Manufacturing of Aluminum Foam as a Light Weight Structural Material

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ABSTRACT

In this study, aluminum foam was fabricated using sintering and dissolution process (SDP). Aluminum powder with a particle size (3.63μm) as a raw material was mixed with NaCl with a particle size between (212-400μm) as a space holderat different ratio (30, 40, 50 ,60, 70 and 80) wt. % and compacted at 200 MPa followed by sintering at 650° C for 2 hrs. The sintered samples were placed into hot water for 10 hrs to dissolve NaCl particles. Uniaxial compression test was carried out to determine the foam structure influence on plastic deformation and damage in the Al foam. The foam porosity increased from 28% to 81% for 30wt. % and 80wt. % of NaCl content respectively. The mechanical properties (compressive strength, yield stress and young's modulus) decrease with increasing NaCl content.

Keyword: Sintering and dissolution process, aluminum foam, NaCl space holder, SDP, metal foam.

INTRODUCTION

In recent years, Aluminum foams have received a considerable amount of attention and used in many fields of engineering due to an excellent combination of physical and mechanical properties such as low thermal conductivity[1,2], high specific toughness [3], low specific weight, good acoustic properties [4,5], and good electrical insulating properties [6]. Metal foams can be manufactured with several methods like melt-gas injection [7], melt-foaming agent [8], powder compact melting [9], dissolution and sintering process [10], replication process [11], investment casting [12] and melt infiltration [13].

Most cellular materials can be classified as both open-cell and closed-cell foams.

By comparing with the metal from which they are made, closed-cell foams possess lower thermal conductivity, higher acoustic damping characteristics and higher impact energy absorbing. Closed-cell foams possess higher degree of strength than open celled [14]. Open celled structures of Al foams needed for functional applications, such as filtration, sound absorption, thermal insulation, heat exchange, air and water cleaning, energy absorption [15, 16].

Powder metallurgy method is one of the most promising techniques for fabricating metal foams. It was invented in Fraunhofer Institute for Applied Materials Research in Bremen, Germany. This method has a good control over the cell size,cell shape and with a relatively homogeneous pore structure. The sintering and dissolution process (SDP) is a developed technique by Zhao and Sun [17] to manufacture low cost open-cell foams using PM route. SDP is one of the most cost effective routes for producing Al foams.SDP is a route which NaCl is used as space holders. Many space holders can be used instead of NaCl like potassium carbonate[18], carbamide (urea)[19] and ammonium carbonate [20].

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By using SDP to synthesize metal foams, the pore size and pore morphology of foams can be controlled by selecting suitable sizes of space holder particles and its volume fraction in the matrix-space holder powder mixture. In addition, the foam porosity can be easily controlled by varying the metal/space holder volume ratio.
This article describes the fabrication open-cell Al foams via sintering dissolution process by using five of Al-NaCl mixture ratios. Foams structure, porosity, density and compressive behavior of the foams are also investigated.

Experimental Procedure:
The raw materials used in this study were aluminum powder with particle size of ~ 3.63 µmand sodium chloride (NaCl) with particle size of 300-400µm.The particle morphology of NaCl is given in figure (1a). NaCl particles have semi-equiaxed shape and the morphology of aluminum powder is given in figure (1b).

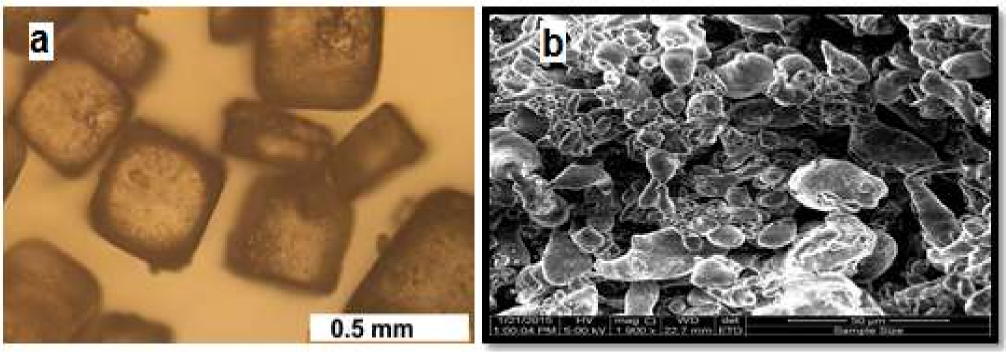

Figure (1): Morphology of (a) NaCl particles by optical microscope, (b) Al powder by SEM.

The Aluminum powder was mixed with different ratios of NaCl powder (30, 40, 50, 60, 70, 80) wt.% as a space holder to create porosity, the mixture was mixed in ball milling for one hour with alumina balls in porcelain jar. The powder mixture was compacted into a steel mold with a diameter (25mm) and height (80mm) under a compaction stress (200 MPa) using a hydraulic press. Figure (2a) shows the pressed aluminum samples were sintered into a direct furnace under argon (Ar) atmosphere at 650°C for 2 hours and then allowed to cool to the room temperature. The last step was the dissolution process, which consists of placed the samples inhot water with temperature of 95° for dissolution time (10 hrs) to remove NaCl particles and create aluminum foam as shown in figure (2b). The density of foam determined according to the conventional equation:

$$\rho = M/V$$

where
ρ =Density (g/cm^3), M= mass (g), V= volume (cm^3). The volume was determined by the physical dimension of samples.
The porosity of the manufactured aluminum foam samples (P_f), can be calculated by the equation [21]: foam porosity

$$P_f = \left|1 - \left(\frac{\rho_f}{\rho_{Al}}\right)\right| \times 100\% \qquad ..(2)$$

where, ρ_{Al}= aluminum density (2.7 g/cm^3), ρ_f = foam density (g/cm^3).
The microstructure of the Al foam samples was examined using the optical microscope. The mechanical properties of foam samples were measured using an Instron machine, model

WDW-200E at a crosshead speed 1mm/min at room temperature to determine the compression strength, Yield point and Young's modulus of foam .

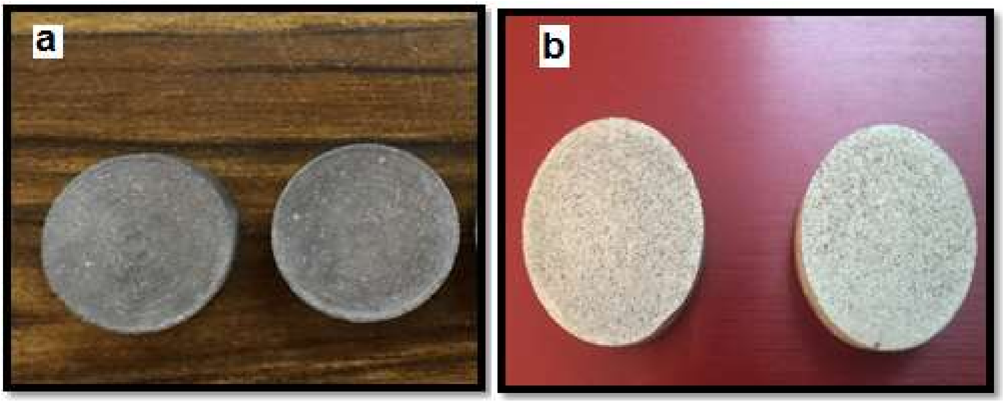

Figure (2): Aluminum specimens (a)after sintering, (b) after dissolution process.

Results and discussion

Porosity and density

Figure (3) shows the effect of NaCl content on porosity and foam density of Al foam. The porosity increases when the NaCl content increases in the Al/NaCl sample and the foam density decrease with increasing NaCl content. During the dissolution process when the NaCl is removed the solid Al turned into foam. NaCl particle dissolves in hot water, and the space that created after dissolving process become pores, and that make the sample lighter. With a higher NaCl content in the sample which is 80 wt. %, some of NaCl particles are in touch with each other and make a continuous three- dimensional network. All the particles in the network shape dissolve in hot water, which results in high porosity and low foam density. A similar trend also reported by Nur Surianni A. S. et al. [22] who studied the effect of dissolution times on compressive properties and energy absorption of aluminum foam. In contrast, with a smaller NaCl content which is 30 wt. %, some of the NaCl particles are confined by the Al matrix and that cause the particles unable to dissolve in hot water, and thus, remain in the foam sample which causes high density and low porosity.

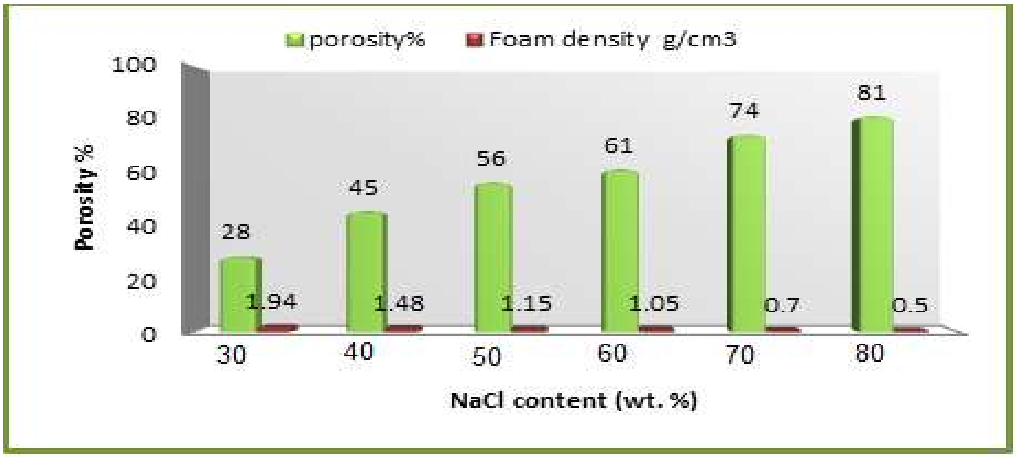

Figure (3): The effect of NaCl content on porosity and foam density.

Mechanical test (Compression test)

Figure (4) shows the compressive stress-strain curve of different aluminum foam with different NaCl content. The curve can be divided into three regions, especially for high concentrations of NaCl particles as shown in the insets.Firstly elastic deformation region;secondly,long deformation plateau region which caused by the plastic bending of cell ligaments;thirdly,the densification region. Where the cell walls contact each other, causing a rapidly raising in the flow stress or the foam deformed as a solid material. Similar curves behavior obtained by J. Appichart and K. Andrew [23].

The pure solid aluminum shows the highest yield stress and young's modulus. Young's modulus which is determined by the slope of the graph, the modulus decrease with increasing of foam`s porosity. This decreasing because ofhigh porosity elastic deformation and results in decreasing in the elastic modulus. Table (1) shows the yield stress and young's modulus of the studied foam samples. It can be observed that, the yield stress and young's modulus decrease with increasing NaCl content and porosity. This reduction is attributed to the increasing of Al foam porosity caused by NaCl content increasing. That means diminishing in matrix material amount in the specimen which not sustains high stresses.

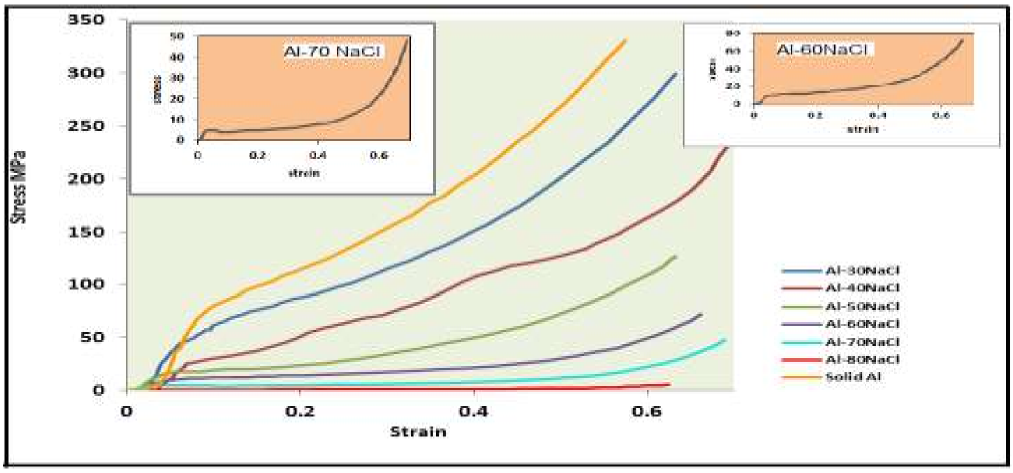

Figure (4): Compressive stress-strain curves of aluminum foam with different NaCl content.

Table (1): stress- strain curves of solid aluminum and aluminum foam with different NaCl content.

Samples	Solid Al	Al-30NaCl	Al-40NaCl	Al-50NaCl	Al-60NaCl	Al-70NaCl	Al-80NaCl
Yield stress (MPa)	60.5	32.707	24.717	9.362	6.549	3.832	0.264
Modulus (GPa)	1.445	1.315	0.617	0.457	0.245	0.140	0.0228

Microstructural analysis:

Figure (5) shows the morphology of foam, it has been shown that when the NaCl content increased larger pore size and higher quantities of pores were achieved, With a high ratio of NaCl in thepreform, most NaCl particles are in contact with each other and form a continuous three-dimensionalnetwork. The isolated pores with thick cell wall observed at 30wt.%NaCl content, and the interconnected pores with thinner cell wall at 80wt.% NaCl content. The results are in good agreement with those obtained by B. J Shamsul. et al. [24]. Table (2) illustrates the average pore size of Al foam with different NaCl content, because of a high NaCl contents leads to the generation of interconnected pores increased because of the formation of numerous channels between cells.

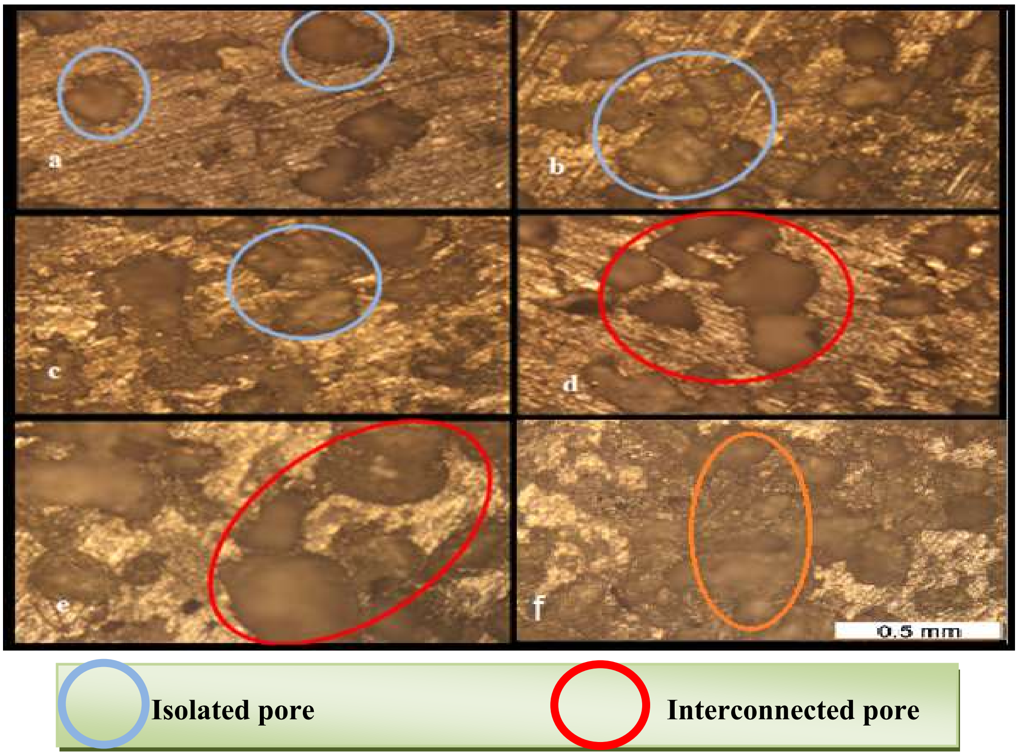

Figure (4): Optical micrograph of samples with different NaCl content; a) Al-30NaCl, b) Al-40NaCl, c) Al-50NaCl, d) Al-60NaCl, e) Al-70NaCl, f) Al-80NaCl

Table (2): shows the average pore size of foams with different NaCl content

Foam samples	Al-30NaCl	Al-40NaCl	Al-50NaCl	Al-60NaCl	Al-70NaCl
Average pore size(mm)	0.29	0.3	0.35	0.414	0.462

CONCLUSIONS

The Aluminum foam was successfully fabricated by a sintering and dissolution process. It can be observed that when the NaCl content increased, the porosity increased whereas the mechanical properties (compressive strength, yield stress and young's modulus) decreased. The microstructure showed that pore sizeof foam become larger when the NaCl content increased.

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