Compressive behaviour and vibration characteristics of Closed Cell Eutectic Aluminium Silicon Alloy foam

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Abstract

Metal foams are a new class of materials with low densities, good vibration, acoustic properties, energy absorption and high specific stiffness. These also exhibit many unusual combinations of physical and mechanical properties that make them attractive in a number of engineering applications. Metallic foams can be manufactured by many methods like powder metallurgy route, melt route, gas injection into molten metal, liquid metal infiltration. The properties of metal foam depend on many morphological features, such as pore size distribution, cell wall curvature, defects etc. The aim of the present work is to study the compressive behaviour and damping properties of eutectic Al-Si alloy. Closed cell foam specimens were produced by melt route using calcium carbonate as foaming agent. The compressive test was conducted and stress verses strain curve exhibits a typical three regions, elastic, plateau and densification. Damping properties of closed cell were measured by experimental modal analysis using impulse excitation technique at room temperature. Material damping factors were calculated by circle fit method. The measured loss factor shows that closed cell eutectic Al-Si alloy foams have a higher damping capacity compared to Al-Si alloy

Keywords: *foam, damping, compressive behaviour*

1. INTRODUCTION

There are many possible engineering applications for metallic foams ranging from lightweight construction, sound and heat insulation to energy absorption applications like bonnets, boot lids, front or rear walls of automobiles. Aluminium foams or foam panels could be very useful in reducing the energy consumption of elevators. In aerospace applications the replacement of expensive honeycomb structure by foamed aluminium sheets or aluminium foam sandwich panels could lead to reduced costs [1]. Potential application area for porous and metal foams light weight structures, mechanical damping, vibration control, Thermal management, heat shield [2].The most interesting properties of aluminium foams are nearly closed porosity, low specific weight, and high energy absorption capacity during plastic deformation, high specific stiffness good mechanical and acoustic damping, not inflammable, recyclable, and good machinability[3].

1.1Production of foams

Closed cell foams can be produced by i. Bubbling gas through molten Al-SiC or Al-Al_2O_3 alloys ii. By stirring a foaming agent (typically TiH2) into a molten alloy and controlling pressure during cooling iii. Consolidation of a metal powder with a particulate foaming agent (TiH_2) followed by heating into the mushy state when the foaming agent release hydrogen, expanding iv. The trapping of high-pressure inert gas in pores by powder hot isostatic pressing(HIPing), followed by the expansion of the gas at elevated temperature v. Dissolution of gas (typically, hydrogen) in a liquid metal under pressure, allowing it to be released in a controlled way during subsequent solidification[2].Foaming of aluminium alloys and aluminium-based composites with $CaCO_3$ blowing agent is caused by the thermal decomposition of calcium carbonate in contact with molten aluminium at temperature above 700^{o}C. Carbon dioxide

ISSN: 2233-7857 IJFGCN

evolution from calcium carbonate powder is relatively high in comparison with that of hydrogen from titanium hydride. The decomposition characteristics of $CaCO_3$ are such that it is well–suited to foaming of aluminium melt [4].

1.2 Compressive Behaviour

The structural defects, the partially coupled cell and missing cell causes serious deviations in the stress–strain response and significantly reduce the elastic modulus and plastic collapse stress of the closed-cell Al foam. The reduction of structural defects through the improvement of the manufacturing techniques is essential to improve the compressive properties of cellular materials**.** [Insu Jeon et al., 2005][5].The aluminum foams of similar relative density can exhibit a wide dispersion of properties due to the various effects, such as gradient density distribution, surface skin, preferred pore orientation etc. These effects results from the foaming process and significantly depend on the geometry of foamed part. Aluminium foams usually collapse or fails via. a weakest pore layer[6].

The typical stress-strain curve of the aluminium foam can be divided into three parts; in the first part the stress increases with increasing compression strain almost linearly (elastic deflection of the pore walls), then follows a deformation "plateau" at nearly constant compression stress (pore wall yield or fracture, whereas the deformation does not require an increase of the load) and finally there is a part of rapidly increasing load after the cell-walls crushed together. The initial failures in the structure of the foam (fracture of pore walls) appear after first peak in the stress/strain curve. The stress drop that follows is related to the shift of the upper part of the sample due to the failure of the walls in one layer of the pores. This shift depends on the size of pores in the fractured layer[7].

Metal foam fails irreversibly. Depending on the type of alloy the foam is made of, the cells suffer brittle fracture, deform plastically without breaking, or show an even more complicated deformation pattern. Metal foams collapse gradually under the critical compressive load until a high degree of compaction is achieved. That process absorbs a great deal of mechanical energy. Metal foam has a high yield stress compared to polymer foams. One cubic centimeter of aluminium foam can absorb up to 10 joules of mechanical energy if crushed to 20% of its original strength**.** [8].

1.3 Damping Properties of foam

The dynamic responses and sound-transmission characteristics of structures are essentially determined by their properties of mass and stiffness, which are responsible for the energy stored in the system, damping which is responsible for loss of the energy from the system. Structural materials that exhibit high damping capacities are desirable for mechanical vibration suppression and acoustic noise attenuation. Loss factor(η)of a structure made of a particular material is defined as a fraction of the system vibrational energy that is dissipated per radian of the vibratory motion at resonance.

Damping capacity, a materials ability to absorb and dissipate mechanical vibration, is usually low in structural metals. Different internal friction mechanisms might be involved in damping in cellular metallic materials (CMM), thermo-elastic damping(Al, Zn foams), reversible dislocation motion, magneto mechanical damping (Ni sponges), micro and macro-plastic deformation, crack induced damping (most of sintered materials)[9].

Density, pore size and other structural parameters, chemical composition, pre-deformation, time of vibrations, and air pressure inside the cell can influence the damping capacity via different structural mechanisms [10].

The internal friction increases with increase in strain amplitude. The loss factors shows that aluminium foams have a damping capacity which is enhanced in comparison with most massive cast aluminium alloys and increases with increasing porosity level [11].

The attenuation in foamed Al is not caused by the usual mechanism but by pores. Pores in foamed Al may be high-energy dissipation resources. The internal friction(IF) of foamed Al increases with increasing porosity when the pore size is kept constant whereas, when the porosity is kept constant, it decreases with increasing pore size[12].

ISSN: 2233-7857 IJFGCN

The mechanism of damping in CMM are similar to those which takes place in the dense materials used for CMM production, Peculiarity of these mechanisms are mostly the result of strain location in the porous or cellular structures when a stress is applied. By combination of intrinsic damping capacity, stiffness and strength, CMM are often better than their dense counterpart[13].

2. METHODOLOGY

2.1Production of closed cell Al-Si alloy

The closed cell foam is produced by a melt route using calcium carbonate as a foaming agent. Metal used for production of the foam is eutectic Al-Si alloy, composition of the alloy is Copper 0.1 max, magnesium 0.1max, silicon 10.0-13.0, iron 0.6 max, manganese 0.5 max, Nickel 0.1 max, Zinc 0.1 max, lead 0.1 max, tin 0.05 max, Titanium 0.2 max, Aluminium remainder.

Figure1: Foam casting after solidification

Figure 2: Cut section of the foam

2.2 Compressive behaviour

A compression test was conducted to determine behavior of the material under crushing loads. The use of specimen having large L/D ratios should be avoided to prevent buckling and shearing mode of

ISSN: 2233-7857 IJFGCN

deformation. Uni-axial compression tests were carried out on a Universal Testing Machine UTM - Hydraulic type, 40 tonnes capacity The size of the Aluminium foam sample used for this study is 30mm×30mm×60mm. This aluminium foam specimen was subjected to compression test by deforming specimen between two parallel platens of Universal Testing Machine as shown in figures 3

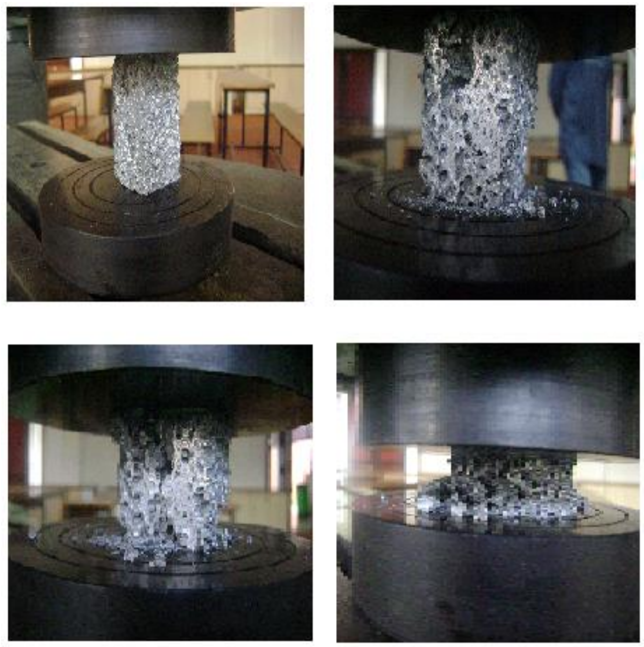

Figure 3: Different stages during Compression of foam

The compressive stress versus strain curve obtained as shown in figure 4 for the compressed aluminium foam which shows three distinct regions.

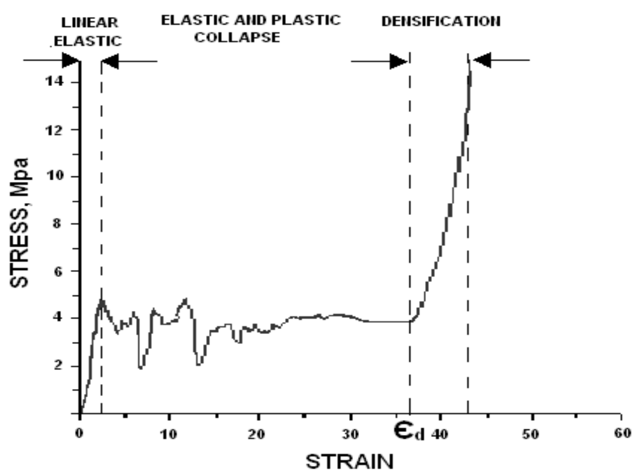

Figure 5: Stress verses strain diagram

Compressive strength: 4.75MPa

2.3 Experimental modal analysis

The two most popular techniques to evaluate damping are frequency domain and time domain. In time domain approach, the fundamental principle is energy lost from the oscillatory system which will results

ISSN: 2233-7857 IJFGCN

in decay of amplitude of oscillation. Free vibration technique is the most common method used to evaluate damping ratio in time domain analysis. A plethora of mathematical transformation exist to transform time signal to obtain processed signals which reveal information that is not easily seen in the raw signal, transformation to frequency domain being the most common amongst these. The time-domain vibration signal is transformed into the frequency domain by applying a Fourier transform, using an FFT algorithm (FFT analyzer). The energy in the original signal is separated into its various frequency components and amplitude various frequency representation of that signal is obtained. The principal advantage of this format is that any periodicities in the vibration signal are clearly displayed as peaks in the spectrum at the corresponding frequencies.

Damping experiments were performed on a specimen through free-free vibration at room temperature. Utmost care was taken to avoid errors due to extra frictional losses in the sample holder; for that reason, the foamed sample were not clamped but carefully suspended in the vibration nodes by means of fine thread.

Loss factor of the foam was determined by experimental modal analysis. The size of the specimen is 20mmX30mmX120m and density 0.48gm/cm^3. By using Frequency Response Function (FRF) damping ratio of system is determined. Damping properties of closed cell foam specimens are determined by circle fit method and required frequency response was obtained by using FFT analyzer.

Figure 5: Foam specimen for damping measurement

The real part of the frequency response function contains the damping information. This can be calculated by knowing the frequency f_a and f_b of the real part corresponding to the two peaks.

Loss factor $(2\xi)=\eta = [(f_a/f_b)^2-1]/[(f_a/f_b)^2+1]$

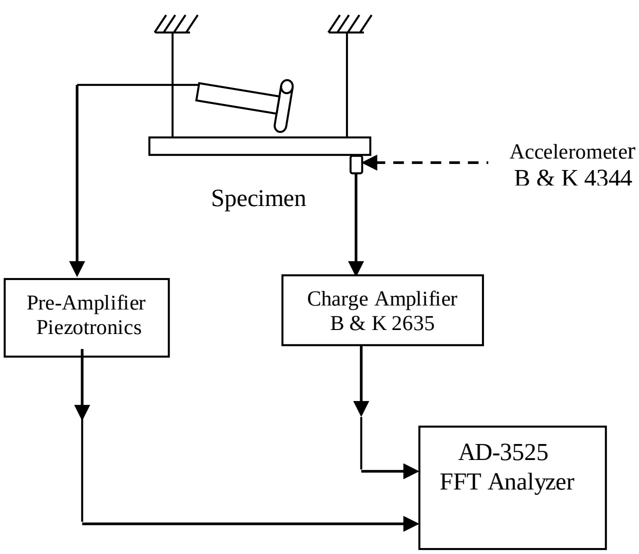

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Figure 6: Schematic experimental set up for modal analysis

An instrumented impulse hammer (PCB, Piezotronics, USA) is used for applying a force to the system, an accelerometer (B&K 4344) and conditioning amplifier (B&K 2635)is used for measuring the response of the system and a signal analyzer (AD-3525, FFT analyzer)is used for evaluating dynamic response of the system. A schematic diagram of the system is shown in figure 6 and actual experimental set up is shown in figure 7

Figure 7: Actual photo of experimental modal analysis set up

Damping properties of closed cell eutectic Al-Si alloy are calculated by using the frequencies
f_a = 1411.25Hz, f_c = 1393.72Hz, f_b= 1376.88 Hz
Loss factor was calculated from this formula $2\xi = [(f_a/f_b)^2-1]/[(f_a/f_b)^2+1]$
Loss factor for the closed cell eutectic Al-Si alloy foam is 0.02461.

4. CONCLUSION

Experiments have been carried out to investigate the compressive behavior of closed cell eutectic Al-Si alloy foam produced from melt route using calcium carbonate as foaming agent. Compressive behaviour of closed cell Al-Si alloy foam produced using calcium carbonate was studied and compressive strength is found to be 4.75MPa. The stress verses strain diagram exhibit a three-stage behavior: elastic region, plateau region and densification region. Mechanical damping of eutectic Al-Si alloy closed cell foams have been studied using experimental modal analysis using circle fit method. The measured loss factor shows that aluminium foams have a high damping capacity in comparison with bulk Al-Si alloy. The material damping factor for the foam is found to be 0.0246.

5. ACKNOWLEDGMENT

The authors would like to thank and acknowledge Visvesvaraya Technological University, Belagavi, Karnataka, India, for the financial support for this Project, under University Research Grant Scheme [Ref. No. VTU/Aca./2009-10/A-9/11476, Dated: 02-01-2010]

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ISSN: 2233-7857 IJFGCN