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Characterization and analysis of compression load behaviour of aluminium alloy foam under the diverse strain rate

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ABSTRACT

The use of lightweight aluminium (Al) alloy foams is rapidly gaining popularity in automotive sector, aerospace, etc., which require crash energy absorption, weight reduction and sound damping capacity. Al–alloy foams, such as, LM 30 + 15wt% SiCp are prepared by melt route process using the principle of compression deformation behaviour. The structure parameters of Al–alloy foams are cell size, cell wall thickness and shape of the cell. The present work describes the compression behaviour of LM 30 + 15% SiCp foams at strain rates varying between 10^{-3} s^{-1} and 10 s^{-1} at room temperature. The stress–strain curve shows linear elastic region, plateau region and densification region. In course of this study, the compressive deformation behaviour of these aluminium foams was examined in order to assess its plateau stress and densification region. The fabricated aluminium foams were assessed by FE-SEM, EDAX, XRD, and Material-pro analyser. It was also noted that LM 30 + 15wt% SiCp Al–alloy foam stress–strain curve exhibits superior plateau stress. The energy absorption capabilities with its microstructures deformation mechanism could also be noted after carrying out the compression test was on the Universal Test Machine (UTM). The results revealed the energy absorption per unit volume of LM 30 + 15wt% SiCp Al–alloy foams.

1. Introduction

In the last 20 years, metallic, and particularly, Al–alloy foams, have led to the development of a new class of material, specially, in automotive industries and aerospace. It has an outstanding combination of mechanical and physical properties [1–3]. Aluminium foams have high energy absorption capacity, high specific stiffness, and, therefore, they are ideal for low-weight structures [2]. Advancements in mechanical science and development of structures and equipment filled with high-performance foams have contributed together to the development of this new class of material [4,5]. Nowadays, foam-filled structures are often being utilised in mechanical engineering applications as they are cost-effective and increase the crashworthiness of vehicles without increasing their weight. The base materials (aluminium, steel, polymer, rubber, plastics, etc.) are all familiar and in many cases are readily modelled with a high degree of accuracy [6–9]. The application of Al–alloy helps in reduction of weight, improvement of stiffness, energy dissipation, mechanical damping and suppression of vibration. During the compression of load, the Al–alloy foams can absorb much more of the crashing energy due to the collapse of foam pores as compared to a solid material. Nowadays, improved energy absorption capabilities and lightweight have made these materials far more attractive compared to the traditional ones, such as, metals [10–15].

In matters of safety concern also, foams applicant have turned out to be much more preferred material for mitigating the extreme effects of blast loads on structures. Researchers have been engaged in investigating the fundamental factors, such as, homogeneous structure, 3D-complex, non-linear behaviour, low specific density, etc., that influence the compression deformation behaviour of Al–alloy foams in diverse loading conditions. Studies have also been conducted to examine the effect of diverse strain rates on the deformation response of Al–alloy foams [16–19]. The energy absorption capacity of the foams depends on plateau stress and densification strain. The plateau stress

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increases with an increase in the strength rate of the foam material. The densification strain, on the other hand, depends on the extent of pores existing in the foams [17–21]. Thus, without changing the spread of pores, if one wants to improve the strength as well as the crash energy absorption rate of the metal foams, one should improve the strength of the foam materials. Nowadays, closed cell aluminium foams have a wide range of applications, particularly in automobile and aviation sectors, because of their outstanding energy absorption capacity at a very low plateau stress condition and superior damping capacity.

In most of the energy absorption applications, closed cell aluminium foams are used. The closed cell Al foams are synthesized by either the Alcan or the Alporas process, using melt route [20]. In the Alcan process, aluminium melt is thickened by dispersing particles, i.e., Al_2O_3 and SiC. Then, it is foamed by injection of different gases. i.e., air, N_2, Ar, etc., using external sources. However, in the Alporas process, aluminium melt is thickened by dispersing Ca metal powder [17]. Then TiH_2 is added as a foaming agent. Addition of SiCp and Ca powder in aluminium melt increases apparent viscosity of the Al melt. The higher viscosity of Al melt facilitates slow downward flow of the liquid metal resulting in its reduced drainage before solidification. Ceramics particles also play an important role in stabilizing the foam structure [22]. They affect the cell size as well. Thickness of the cell wall increases with the increasing size of SiCp at a constant foaming temperature. As a matter of fact, ceramic particles usually attach the liquid or gas interface, raising strength of the cell wall by reducing the pressure difference between the plateau boarder and the cell wall. Thus, they help avoid the collapse of the aluminium foam structure during solidification. The deformation behaviour of the Al–alloy foams depends on the shape and orientation of the cells. The elliptical orientation of cells allows early initiation of cell deformation as compared to the round shape orientation. Observation of the compression behaviour of the Al–alloy foams reveals that the plateau stress is insensitive to the strain rate. Mechanical properties mainly depend on two factors, namely, (1) cell wall material, and, (2) presence of air inside the cell. Mechanical properties of Al–alloy closed cell foams are found well below the predicted value. Moreover, mechanical properties weaken due to the presence of the defective cellular microstructure. However, recent researches have largely resolved these problems by development of new production technologies in these areas [23,24]. These technologies enable the production of Al–alloy foams of a considerably high quality. At the moment, Al–alloy foams do not have any bulk application However; several prototypes show their huge potential in different sectors. Al–alloy foams are very expensive because they are not yet produced on a large scale. In future, they are expected to find wide applications [25].

1.1. Foam properties

Aluminium has always been an extremely conducive material to foams due to its mechanical and physical properties and for the convenience of its casting and recycling. In recent period, improved production process allows one to obtain the base material both in close cell or open cell foams, which have a wide variety of interesting properties. In view of their energy absorption capacity, closed cell Al–alloy foams are found to have a very lightweight structure and low specific density [12]. Light weight structure is directly related to fuel reduction, ensuring economy and environmental safety. Al–alloy melt can be mixed with thickening and foaming agents. Fifteen percent (15%) of SiCp is used as thickening agent and TiH_2 is used as foaming agent, respectively. TiH_2 hydride releases a large volume of hydrogen gas when added to a liquid metal. This gas creates bubbles that lead to the formation of foam structure. When foaming is complete, the foam structure is cooled by compressed air.

An experiment was carried out using LM 30 + 15wt% SiCp foam. Foam samples were collected using a slow speed cutter and then they were metallographically polished using standard polishing technique. The pore structure was scanned. The pore size distribution was studied using Material Pro software. The sizes of around 70% of the pores were in the range of 0.5–1.5 mm as shown in Fig. 1 (a) and (b). The advantage of foams can be realised when energy absorption capacities are measured as a utility of weight in lightweight constructions that has comparatively high stiffness and low relative density. It is essential to note that if only direct strength is measured, foams often have a greater absorption capacity compared to solid materials of the same weight [19].

1.2. Mechanical properties

The fact that metal foams are drawing increasing interest among researchers is visible from the increasing numbers of publications in recent period in leading materials science journals. The most important structural characteristic that a cellular material has is the relative density. The characteristic parameters of relative density depend on the type of open or closed cell foams. On the other hand, the compression behaviour of metal foams depends on a number of properties. Moreover, there are certain specific problems of measuring the properties of cellular metals. Hence, it is not enough to focus only on one property. For the application of foams, various issues, such as, absorption of energy, compression behaviour, cheap production of 3D-complex shapes, etc., have to be considered as well [24]. In the case of Al-SiCp alloy foams, the mechanism of deformation can be detected in individual debonding at the SiCp interference.

In the present paper, an attempt has been made to synthesize closed cell Al–alloy (LM 30 + 15wt% SiCp) using melt route process. In this context, a detailed microstructure study was carried out. The results show the energy absorption per unit volume of LM 30 + 15wt% SiCp Al–alloy foam [19].

2. Materials and methods

2.1. Material properties

LM 30 Al–alloy contains 4.56 wt% Cu, 0.57 wt% Mg, 0.67 wt% Fe and 0.4 wt% Mn, 17.05 wt% Si, and the rest is aluminium. LM 30 + 15wt% SiCp foam samples were produced through the melt route process. Energy dispersive X-ray analyses (EDAX) investigation was also performed on aluminium alloy foam with the trade name LM 30 as shown in Fig. 2. The porosity of aluminium alloy foam varies from 70% to 85% and the cell sizes of the aluminium foam vary from 0.5 to 3 mm. The compression deformation behaviour of five samples of square Al–alloy (LM 30 + 15wt% SiCp) foams was studied. The density of LM 30 + 15wt% SiCp composite foams is found out by mass and volume measurements. For density measurement, sampling was done with foams having the dimension of $23 \times 23 \times 40$ mm^3. These were prepared using a wire-cutting machine [25].

The data is presented in Table 1 where the average values of five samples have been taken. The compression tests of Al–alloy foams were performed with a Universal testing machine (INSTRON-8801) at a loading speed of 0.001–10 mm/min at CSIR-AMPRI Laboratory, Bhopal.