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Metal Foaming of Aluminium Alloys

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Abstract: *Aluminium foam can be manufactured by various processes such as direct foaming of aluminium alloy and powder metallurgical methods. Different properties and applications of various types of foams are discussed in this paper. Such studies give us an idea of the fields where aluminium foams can perform well and how can we use it in future development.*
Index Terms: *Aluminum foams, energy absorption, light-weight construction, precursors, sandwich panels*

I. Introduction

Metal foams are generally light weight metals flourished with a combination of several properties like very low specific weight, high stiffness, good energy absorption quality and high compression strength.

Manufacturing of metal foams is a very difficult task because of the simultaneous occurrence of solid, liquid and gaseous phases at different temperatures. Few technologies of manufacturing foamed metals are now available but still the foamed metal suffers from deficiencies and non-uniformities. We need to control and understood the foam stability of liquid metals in order to improve foam quality and to make the production techniques of foam metals more reliable and producible.

The term metal foam is often mistaken and creates confusion but metal foams are a subgroup of cellular metals having polyhedral cells. The liquid counterpart is expressed by liquid metal foam while the solid phase is described as metal foam. The present paper will be restricted to closed-cell aluminium alloy foams which have a good potential for market introduction. We shall first review different manufacturing methods address the importance of fundamental research and then discuss applications.

II. Production Methods Of Metal Foams

Aluminium foams can be made by using two main strategies (Table 1). Direct foaming methods begin from a metal in liquid form which contains uniformly dispersed blowing agent particles into which we infect gas in order to create foam. We can also add titanium hydride to the molten metal, which would lead the same effect after decomposition. Indirect foaming methods begin from solid precursors of aluminium matrix containing zirconium hydride and titanium as uniformly dispersed blowing agent particle. On melting this precursor expand and create foam.

II.I. Direct foaming of metal by gas injection

Foaming aluminium alloys by gas injection method of foaming is already in the state of commercial exploitation [1]. Aluminium oxide, Silicon carbide or other ceramic particles are required to admixed, in order to make the alloy foam able. The mean particle size of the reinforcing particles typically ranges from 5 to 20µm and the volume fraction from 10 to 20%. Specially designed injectors which have been described to rotate or vibrate are utilized for gas injection (usually air). The resultant metal foam comes on top of the liquid from where it can be taken off with a conveyor belt, and then allowed to cool and solidify. The foamed material is either used by cutting into the required shape after foaming, or in the state it comes out of the casting machine. Large volume of foams with low densities can be produced by this foaming method. 'Stabilized Aluminium Foam (SAF)' in Cymat, Canada is produced in this way.

Table I. Basic foaming route for metal foams and current manufacturers for aluminium-based foams
(Names given in brackets are registered trademarks.)

Direct Foaming	Melt alloy Make alloy foamable Create gas bubbles Collect foam Solidify foam	Indirect foaming	Prepare foamable precursor remelt precursor Create foam Solidify foam
Manufacturers (products)	Cymat, Canada (*SAF*) Foamtech, Korea (Lasom) Hutte Kleinreichenbach (HKB), Austria (*Metcomb*) Shinko-wire, Japan (*Alporas*) (Distributor: Gleich, Germany)	Manufacturers (products)	alm, Germany(AFS) Alulight, Austria (*alulight*) Gleich-IWE, Germany Schunk, Germany

II.II. Foaming of precursors

The second method of metal foaming includes preparation of a precursor which contains a uniformly dispersed blowing agent, instead of foaming the melt directly. In the second method of metal foaming, the foam is created by melting the precursor during which the blowing gas evolves and bubbles are created. Several procedures are there to produce foamable precursors, one simple process includes the use of a hot uniaxial pressing to compact the powder mixture at temperatures close to the thermal decomposition of the blowing agent. This procedure gives the yielding more than 99% relative density of the precursor (Fig. 1).

Fig.1. Precursor materials of Al-alloy

The main parameters in foaming of precursors are the density and the distribution of the blowing agent particles into the metal matrix which can be evaluated by scanning electron microscope (Fig. 2).

Fig.2. Foamable precursor sample of Al-alloys

III. Fundamental Research

The history of metal foams is quite interesting and dates back to the 1940s [2]. In the first surge from the late 1950s to the 1970s, a large number of patents were issued and many variants of foaming processes were proposed. In the late 1980s, the second surge of scientific activities got started and led to the re-establishment of some old techniques and discover some new ones. In the year 1990, Fraunhofer-Institute entered in the field and re-discovered an old powder based metal foaming process. This institute worked hard related to the processing of foams and still the processing issues were solved by trial-and-error manner.

First lively research area is that of *metal foam physics* and the task is to find out how the stability of metal foams can be increased. The main goal is to improve the properties of foamed metals and to make the production more reliable. But the presence of non-metallic particles of size range from tens of nanometres to tens of micrometres in the liquid metal was realised crucial for foam stability. In analogy to aqueous foam physics the term *high-temperature colloid chemistry* has been coined for this research field [3].

The investigation of *structure-property relationships* is the second important field. It seems that the best mechanical properties are yielded by the uniform metal foam with smooth cell walls, but the actual proof is still lacking. To interpret the experimental data and to help design engineers to apply the material, *modelling* of metal foam structures is important. Apart from these, there are other more technological fields such as cutting, coating and joining of metal foams.

IV. Properties

Metal foams reflect the properties of cellular materials with those of metals. Thus, the metal foams are more advantageous for lightweight constructions because of their high strength-to-weight ratio. A brief overview of the main properties of closed-cell Al-alloy is presented here. Metal foams of any metal and their alloys can be formed but, the metal foams of Al-alloys are commercially most exploited due to their high thermal conductivity, low density, high ductility, and metal competitive cost.

IV.I. Structural Properties

There are a number of structural parameters of these foams, such as number, average size, thickness, intersections and defects in the cell-walls, size-pore distribution, shape and geometry of the pores, defects and cracks of the external dense surface for describing the cellular architecture of the foams. In order to understand the relationship between properties and morphology a number of experiments has been made, but the exact interrelationship is not yet sufficiently known. It was assumed that the properties of metal foams improved when all the individual cells of foam have a spherical shape and similar size but this has not really been verified experimentally.

Missing or wiggled cell-walls reduce strength and result in a reduced deformation energy absorbed during compression (Markaki & Clyne, 2001; Campana & Pilone, 2008) [4].The fact that defect free foams with a uniform pore distribution are desirable is widely accepted. This would make the properties of the foams more predictable, and it will be considered as a reliable material for engineering purposes and will be able to compete with classical materials.

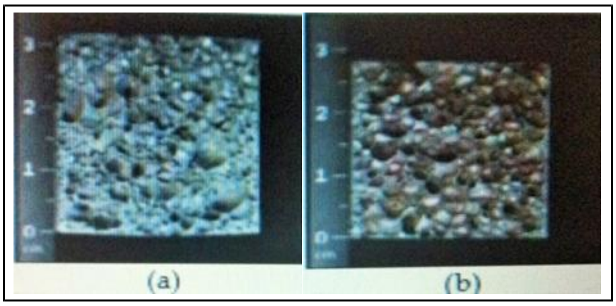

Fig.3. Cellular structures: (a) AlSi7,(b) AlSi1Mg

Foam characterisation results revealed that the cellular structures of the Al-alloy foams obtained by PM method have pores with different sizes and shapes (Fig.3). A large size distribution of the cellular pores with irregular cell shape is observed. The closed pores are- mostly- of polyhedral or spherical geometry (Fig. 3 and 4).

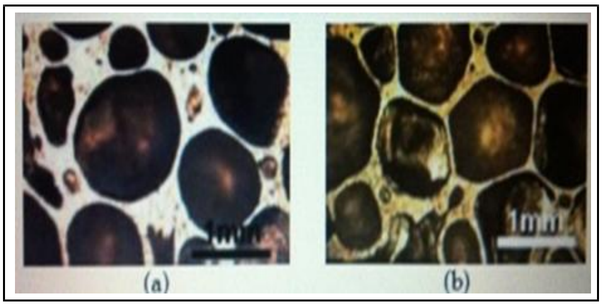

Fig.4. Pore geometries: (a) spherical, (b) polyhedral

Spherical pores with a thick thickness of cell-wall are mostly observed in the bottom and lateral sides of the foam samples. Polyhedral pores with a thin cell-wall thickness are mainly observed at the top of the foam samples.

IV.II. Mechanical Properties

Several studies have been done on the mechanical properties of metal foams. Gibson and Ashby provided the mechanical behaviour of wide range of cellular solids (Gibson & Ashby, 2000). Experiments have carried out to investigate the properties of metal foams under various loading conditions, especially under impact loading. To evaluate the compressive behaviour and the energy absorbed of these foams, uniaxial compressive mechanical tests are commonly used.

The compression behaviour of Al-alloy foams depends on various parameters such as: (i) the foam morphology (cell size range); (ii) the Al-alloy composition; (iii) the defects of cellular structure (cell walls);(iv) the density gradient of samples; and (v) the characteristics of the external surface skin. The mechanical properties are strongly influenced by the density and the architecture of these foams. The compressive properties, such as, the elasticity, the energy absorption, modulus and the average plateau stress, depend on the foam density and their values increase with the rise of the density (Fig. 5).It is clear from Fig.5, the stress-strain curves are divided into three characteristic regions. Region (i) is linear-elastic where the load increases with increasing compression displacement almost linearly. Region (ii) is plastic collapse plateau with a nearly steady compression load. Region (iii) is the densification of the foam, here after the cell walls crushed together there is a rapid increase on the load. The mechanisms associated to these foams and the failure modes at different regions of the load-displacement have been identified.

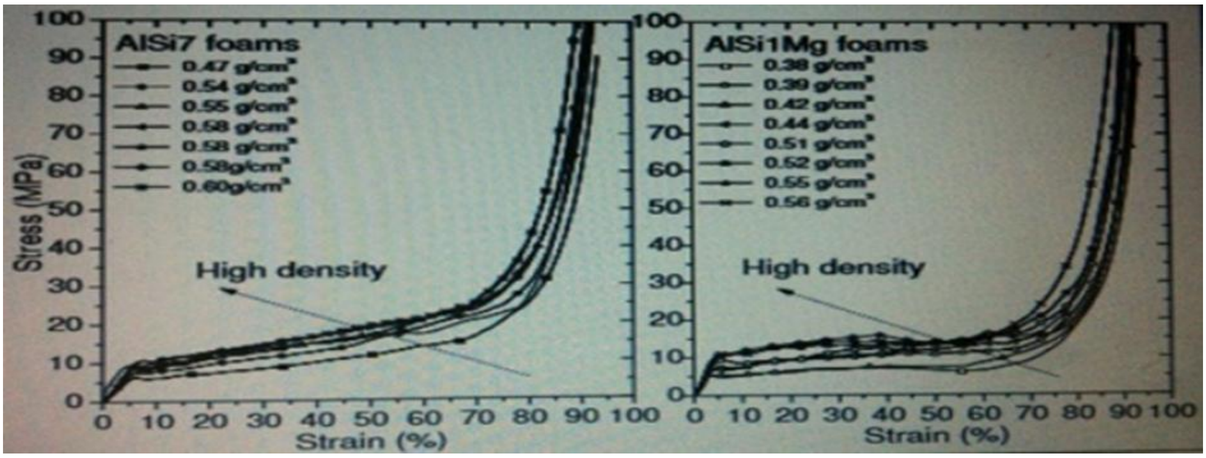

Fig.5. Compressive stress-strain curves for the different specimens (cylindrical samples height/diameter ratio equal 1: h=□= 30mm x 30mm).

In lightweight structures Al-alloy foams are often used as filler material. The capability of these foams to absorb energy can be estimated from the stress-strain compression behaviour of the material which is estimated from the area under the stress- strain curve.

The further advantage of aluminium foam is that the absorbed energy is irreversibly converted into plastic deformation energy. Higher energy absorption capabilities are exhibited by Al-alloy foams and it increase with increasing foam density.

V. Application

The fantastic properties of metal foams make it suitable for automotive industries and the potential application also exist in aerospace industry and ship building. The other applications can be discussed as follows:

V.I Light-weight construction with aluminium foam sandwich (AFS) panels

A German car builder Fraunhofer developed the AFS technology in 1994 and it is an example of the use of metal foams in conjunction with dense material [5]. Sandwich panels of foamed metal can be obtained by roll-cladding the conventional aluminium sheets to a sheet of foamable precursor material manufactured from powders. The conventional stamped steel parts in a car could be replaced by AFS and also lead to weight reductions. Apart from this AFS could reduce the number of parts in the frame of car, facilitate assembly, improve performance as sandwich panels serves as vibration dampers and also reduce the cost. Aluminium sections can be joined with AFS sandwich panels by using several welding techniques and can be integrated into the car body [6].

V.II Metal foams as reinforcement of polymer structures

For rail based vehicles such as trams, crash absorbers are also required. An underride protection must be given to trams to prevent pedestrians to be dragged under the vehicle. The Al foam core was made by foaming precursors obtained by extruding powder mixtures and embedding the foam into a rubber shell. Now hundreds of crash absorber are being produced and sold to tram manufacturers and operators for refurbishment.

V.III Aluminium foams as cores for castings

Fig.6 Prototype of BMW engine mounting bracket. From left: empty casting, composite part consisting of foam core and cast shell, and section through composite part.

Another application uses the beneficial properties of Al foam inside a dense aluminium shell during manufacture and also in use after. It starts from a shaped part of aluminium Metcomb or Alulight foam (indirect or direct foaming) having dense outer skins and can be used as cores in low pressure die-casting. Based on such composites the German car maker BMW and LKR (Austria) have jointly designed an engine mounting bracket (Fig.6). The produced parts can be loaded with the weight of a car engine and also absorbs mechanical vibrations. These parts are also helpful in enhancing the safety of the car in crash situations because of enhanced stiffness and high fracture toughness.

VI. Challenges

Apart from the technological advances, the metal foam still poses challenges related to the controlling of pores size and shape of metal foams. The major challenge is to produce metal foams in series with uniform cellular structure and controlled foam architecture. Other challenges includes: Lack of understanding of the basic mechanism of metal foaming, Insufficient ability to make foams of a constant quality, insufficient knowledge of foam properties, and the interrelationship between morphology and structures.

VII. Conclusion

Metal foams became an attractive field of research from both points of view, scientific and industrial applications. Numbers of metal foaming techniques have introduced with different foaming metal, but Al-alloy can be used as lightweight, energy-absorption and damping structures in several industrial sectors and even in ships, cars, and aircrafts.

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