Production of Al2024 Foams by Powder Space Holder Technique

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Abstract
Open cell Al2024 foams with varying porosities were successfully fabricated by powder-space holder technique using spherical granulated sodium chloride (NaCl) particles (500µm) as space holders. In order to ensure sufficient handling strength in cold compacted pallets, 2 wt.% polyvinyl alcohol (PVA) solutions (wt.% PVA and 95 wt.% water) was mixed with the mixture of AA2024 and NaCl powders prior to cold compaction. Green compacts were sintered at 5600C for 2.5h under the vacuum atmosphere. After sintering, NaCl salt was removed by dissolving it in hot water. The cell morphology of sintered AA2024 foams was examined using a scanning electron microscope. The micro-architectural characteristics, density, porosity and hardness of the Al-foams were evaluated to examine their suitability as engineering applications. The results revealed that the powder-space holder technique was practically feasible. From SEM observation of the pore structures of the fabricated AA2024 foams, it was found that almost the entire specimen had a pore structure similar to the NaCl morphology, regardless of the NaCl volume fraction.

1. Introduction
Porous materials have been used for a lot of industrial areas such as automotive, aerospace, defense and energy due to energy absorption ability, energy absorption properties and superior acoustic performance [1] and have found a wide range of applications, such as, light weight sandwich panels, heat exchangers, exhaust mufflers, filters, biomedical prostheses, sound barriers and vibration dampers. Metal foams have emerged as promising materials due to their superior combination of properties such as low density, high energy absorption capacity, and high bending strength [2,3]. Porous structure of metal foams, which changing from 40 to 90, provides these excellent properties [1]. Also, the metal foams can be used for high temperature applications, such as cooling system, heat exchanger and heat shielding [4].

Aluminum (Al) foams are a lightweight, non-flammable and porous materials with high energy absorption, lower conductivity and better sound absorptivity and electromagnetic pulse shielding comparing with bulk Al.[5]. Al foams are widely used because of its low cost, relatively easy manufacturing with functional shapes and geometries, and good mechanical properties compared to other low melting metals. Al foams have compressive strength and shock absorbing capacity, and so they are preferred to automotive, railway, and aerospace applications where light weight and shock absorbing properties are of priority. The Physical and mechanical properties of Al foams can be improved by controlling the foam parameters such as foam density, porosity, morphology (shape and size of the cells). Also, Al foams are ideal for energy absorption materials due to their ability to undergo plastic deformation at a nearly constant stress level. Sandwich panels fabricated by using Al foam can be used as lightweight crash pads in transport materials [6].

During the last years, a lot of processing technologies have been developed for fabrication of aluminum foams. Among these, the space-holder technique is well suited for the production of fairly uniform and homogeneous open-cell foams of low melting point metals such as aluminum. In the space holder technique, carbamide, sodium chloride, carbonate particles and several polymers were used as extractable materials for manufacturing metal-foams [7]. In this study a space-holder method for fabricating Al2024-foams using sodium chloride particles as a leachable material is reported. The present paper aims to study the influence of sodium chloride content on the relative density, porosity, microstructure and hardness of the produced Al2024-foams.

2. Experimental Procedure
AA2024 powders (d0.5:25 µm) with chemical composition of (in wt.% ) 4.85 Cu, 1.78 Mg, 0.312
Mn, 0.005 Ti supplied by Gundogdu Exhoterm Company, was used as the parent material and sodium chloride as a leachable space-holder material in this study. The sodium chloride particles used in this study are a type of commercial salt with average size of 500 μm. It is cheap and easy to purchase in the market. The AA2024 powder and the sodium chloride particle with a chosen size range were weighed using an electronic balance with an accuracy of 0.001 g. The volume fraction of each constitutive element in the powder mixture can then be easily obtained by conversion of the weights into volumes.

Initially, the metal powders were mixed thoroughly with sodium chloride powder at a pre-specified weight ratio depending on the desired porosity of the final product. A small amount of PLA (about 2% in weight) was added in the mixture in order to avoid segregation of dissimilar powder and particles. The mixed powders were compacted using a hydraulic press. The mixture was uniaxially pressed at a given pressure, varied over a range of 300 MPa, in a stainless steel cylindrical mold with a diameter of 30 mm and height of 50 mm. The sodium chloride powder was removed from the green compact by water leaching at 800°C. The final stage involved sintering which was performed in a vacuum furnace (p = 0.01 MPa) at the temperature of 560°C and the holding time was fixed to 2.5 h. Fig. 1 shows the steps for fabrication of AA2024 foams via space holder technique.

The density \( \rho \) of the final AA2024-foam was calculated by dividing the mass of the foam by its volume, which was measured based on Archimedes principle. The porosity of the as-manufactured AA2024-foam \( P_f \) was estimated by \( P_f = 1 - \rho_f / \rho_{AA2024} \), where \( \rho_f \) is the calculated density of the foam and \( \rho_{AA2024} \) is the density of aluminum (\( \rho_{AA2024} = 2.79 \text{ g/cm}^3 \)).

A scanning electron microscope was used to characterize the cell morphology and cell wall microstructure of the produced foams. Vickers Microhardness measurements of sintered foam samples were made using Innovatest microhardness tester at a load of 100 gf. For each sample, average of 6 microhardness measurements has been reported.

3. Results and discussion

The morphologies of the initial powders and sodium chloride powders were given in Fig. 2. It can be seen in Fig. 2., the as-received AA2024 powders have acicular, angular and irregular shape while the sodium chloride powders have spherical shape.

Fig. 3a-c demonstrates a homogeneous distribution of NaCl particles and also pore distribution. As the NaCl content increases from 30 to 70 (wt.%), the sample exhibits more pore structure and also more porosity. As can be seen in Fig. 3, pore morphology is spherical shape. Moreover, the foam shows interconnected cellular microstructure. When the foam microstructure examine, it is observed the large spherical cells with homogeneous pores.
As a result of the presence of pores important changes is observed in the densities of the fabricated Al2024 foams. For the Al2024 alloy, density value is 2.78 g/cm³; while the end of foaming with space holder method the densities are changed importantly. The amount of NaCl from 30 wt% to 70 wt%, the porosity of the Al2024 foams increased from 15% to 65%, and the density decreased from 1.60 g/cm³ to 0.68 g/cm³.

**Figure 3.** The pore microstructure images of samples at different magnifications, (a) 30% NaCl, (b) 50% NaCl and (c) 70% NaCl. With increasing NaCl content, the density of the fabricated Al2024 foams decreases.

**Figure 4.** The change of density and porosity content with increasing NaCl content. Fig. 5 shows the variation of hardness changing NaCl content. It should be noted that hardness decreases with increasing pore content which increases with increasing space holder content.
4. Conclusion

In the study, an endeavor has been made to synthesis Al2024 foams by space holder method and analyzes its properties such as microstructure, density, porosity and hardness. From the detailed experimental investigation, the following conclusions have been made;

1) The uniform pore distribution is observed in the Al2024 alloy matrix without non-homogenous distribution.
2) The mass fraction percentage of NaCl content has significantly effect on the density and porosity of Al2024 foams.
3) Pore content increased with increasing NaCl content and also density and hardness decreased due to porosity effect.

References