Noorullah et al. 2015. *Int. J. Vehicle Structures & Systems*, 7(4), 141-144
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.7.4.04

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Development of Closed Cell Metallic Foams for Automotive Crashworthiness

D. Noorullah[a,b], S.S. Mohamed Nazirudeen[e], A. Mukesh[a,d] and V. Karthik[a,c]

[a]*Dept. of Metallurgical Engg., Government College of Engg., Salem, Tamilnadu, India*
[b]*Corresponding author, Email: noorullahd@gmail.com*
[c]*Email: karthikv.gce@gmail.com*
[d]*Email: mukeshmet28.3@gmail.com*

[e]*Dept. of Metallurgical Engg., PSG College of Tech., Coimbatore, Tamilnadu, India*
Email: ssmdnazir@yahoo.co.in

ABSTRACT:

Metallic foams with controlled porosity are an emerging class of ultra-lightweight materials that are receiving increased attraction in automobile, military and other commercial applications. Metal foams exhibit high stiffness to weight and strength to weight ratios, and thus offer potential weight savings. They also have the ability to absorb high amounts of energy during compressive deformation for efficient crashworthiness. In the present work, closed cell aluminium metallic foams were produced through liquid state processing by using calcium as viscosity modifier and titanium hydride as blowing agent. The porosity content of the foam was 88 %. The pores are differently sized and uniformly distributed. The cell wall microstructure was studied using optical microscope. The compressive response of the foam was studied at different percentage of deformation using uni-axial compression testing machine.

KEYWORDS:

Metallic foam; Aluminium; Compression test; Microstructure; Pore collapse

CITATION:

D. Noorullah, S.S.M. Nazirudeen, A. Mukesh and V. Karthik. 2015. Development of Closed Cell Metallic Foams for Automotive Crashworthiness, *Int. J. Vehicle Structures & Systems*, 7(4), 141-144. doi:10.4273/ijvss.7.4.04

1. Introduction

Numerous research works are on-going towards the development of ecological technologies for automotive vehicles manufacturing. One of the major problems of this century is depletion of natural fossil fuel resources and the increasing air pollution due to exhaust emission from automotive vehicles. These problems can be overcome by reducing the weight of the vehicle thereby lowering the rate of fuel consumption. The reduction in consumption and emissions remains the greatest technological challenge for the automotive industry. Reducing weight by 100 kg leads to a fuel savings of 0.35 l/100 km and 8.4 g CO_2/km with gasoline engines if taking into account an adjustment of the gear shifting without a change in elasticity and acceleration values due to the lower weight [1]. The exhaust emissions from motor vehicles can be minimized by reducing their fuel consumption. Fuel consumption can be improved by increasing the thermodynamic efficiency of the engine. Significant gains can also be achieved by reducing the weight of the vehicle and its aerodynamic drag. To achieve a weight reduction high performance materials are required. Materials with high specific stiffness and strength properties allow the production of highly efficient lightweight load bearing structures.

Foams and other highly porous materials with a cellular structure are known to have many interesting combinations of physical and mechanical properties, such as high stiffness in conjunction with very low specific weight or high gas permeability combined with high thermal conductivity [2]. Aluminium metal foam materials, which can be fabricated into a variety of functional geometries, offer significant performance advantages for weight-sensitive applications. The properties of the metal foams strongly depend on the pore structure. The processing method and conditioning decide the size, shape, volume fraction and spatial distribution of pores in metal foams. The metal foams can be produced by different routes, such as liquid state processing, solid state processing, electro-deposition and vapour deposition [2]. In liquid state processing, molten metal is processed into a porous material either by foaming it directly or by using a polymer foam. Finally, by casting the liquid metal around solid space to hold filler materials followed by further processing to form the pore space. One further possibility is to melt powder compacts containing a gas blowing agent.

Ultra-lightweight aluminium foams possess unique microstructural characteristics and physical properties which make them attractive for automotive applications. The aluminium metal foams were produced by using variety of blowing agents [3-5] such as titanium hydride (TiH_2), zirconium hydride (ZrH_2), calcium carbonate ($CaCO_3$) and dolomite $CaMg(CO_3)_2$. TiH_2 is the commonly used blowing agent because of its better foaming ability. In the present work, aluminium metal foams have been produced through liquid state processing route using TiH_2 as blowing agent. The compressive deformation behaviour of the aluminium foam are characterised by experimental tests followed by close examination of their microstructures.

2. Materials and methods

The pure aluminium bars have been heated to a temperature of 700°C in a stir casting furnace. As a viscosity modifier, 1.5% of pure calcium tablets were added to the melt and stirred for 3 minutes. The viscosity of the melt continuously increases, owing to the formation of calcium oxide (CaO), calcium-aluminium oxide ($CaAl_2O_4$) or Al_4Ca inter-metallics which thicken the liquid metal. Then 1.6% of TiH_2 was added as blowing agent and stirred for 3 minutes. The blowing agent releases the hydrogen gas in hot viscous liquid, which facilitates the formation of foam. The stirring and additions were carried out in the crucible which is maintained at 700°C. The stirring speed was maintained at 150 rpm. After stirring, the crucible was taken out of the furnace and allowed to cool. Fig. 1 and 2 show the as-cooled and cut section of the produced Al metallic foam respectively.

Fig. 1: Photograph of the Al metallic foam as-produced

Fig. 2: Photographs of the Al metallic foam-cut section

The produced aluminium foam was sectioned into dimensions of 22×22×19 mm^3 and 30×30×25 mm^3. The density of the foam was calculated by weighing the sample in A&D digital balance with an accuracy of 0.01 mg and measuring the dimensions of the sample using vernier callipers. The cell morphology was viewed and captured using stereo microscope. The specimens were metallographically polished and etched using 5% hydrofluoric acid solution to reveal the cell wall microstructure under optical microscope. The specimen with 30×30×25 mm^3 dimension was loaded in uni-axial compression testing machine in 30 mm direction to study the compressive response of the foam.

3. Results and discussion

3.1. Material density & microstructure analysis

The foam was characterized in terms of its density, cell morphology and cell wall microstructure. Fig. 3 shows the section photography of polished foam specimens used for density, microstructural and compressive response measurements. Some of the pores are appearing as interconnected with other pores, whereas some of them are appearing as closed pores. The pores are distributed uniformly throughout the space and differently sized. The pores are irregular in shape. Table 1 shows the density of the produced Al metallic foam. Relative density is calculated as the ratio of density of foam over theoretical density of aluminium. The theoretical density of aluminium as 2.7 g/cm^3 was used for relative density calculation. The porosity content of manufactured foam is around 88%, which makes the foam lighter in weight. The produced foams are closed cell type and can float over water.

Fig. 3: Section view of Al metallic foam polished

Table 1: Density of Al metallic foam

Weight, g	Volume, cm^3	Density, g/cm^3	Rel. density
3.4501	9.8294	0.35	0.12

The cell morphology of the Al metallic foam was studied using stereo microscope and shown in Fig. 4. The Al foam shows structural in-homogeneous and imperfection. In-homogeneous in the structure was characterized by varied pore size and wall thickness. The measured pore sizes were in the range of 1.3 to 2.1 mm. In addition to in-homogeneous, morphological defects like cell wall fracture and buckling in the cell walls are also appearing in the stereo micrograph. Few pores are interconnected to the inner pores. Very small size pores also appear in the structure but their sizes have not been measured owing to lesser quantity. The cell wall microstructure of the Al foam has been studied under optical microscope and shown in Fig. 5. The microstructure clearly shows a network of Al-Ca-Ti eutectic (dark) in the aluminium matrix [6]. The aluminium matrix shows fine grain structure which promotes plastic deformation instead of brittle failure of the cell walls under compressive load.

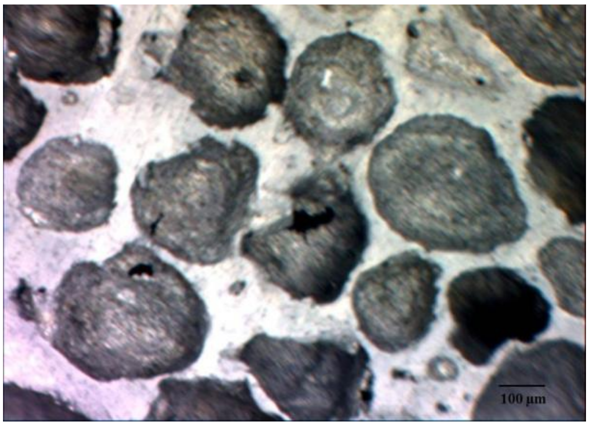


Fig. 4: Stereo microscopic image of Al foam

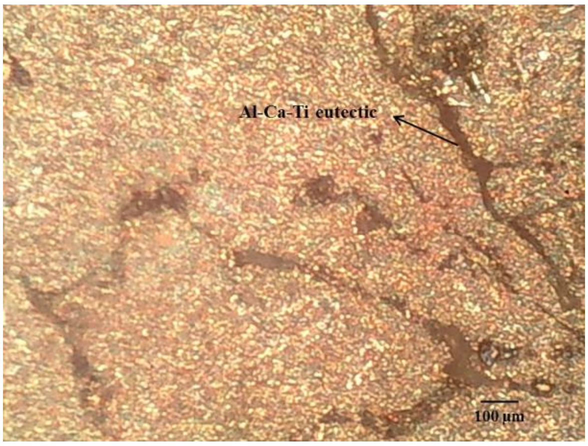


Fig 5: Al foam cell wall microstructure (x100 magnification)

3.2. Compressive behaviour

The compression test specimen before and after the uni-axial compressive loading (70% deformation) is shown in Fig. 6 and 7 respectively. The compressive stress vs. strain curve of Al foam is shown in Fig. 8. The compressive stress vs. strain curve shows a stress maximum, corresponding to the onset of global collapse of the pores, followed by a load softening region to a plateau, at which successive bands of pores collapse. Beyond the deformation plateau, the stress rises steeply as complete compaction commences. The compressive response of the present Al metallic foam matches with the trend reported by Markaki and Clyne [6].

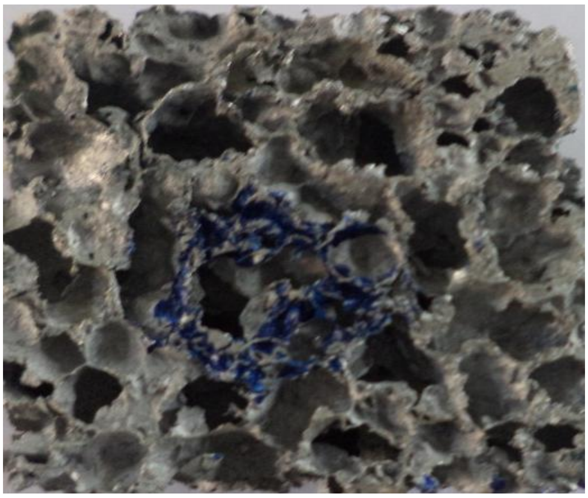


Fig. 6: Al metallic foam specimen before the compression test

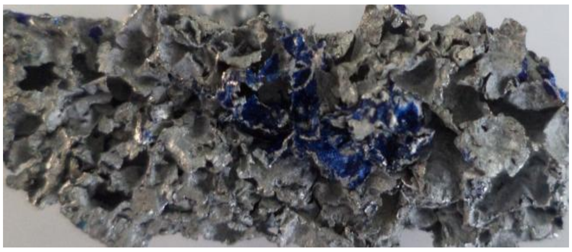


Fig. 7: Al metallic foam specimen after the compression test

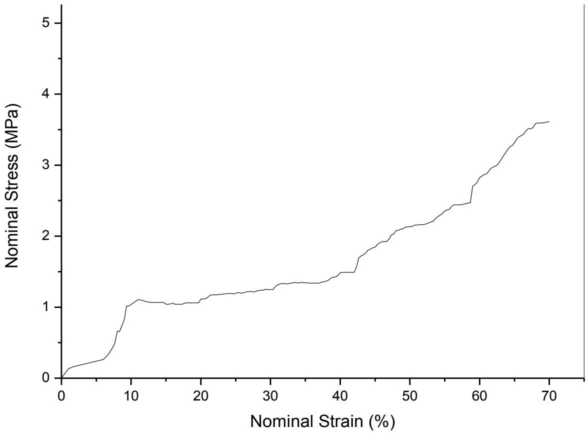
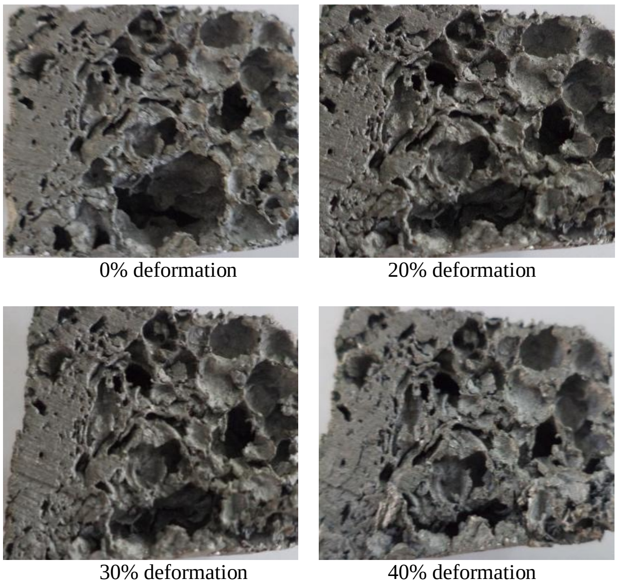


Fig. 8: Compressive stress vs. strain curve of Al foam

There was an enlargement in the lateral side of the foam after the compression test. The sequence of deformation events occurred during compression of Al metallic foam has been shown in Fig. 9. The deformation is largely concentrated in cells close to the bottom surface of the sample. The large pore shown in the Fig.9 is probably triggered this localization by generating some stress concentration in adjacent areas. It can be seen that cells subsequently deformed in shear, spreading outwards from the large pore. As deformation progressed, co-operative collapse occurred. Some of the pores failed in shear, which leads to the lateral expansion in the sample. The in-homogeneous in the height of the sample in the left and right side of the sample may attributed to the large quantity pores compaction in the right side compared to left.



0% deformation | 20% deformation

30% deformation | 40% deformation

Fig. 9: Sequence of deformation events in Al foam under compressive load

4. Conclusions

The closed cell aluminium metallic foams were successfully produced through liquid state processing route. The produced Al foam contained almost 88% of porosity. An addition of 1.5% calcium (viscosity modifier) and 1.6% of titanium hydride (blowing agent) resulted in good quality foam with uniformly distributed pores throughout the casting. Cell morphology showed that the in-homogeneous in cell size and cell wall thickness as well as imperfections in the structure. The cell wall contains aluminium matrix of fine grains, which imparts ductility to the cell walls which lead to increased load softening region in the stress strain curve which is an important characteristic required for automotive crashworthiness.

REFERENCES:

[1] M.W. Andure, S.C. Jirapure and L.P. Dhamande. 2012. Advance automobile material for light weight future - A review, *Int. J. Computer Application*, 1, 15-22.

[2] J. Banhart. 2001. Manufacture, characterisation and application of cellular metals and metal foams, *Progress in Materials Science*, 46(6), 559-632. http://dx.doi.org/10.1016/S0079-6425(00)00002-5.

[3] H. Fathi, E. Emadoddin and A. Habibolah. 2012. Manufacture of aluminum closed-cell foam by ARB process using $CaCO_3$ as the blowing agent, *Iranian J. Materials Science and Engineering*, 9(3), 40-48.

[4] V. Kevorkijan, S.D. Skapin, I. Paulin, B. Sustarsic and M. Jenko. 2010. Synthesis and characterisation of closed cells aluminium foams containing dolomite powder as foaming agent, *Materiali in Tehnologije*, 44(6), 363-371.

[5] J. Lázaro, S. Eusebio and M.A. Rodríguez-Pérez. 2014. Alternative carbonates to produce aluminium foams via melt route, *Procedia Materials Science*, 2(4), 275-280. http://dx.doi.org/10.1016/j.mspro.2014.07.557.

[6] A.E. Markaki and T.W. Clyne. 2001. The effect of cell wall microstructure on the deformation and fracture of aluminium-based foams, *Acta Materialia*, 49(9), 1677-1686. http://dx.doi.org/10.1016/S1359-6454(01)00072-6.

EDITORIAL NOTES:

Edited paper from National Conference on Technological Advances in Mechanical Engineering TAME 2015, 20 August 2015, Chennai, India.

GUEST EDITOR: Dr. K. Umanath, Dept. of Mech. Engg., VelTech HighTech Dr. Rangarajan Dr. Sakunthala Engg. College, Chennai, India.