Development of Aluminum Metal Foam, and Study of its Properties

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ABSTRACT

The goal of this research paper is to develop metal foam that demonstrates improvements in product uniformity and mechanical properties over the currently available foams. To accomplish this goal, the study included the identification of the various technologies used to manufacture metal foams, the assessment of the improvements needed to augment the quality of foamed metals. The experimental equipment is designed and developed, while the raw materials were obtained. Then the hollow sphere foam samples were successfully produced. Using these samples a series of characterization studies was done to qualify and quantify the results. These findings were then compared to presently published data to gauge the relative success of the work.

The bonding strength between sphere and matrix needs improvement, and different material choices and processing changes have been identified in this paper to achieve these improvements. The packing density of the spheres can be improved, and a new method of vibrating the sphere arrangement prior to molding may increase the packing density. The porosity of the aluminum matrix can be reduced, and the design of the casting mold and processing conditions can be modified to reduce undesirable porosity. Additional testing methods have been identified to further characterize the foam and reveal insights for further improvement.

Keywords: Aluminum, Metal foam, Porosity

1. INTRODUCTION

The first metal foam was invented in 1943, by Benjamin Sosnick of San Francisco California [1]. He created a "sponge metal" using mercury as a foaming agent in molten aluminum. Later the research into the manufacturing of these cellular metals has developed various techniques to include: metal casting, powder metallurgy (PM), electro deposition, chemical vapour deposition (CVD) and physical vapour deposition (PVD) [2]. Casting and PM are common techniques used to manufacture larger quantities of foams made from steel, titanium and aluminum, whereas electro deposition, CVD and PVD are used to produce more exotic foams such as those using refractory metals.

Cellular materials have received a great deal of interest for more than 20 years, owing to their practical and academic importance. They can be made to combine high strength-to-weight ratio, elastic resilience and good energy absorption properties. These are increasingly being used for load bearing, thermal insulation, shock and impact absorption, and noise protection components in many applications of lightweight structures. Metallic foams provide excellent energy absorption properties on a much higher strength level than foamed organic materials.

Many fabricating processes of metal foams have been developed. Among them, the practical processes for producing metal foams are classified into two routes: melt route and powder metallurgy. In the melt route, blocks of aluminum foam with a regular shape are commercially manufactured in batch operations, and the mechanical properties of the produced foams have been reported. Sheets of aluminum foam are continuously fabricated by drawing out from the surface of the molten metal injected bubbles of gas. The melt route is suitable for mass production of metal foams with a simple shape [3].

The characteristic properties that define metal foam include its cellular structure and relative density. Metal foams are either open cell, closed cell, or a combination of the two [4]. Open cell foam can be thought of as a network of interconnected solid struts. Open cell foam will allow fluid media to pass through it. Closed cell foam is made up of a network of adjacent sealed pores, all sharing walls with each other. A fluid media cannot pass through closed cell foam. A combination of open cell /closed cell composition is technologically possible. An example is closed cell foam whose cell walls have been partially fractured. Another example is a stacked arrangement of hollow spheres sintered together. The pore space inside the hollow spheres represents the closed cell nature, but the open interstitial space between the spheres constitutes an open cell nature. An in-house facility was developed to produce aluminum metal foam. This paper describes the production and properties of developed metallic foam.

Metal foams are porous media with low density and novel thermal, mechanical, electrical, and acoustic properties. They can be categorized as open-cell or closed cell foams, but only open-cell metal foams appear to have promise for constructing heat exchangers. Open-cell metal foams have high specific surface area, relatively high thermal conductivity, and a tortuous flow path to promote mixing. Metal foam have been studies by a number of researchers for thermal applications; some were focused on metal-foam heat exchangers (and heat sinks), and many others investigated the basic thermal transport properties of metal foams [5]. In many industrial fields, much attention has been focused on metallic foams with extremely low relative densities. This is because these materials have a variety of beneficial properties, such as low weight, high energy-absorbing capability and good acoustic damping capacity, which result from their unique cellular structure composed of a great number of open and/or closed pores and thin metallic cell walls. In addition, they exhibit excellent recycling efficiency, high specific stiffness, good thermal conductivity and high melting point [6].

2. PRODUCTION OF ALUMINUM FOAM

The production process includes a preheated mould with vent hole in which high purity molten aluminum is poured and small amount of calcium carbonate powder is dispersed in three stages. First stage one third amounts sprayed in empty mould; afterward another one third is mixed while pouring the molten aluminum metal and finally remaining part mixed while stirring operation. The decomposition of calcium carbonate release gases, which are entrapped in high viscous mixture of the molten aluminum and calcium residues and create low density porous aluminum foam.

This low density foam float on the top of molten aluminum metal. Left out metal is drained though vent hole and remained foam is allowed to be cool-down in the mold. Afterward foam is removed from the mold and cut to the desired sizes by EDM. Microstructure of the typical sample is given in figure.

Figure 1: Molten metal poured in to mould

Figure2: Calcium carbonate added and stir

Figure 3: Foam is developed

Figure 4: Structure of Aluminum foam

3. PROPERTIES OF FOAM

1. DENSITY

The most important parameter characterizing a foamed material is its relative density, ρR. This is defined as the quantity, ρR= ρ*/ρs., where ρ* is the density of the cellular solid itself, and ρs is the density of the parent material from which foam is made.

Density of pure aluminum is 2319 Kg/m^3

Whereas the Density of parent aluminum metal measured was,

$\rho_s = 2480$ Kg/m^3

It shows that there are some impurities in the aluminum that used.

Density of Metallic Foam,
Dimension of piece = 67×14×11 mm

Volume of piece = 1.0318×10^{-5} m3

Weight of metallic foam piece = 8.75 gm = 0.00875 Kg

$$\rho^* = \frac{m_f}{v_f} = \frac{0.00875}{1.0318\times10^{-5}} = 848 \text{ Kg/m3}$$

Relative Density of Aluminum Metal Foam

ρR= ρ*/ρs.

= 848/ 2480 or 0.342

This shows that the density of aluminum metal foam is much less than that of casted aluminum.

4. PORE SIZE

The Lieca microscope was used to measure the pore sizes of the foam. This facilitates to take the photograph of cut section as well as provides the dimension with marking. Microscope directly gives the values of pore size and wall thickness. The red color arrows shown in figure are the pores that were measured. Typical values are follows:

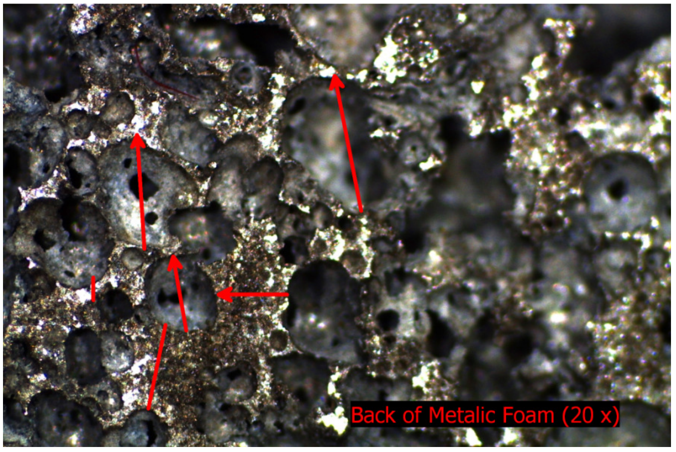

Figure 5: Pore size of foam

1. Maximum size of pore = 1 mm
2. Minimum size of pore = 500 μm
3. Average size of pore = 750 μm
4. Wall thickness = 50 μm to 85 μm
5. Volume of solid aluminum = 45%
6. Volume of foam = 55%

5. COMPRESSIVE STRENGTH

Choosing the foam of dimension 100×25×25 mm a compressive test was conducted on a universal testing machine (UTM). A uniform load of 75kN was applied to it. It was seen that same like other material, aluminum foam initially shows an elastic deformation at the beginning to a load of about 5kN and then a continuous plastic deformation regime is achieved. We see that the specimen shows a non uniform results of about 35-50 KN of load on the foam. The compressive strength was approximately found to be 1.87 MPa. This fluctuation was due to the reason that the foam produced was not so perfect, having imperfection in the cell structure, with a combination an open and closed cell.

6. TENSILE STRENGTH

The tensile strength of aluminum foam depends on cell wall material, the geometry of structure and the volume fraction of the solid. The similar dimension specimen that was used initially was tested for the determination of tensile strength. The tensile tests were conducted on a flat dog bone shape specimens under UTM which was been used by different researchers. The test was conducted with a uniform stress acting on the specimen, it was observed that same as that of compression the elastic regime was observed initially but the amount of strain in elastic region was much less that of the compression with the increasing value of the stress. Further increase in quasi-static load gives a plastic deformation to larger extent to finally lead to a fracture ~ 1.24MPa. The test was conducted many times to confirm the result, leading to a varying results, the value which was accepted was of about 1.12MPa.

7. CONCLUSION

The aluminum metal foam was successfully developed using the blowing agent technique. It shows the desired properties as demanded by the user industries. It needs some more effort to produce at mass scale production as well characterization of the product to be included in the list of standard materials.

The system was designed, fabricated and controlled for aluminum foam generation. The obtained foam was tested and results were: Wall thickness = 50 μm to 85 μm, Maximum size of pore = 1 mm, Minimum size of pore = 500 μm, Average size of pore = 750 μm. Relative density was determined about 0.342 and the compressive and tensile strength of aluminum foam was approximately 1.87 MPa and 1.12 MPa respectively.

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