inside the commercially available crash-box and tested using drop weight test methodology. The weight is varied up to 375 kg and speed is varied up to 55 km/h. The deformation behavior of bare foam blocks, foam filled crash box and empty crash boxes have been studied. It is observed that the foam synthesized through this technique is excellent for crash energy absorption. It is also noted that hardly any significant weight will be added into the vehicle. These closed cell foam has also the potential to be used in other transport sectors.

Keywords: Aluminium foams, Micro-architectural characteristics, Deformation behaviour

Introduction

A lot of casualties and damage to the vehicles are being encountered in transportation sectors particularly in road ways and railways. To avoid these, there is requirement of materials which can absorb accidental impact energy or blast energy without increasing the stress waves or impulse waves to the vehicles or to the passengers on board. In this connection ultra-light weight material with exceptionally high energy absorbing capacity at low stress or impulse waves are being developed[1-4]. Aluminium foams are one such kind of materials. It can also be used as core of sandwich panels for increasing strength and stiffness of the structure[5, 6], vibration and sound attenuation[7,8]. CSIR-AMPRI, Bhopal has developed expertise, facilities and know-how for synthesis, characterization and utilization of these materials under one umbrella. The aluminium foams have been developed and characterised in detailed for their micro-architectural characteristics as well as deformation response in sample level as well as in component level.

Synthesis of Closed Cell aluminium Foam and its Characterisation

Aluminium composites based with different aluminium alloys and reinforcements are developed in large scale in the laboratory. Different kinds of reinforcements like SiC, Al_2O_3, Fly ash, Zircon sands are successfully reinforced uniformly within the matrix. CSIR-AMPRI has developed closed cell aluminium foams of different densities. High strength low cost closed cell hydride aluminium foam is also developed. Presently, in the laboratory, the technology is developed to make ~150 kg of foam per day (A foam billet weight of 35 kg). The relative density of foam varies from 0.25 gm/cc to 0.90 gm/cc. The Foam billet, its cross-section and its typical digital microstructure are shown in Fig. 1 (a, b & c), respectively. The cells are quite uniformly distributed throughout its cross-section.

The density of foams was measured from weight per unit volume using its mass and dimension. Regular dimension of foam samples were considered. The density is measured from different locations of the foam billet. It is noted that the bottom portion of foam has around 10% higher density than the top portion.

The digitised photographs are taken to measure the cell size and cell wall thickness. The density of foam is used to get the porosity content in foams. The porosity of foam is defined as (1-relative density), where relative density is defined as the ration of foam to the ratio of dense composite. Compressive deformation behavior of these foams were studied under quasi static condition (in an INSTRON UTM)

*Corresponding author (E-mail: mondaldp@yahoo.com)

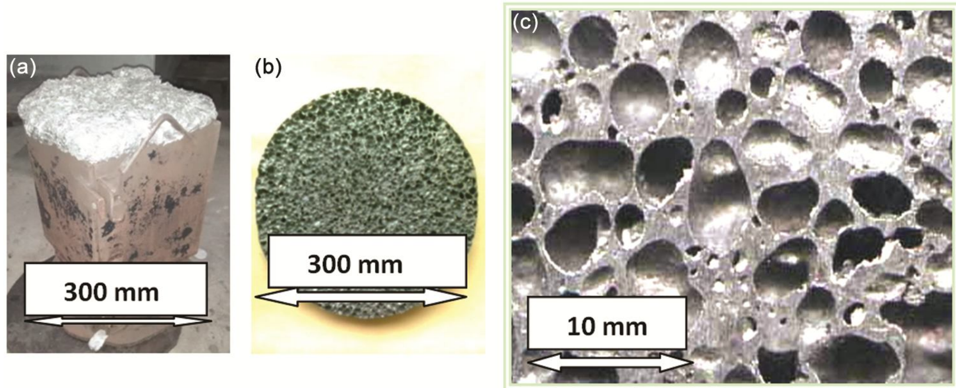

Fig. 1 – (a) foam billet, (b) cross-section of foam billet and (c) higher magnification digitized micrograph of foam (relative density =0.15).

and under dynamic condition using speed Hopkinson pressure bar. In addition the bare foam block, empty crash box and foam filled crash boxes were tested using Drop weight test facility at ARAI, Pune (Drop weight ~375 kg and speed 55 km/hr).

Results and Discussion

The quasi-static compressive stress–strain curves of foam of varying relative density are shown in Fig. 2. It is evident from this figure that the foams deform under zig-zag stress response upto densification strain after yielding. The yield stress is defined as the plateau stress. It is noted that the plateau stress or flow stress increases with increase in relative density. It is noted that at a relative density of 0.31, the plateau stress is around 24 MPa.

The energy absorption is calculated from the stress strain curve upto strain of 0.6 and it is noted that the maximum energy absorption by the foam of RD=0.31 is 10 MJ/m^3 up to 40% od deformation. When these foams are tested under dynamic conditions in an speed Hopkinson pressure bar, the plateau stress and flow stress increased significantly (Fig. 3). For the foam with relative density of 0.31, the plateau stress increased to 45 MPa at a strain rate of 1000/s. This signifies that its energy absorption increased to 16 MJ/m^3 when foams deforms up to 40%. This also demonstrate that the foam have greater capability to absorb more energy under dynamic condition.

In view of these the foams were filled into the crash box commercially available and tested using drop weight test facility at a speed of 55 km/h.

The force displacement curves under drop weight tests for empty crash box and the foam filled crash boxes are shown in Fig. 4 and Fig. 5, respectively. It is evident from this figure that initially stress increases upto certain limit and then there is a hump, followed by which the stress again increases and reach to the maximum. After reaching to the maximum the stress again decreases. This behavior is for empty crash box. The initial hump is for starting of folding of crash box during deformation.

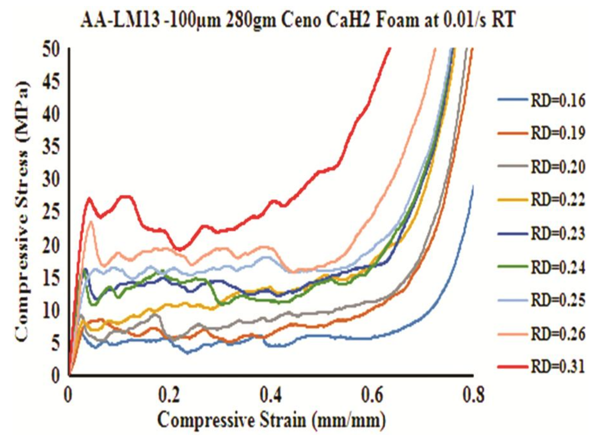

Fig. 2 – Compressive stress strain curves of closed cell foams under quasi-static loading condition.

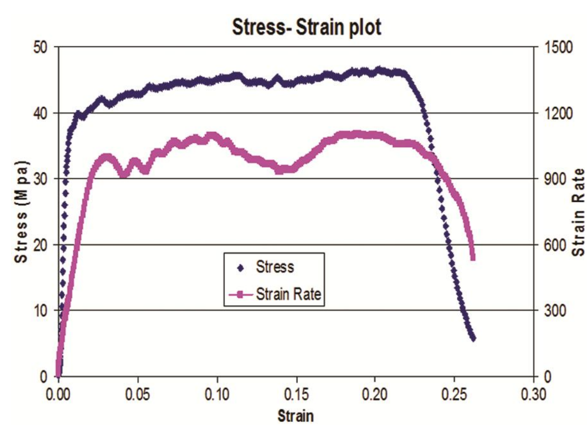

Fig. 3 – Compressive stress strain curves of closed cell foams under dynamic Loading condition.

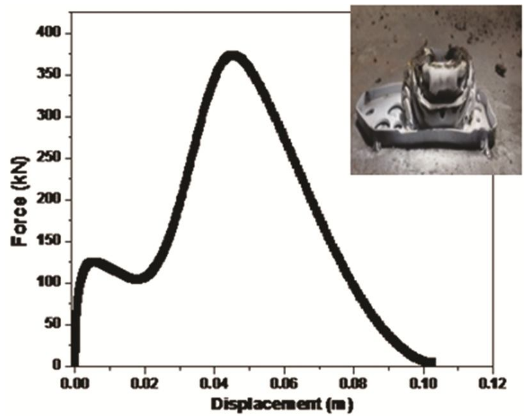

Fig. 4 – Force displacement curves of empty crash box under dynamic loading condition (drop weight tests).

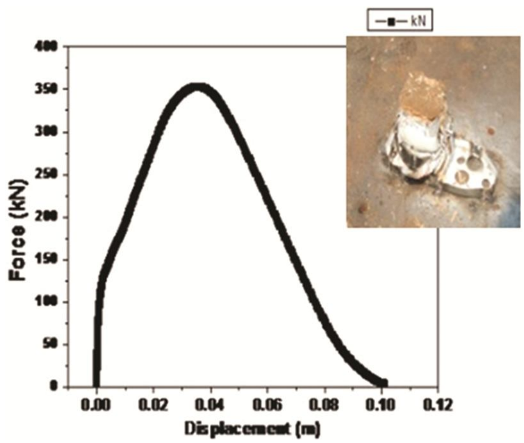

Fig. 5 – Force displacement curve of foam filled crash box under dynamic loading (drop weight test).

When the crash box is filled with foam, the clear hum in the initial period does not exist. But the slop changes at certain displacement where the increment of stress with strain decreases, indicating slower rate of load transfer which causes deceleration of impacting object. This is required for any crashworthiness applications. This is happening because of change in the nature of deformation in both the cases. In case of foam filled tube the tube does not get folded easily and it resists the deformation or compaction of the inserted foam. These two interactions cause higher energy requirement for crushing.

It may further be noted the maximum load experienced during crushing is around 250 to 300 KN. The cross-section of the tube is ~110 mm × 110 mm =12100 m^2. Thus the stress generated on the crash box at peak loading condition is around 20 to 25 MPa. The tube, chassis or other structural part can withstand this stress quite efficiently. The energy absorption calculated for these tests were 9.5 KJ and 20.5 KJ for empty crash box and foam filled crash box. The foam block absorbs ~ 4 KJ. It is further noted that the base plate at which the crash boxes were fixed for testing did not undergo any damage. In this case the crash box weight was 850 g, the foam weight was 350 gm. Thus by adding 350 gm of foam the energy absorption is improved more than 100%. This is even much higher than that of sum of energy absorbed by bare foam and empty crash box. This clearly demonstrates that the bare foam should not be used. For getting effective crash-energy absorption, and foam filled crash boxes are better option. If one considers for weight increment, it is hardly anything as compared to the weight of the car.

The crash energy of the car can further be increased by inserting foam strip into the bumper channel place before the crash box. As the testing facility is not available and also difficult to examine and understand the deformation behavior of bumper - crash box assembly filled with and without aluminium foam is simulated.

The simulated bumper-crash box assembly before and after numerical tests are shown in Fig. 6. The simulated results are also reported within these figures. It may be noted that when bumper and crash box both are inserted with aluminium foam, the assembly absorbed ~200 KJ energy during head on collision.

This energy is equivalent to the energy of a car having weight of 1000 kg while moving at a speed of 70 km/h. After getting the simulated results, both the crash box and bumpers are filled with Al-foam (Fig. 6). Here one require around incorporation of 2 to 3 kg of foam depending on the cars. This weight increment is very low as compared to the weight of the car. Further, while one will use these foams filled crash box or the foam filled cradle, pillar or chassis, the design of the car may be made more compact and lighter. Under present circumstances, without any redesign of the car, simply by adding 2 to 3 kg of foam in the bumper and crash box, huge damage of the car and casualties can be avoided from head on collision. As per as safety is considered, the cost of the foam is hardly anything in comparison to the car or the life of the passenger. The foam required for the crash boxes would be costing hardly Rs 2000.00 to 3000.00/- depending on the weight of the car and level of safety.

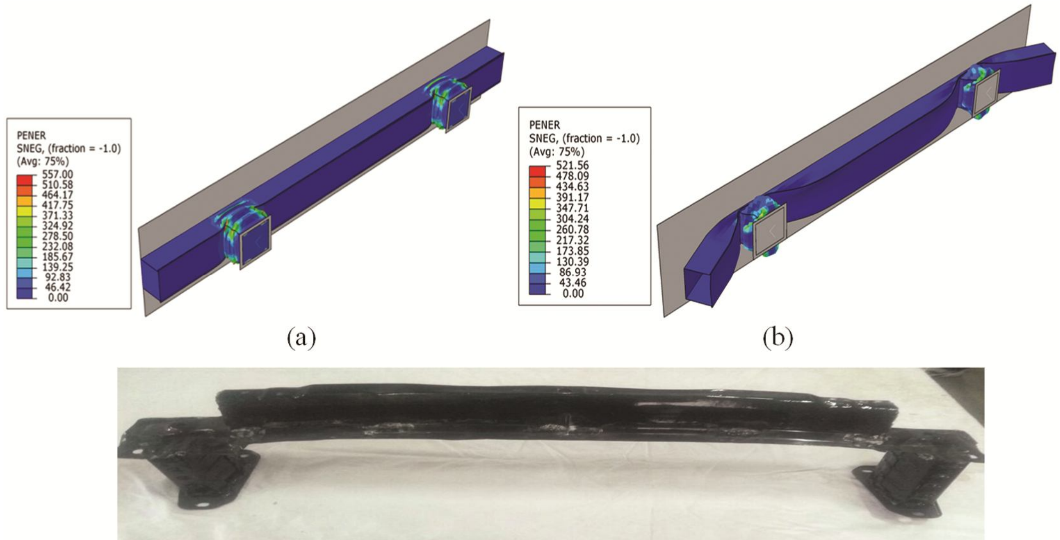

Fig. 6 – Simulated bumper plus crash box assembly (a) foam in both bumper and crash box (energy absorption; 200 KJ, (b) No foam. Crash and bumper (energy absorption 11 KJ) and (c) foam filled crash box and bumper assembly.

Conclusions

The following conclusion can be drawn from the present study:

(i) Closed cell aluminium foams in batch scale process have successfully synthesized. In a single heat a foam billet of size up to 35 kg could be made.
(ii) The foams have quite uniform cell size and its densities could be varied by varying the process parameters.
(iii) The closed cell foams exhibited significantly higher strength and flow stress under dynamic condition as compared to that in quasi-static conditions.
(iv) Closed cell aluminium foams could economically and technically be used for crashworthiness of vehicles.
(v) Crash box and bumper assembly filled with 2 to 3 kg of aluminium foam is sufficient to absorb crash energy of a vehicle with weight of 1000 kg and running at a speed of 70 Km.
(vi) The extent of stress transferred to the rear end is much lower than the stress required for the severe damage of the car body.

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