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Characterization and Fabrication of Aluminium Foam using Powder Metallurgy Method

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Abstract
In today's modern age of engineering evolutions, the need for light yet strong materials has become very prominent. One of the significant needs of these materials is in the Aerospace and Automobile industry, where the strength-to-weight ratio plays a central role. To fulfil these demands various types of materials have been invented and innovated. One of them is Aluminium Foam. A unique property is that Aluminium foam has higher compression strength, lower specific weight, high stiffness and better energy absorption quality in combination with lightweight. Due to these wide applications for lightweight construction, it has become an attractive research field too. Many manufacturing techniques have been adopted to manufacture this foam, but results have not been encouraging. This paper deals with the development of Aluminium foam produced by the Space Holder Technique. Sodium Chloride, acting as a space holder, is mixed with Aluminium and compacted to obtain the green compact, which is then sintered in a sintering furnace to obtain foam. X-Ray Diffraction, Analysis and Microstructure, Analysis is Performed on a Green Compact and sintered specimen. The results are compared and used to analyse the specimen's chemical composition.

Keywords: Metallic Foam; Closed-Cell Foam; Powder Metallurgy; Space Holder Technique; X-Ray Diffraction.

1.Introduction

Aluminium has a greater strength-to-weight ratio compared to steel and other engineering materials, but there is a requirement for a much lighter and better-built material than aluminium in a range of dedicated sectors. [1, 4]. To accomplish such a stipulate, metallic foams must be made. Metallic Foam is a high-strength, low-weight absorbent material capable of absorbing a huge amount of energy beneath loading. [2]. The defining quality of metallic foams is porosity. Mounting pores in the metal reduces its weight considerably, due to which various properties are varied and new enviable properties are obtained. [3]. The accumulation of aluminium like a metal inside metallic foam will show the way to the enlargement of aluminium foam. Aluminium foams can be produced using a variety of production techniques, like Cymat, Alcan, Alphoras, Melt Route Method [8] and Powder Metallurgy Space Holder Technique. This paper deals with the space holder technique adopted to fabricate the aluminium foam. Foams are categorised into different types: based on pore connectivity, foams are classified as open and closed foams, and based on pore distribution, foams are classified as regular and stochastic. Fabrication and characterization of closed-cell foam are dealt in this paper.

1.1 Closed-Cell Foam

The pores present in closed-cell foam be preserved by means of cell walls. Closed cell foams are the most popular type of insulation used in remodelling and new construction applications. They can provide support to the structure due to the composition of their cells [5, 6]. They protect against water damage. Due to their ability to float on water, closed-cell foams have a variety of applications, such as construction of boats, ships, and other vessels. They are also often employed as thermal insulators.

1.2 *Materials*

Aluminium air atomized elemental Powder with purity 99.5 % is procured from the supplier, A1 Vision Casting, have been tested and powder morphologies are observed by a scanning electron microscope The NaCl particles have been procured from SAC laboratory reagents, with different sizes. To control the sizes of the resulting foam, this salt has been sieved into 2 groups with different particle diameter <3.5, 3.5-4, mm. large particles 60 wt. % is mixed with medium size particles 30 wt. % to increase porosity and create interconnected structure.

2. Methodology

2.1 Space holder technique

The space holder procedure is an element of the powder metallurgy method in which powdered metals are changed into solid foams by means of a sequence of processes. The four processes embrace mixing, compacting, dissolving, and sintering. Initially, the base metal is mixed with the space holder and is then compressed in a compacting machine, squashing a green compact. The obtained green compact is reserved for disbanding to get rid of the space holder and to engender a metallic scaffold. This scaffold is sintered within a sintering furnace to augment the strength of the foam. Metallic scaffold after the casting process yields syntactic foam. Alternatively, these granules can also be detached by leaching specimens as required.

3.Experimentation

3.1 Mixing

The fabrication of Aluminium Foam was done by using space holder process incorporation of Aluminium and NaCl. In this method, we follow four steps to get the Specimen fabricated. First is Mixing Aluminium powder and other space-holder. This is the main and essential step in the manufacture of metallic shell. Then binding material is added during the mixing process, which improves the consistency between the powder particles. The consistent spreading of space holder in Aluminium will make the uniformity of pore spreading in the metallic shell. This is done by using Mortar and Pestle shown in Figure 1. Before mixing, NaCl powder was dried at 115 ˚C for 50 minutes in a heater and at 410 ˚C for 40 minutes in an electrical furnace.

Figure 1: Mortar and Pestle

3.2 Compaction

Compaction follows the mixing process. The compaction machine, whose maximum capacity is 25 tonnes, is shown in Figure 2. Compaction is done to obtain a green compact that can hold the mixture unbroken during dissolution and sintering. The compaction pressure will increase the bondage between the mixture particles, increasing the density of the green compact [11]. As a result of the compaction process, the oxide layer on the surface of the particles will be disturbed due to stress concentrations and shear strains among the metallic powder and the space holders. The sintering ability of metallic powders is also improved by the compaction process. The decrease of the oxide coating on the mixture surface will form inadequate bonding of particles.

Figure 2: Compaction Machine

3.3 Dissolution

Subtraction of the space holder from the metallic shell leads to the formation of macropores. The distilled water should be heated at 100˚ C on hot plate. The Heater used for Dissolution process is shown in Figure 3. After the water reaches 100˚ C temperature, the green compact is placed in the hot water. The green compact is allowed to stay in boiling water for 3 hours. The green compact is removed from the boiling water and dried at 80˚ C for 2 hours in oven. The weight of the green compact is checked, and if the weight of the green compact is reduced to 40 to 50 %, then sintering process is started; otherwise, the above process is repeated until the desired weight is obtained. The complete elimination of the space holder from the metallic shell will help us obtain the desired permeability. Some dashes of space holder deceived in the shell will lead to reduced porosity and the collapse of the green compact. This is going to affect the value of the result.

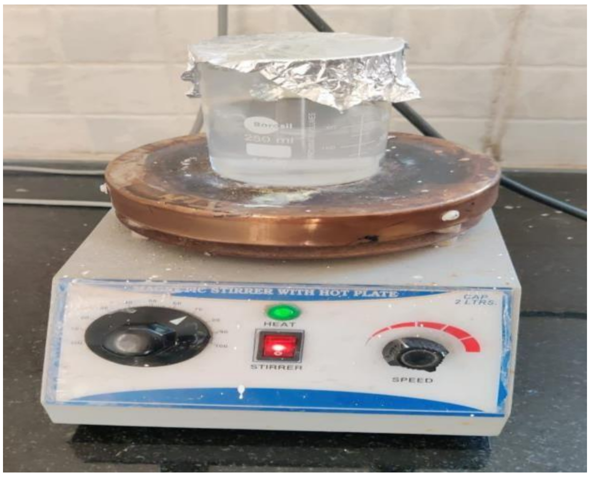


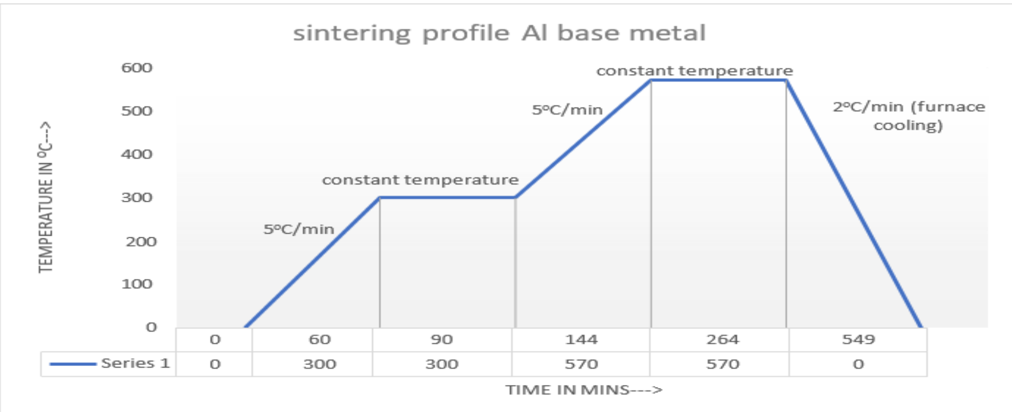
Figure 3: Heater

3.4 Sintering

Sintering process is the final step in the formation of metallic shell. The dissolved green compact or specimen is sintered in a sintering furnace at sintering temperature. For the sintering process, a box furnace with a maximum temperature of 1600˚ C is used, as shown in Figure 4. In sintering, the inter-particle bonding fills the void regions in the shell [7], which leads to the compaction of the foam. This bonding between the metal particles is created in the metal shell. The compaction of the shell improves the microhardness, and it will also improve the mechanical properties. Sintering that is incomplete will lead to the formation of micropores, which is undesirable for improving the mechanical properties of the foam. The increase in the sintering time increases the compaction, microhardness and reduces the size of pores. Pollution of the shell may take place due to the high sintering temperatures.

Figure 4: Box Furnace

Pollution can take place due to the impurities present in the sintering furnace, the hints of the space holder in the shell, and the oxidation of the sample due to the atmospheric contact during sintering. Sintering is performed in an inert gas or vacuum environment to prevent the oxidation of aluminium. A tubular furnace with argon gas connected to it is used. Flow rate was maintained constant throughout the heating process to remove the gases generated from the samples. Figure 5 shows sintering profile. For the initial 300 °C temperature, the constant rise in temperature was maintained at 5 °C/min for 60 minutes. For the next 30 minutes, the specimen was kept at a constant temperature of 300 °C. Then the temperature was increased by 5 °C per minute for 54 minutes. After that, a constant temperature of 500 °C was maintained for 120 minutes, and then the temperature was decreased from 500 °C to 0 °C.



	0	60	90	144	264	549
Series 1	0	300	300	570	570	0

Figure 5: Sintering profile for Aluminium base metal

4.Results and discussion

4.1 Macroscopic analysis

The equipment used for analyzing the macroscopic properties was a Nikon SMZ74T microscope with a 7.5X maximum zoom capacity. NIS-Element is the imaging software used. The surface properties of the foams are known by the macroscopic analysis of each sample.

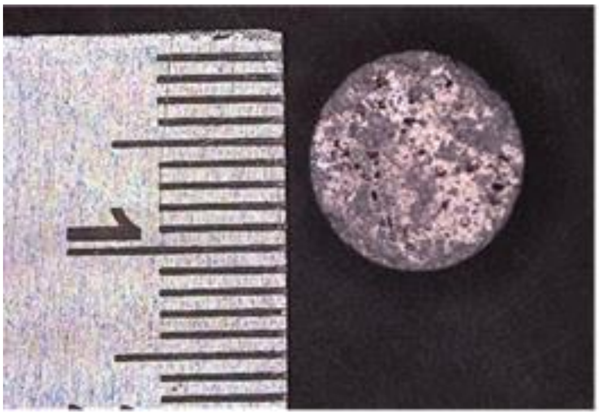


Figure 6: Pre-Sintered Macroscopic Image at 2.5 x Magnification

From the macroscopic images obtained, the even distribution of aluminium and space holders throughout the sample can be clearly seen in Figure 6. The white flakes on the pre-sintered surface seen in Figure 6 are removed during the dissolution and sintering processes. The post-sintered specimen is shown in Figure 7, where there are no white flakes.

Figure 7: Post Sintered Macroscopic Image at 2.5 x Magnification

4.2 Microscopic analysis

The equipment used for microscopic analysis is shown in Figure 8: the AE2000 MET Trinocular 100W with 100X maximum zooming capacity. The distribution of pores from inside can be found by microscopic analysis. For microscopic examination, representative foam samples were polished with standard sandpaper.

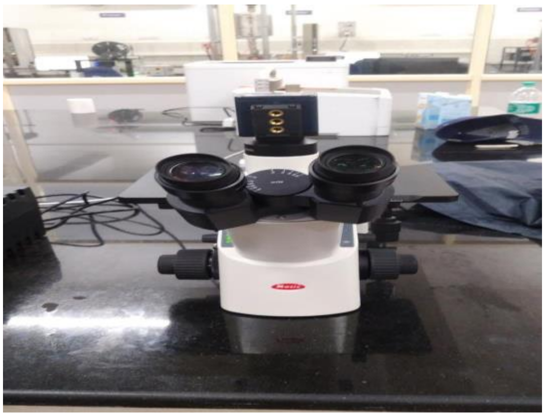


Figure 8: AE2000 MET Trinocular 100W

Figure 9: Pre-sintered Microscopic Images

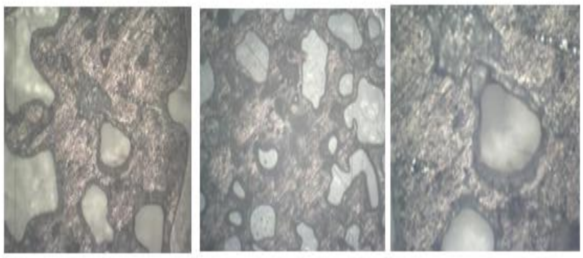


Figure 10: Post Sintered Microscopic Images

Figures 9 and 10 show micrographs of aluminium foam using NaCl as space holders developed by the space holder technique at a hydraulic pressure of 5 tonnes. From Figures 9 and 10, it may be noted that the even distribution of aluminium and space holders throughout the sample can be clearly seen, and there is a uniform distribution of pores. The white flakes in the pre-sintered specimen are removed in the dissolution sintering process, as can be seen from Figure 10. Post-sintering, the white flakes are removed, which are hints of NaCl, the space holder. In Figure 9, there are two types of structures that can be identified: aluminium base metal and sodium chloride. But in Figure 10, showing the post-sintered specimen, there are two structures: one is aluminium, and the other is a round structure called pores, where the NaCl is eliminated and pores are created. Moreover, there are some impurities that have developed. They may have formed during the addition of ethanol in the mixing process and compaction, as well as due to the sintering process temperature. The gases evolved during the sintering process are entrapped in the foam.

4.3 X-Ray Diffraction (XRD) Analysis

The objective of the work is to find out the chemical composition of the sample. This was performed using XRD test. Figure 11 shows the X'Pert Powder X-Ray Diffraction Machine. The chemical composition and percentage of chemicals that are present in the sample are determined by XRD analysis. The XRD machine ejects X-rays, which are directed towards the sample at multiple angles. X-rays are diffracted from multiple angles by the multiple phases present in the sample. These angles are noted down by the machine component and then sent to High Score Plus XRD analysis software. This High Score plus XRD analyses the angles and gives information about the type of element or compound with its crystal structure.

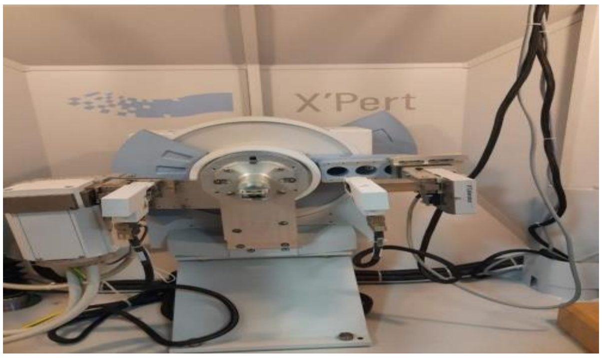


Figure 11: X' Pert Powder X-Ray Diffraction Machine

Figure 12 shows the results of an XRD test on a green compact that has not been sintered and dissolved in water. This test from Figure 12 shows aluminium content as 60.3%, halite as 39.7% and other impurities are 0%. These proportions indicate the percentages of constituents taken in sample. Figure 13 shows the composition of the sintered specimen after an XRD test. From Figure 13, the amount of aluminium is 91.2%, sodium chloride is 1.5%, and other impurities are silicon carbide 0.4% and moissanite 6H 6.9%. Impurities are formed during the sintering process, and a small amount by binding agent. Apart from impurities, the sodium chloride from Figure 12 to Figure 13 decreased from 39.7% to 1.5%. This shows the space holder material, NaCl, has dissolved during the dissolution process and pores have formed. There may be some minute traces of NaCl left during the dissolution process, but they can be removed during the sintering process. In the sintering process, due to the sintering temperature, the NaCl will evaporate as a gas.

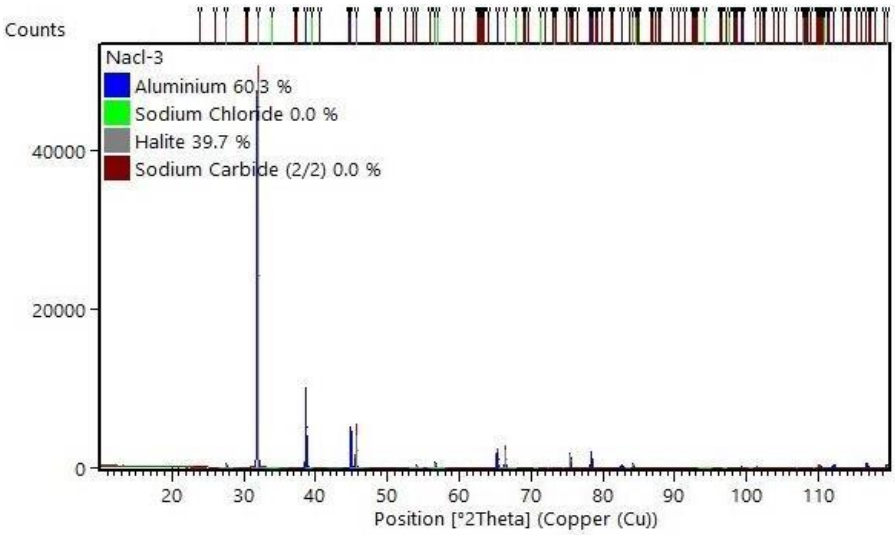


Figure 12: Pre-Dissolution chemical composition of aluminium and Sodium chloride green compact

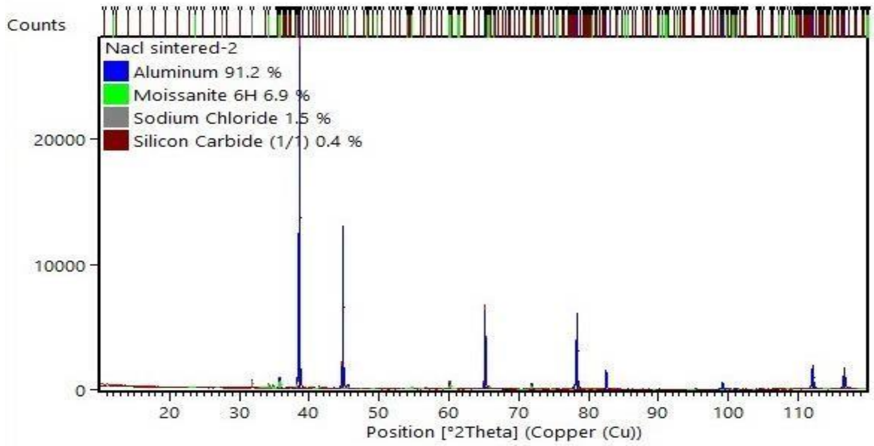


Figure 13: Sintered specimen aluminium and sodium chloride chemical composition

- From the graphs, it can be observed that the maximum quantity of NaCl has been removed by dissolving.
- The minute amount of NaCl is unremoved which indicates that some of the pores inside the sample are closed pores.

4.4 Density

Practically, density can be measured by using a density kit with a precision measuring scale. Here, the weighing scale used is BSA2245-CW, which is shown in Figure 14 and follows the Principle of Archimedes.

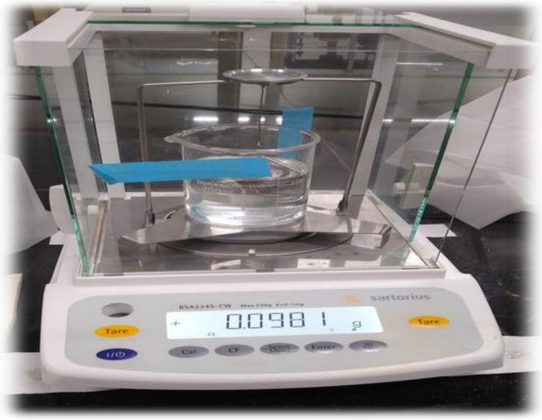


Figure 14: Weighting Machine

Table 1. Parameters with their quantities and values

Parameter	Quantity / Value
Mass of sample in air	0.5435 gm
Mass of sample in liquid	0.5435 gm
Density of liquid	0.9970 g/cc
The resultant practical density	1.64 g/cc

Table 2. Parameters for theoretical density with their quantities and input values

Parameter	Quantity / Value
Mass of specimen	0.545 gm
Height of specimen	0.60 mm
Diameter of specimen	0.90 mm

Theoretical density was calculated as

$$\text{Density, } \rho = \frac{mass}{volume} = \frac{0.545}{\left(\pi \times \left(\frac{900}{2}\right) \times 0.60\right.} = 1.39 \text{ g/cc}$$

From the above computation result, we can say that there is a difference between the theoretical and practical densities. This can help in concluding that some amount of NaCl is left in the interior parts of foam due to the formation of closed pores.

4.5 Porosity

The formula used to calculate porosity percentage is:

Porosity percentage = (Al Density-Foam density)/ (Foam density) ×100

$$= \frac{(2.676 - 1 \cdot 650)}{2.676} \times 100$$

$$= 39.03\%$$

The porosity percentage obtained from the theoretical formulation shows that pores are generated with a good porosity percentage, and this porosity gives good strength to the foam and reduces its weight.

5. Conclusions

A Closed-Cell Aluminum Foam has been successfully fabricated using the space holder technique with NaCl as the space holder. The conclusions made are:

- 40:60 ratio of aluminium powder and space holder has shown good results, whereas other compositions holding less than 60% of space holder resulted in poor foaming and space holder greater than 60% has collapsed.
- The optimal compaction time is 60 seconds (time of application of load).
- It is found that stiffness of the foam increases with multi-sized cells of the same relative density.

- From XRD analysis, it is determined that minute traces of space holder are present in the cores of the foam due to the creation of a minute number of closed pores.
- Impurities such as silicon carbide can be induced into the foam due to the high temperature of sintering. The impurities in the aluminium powder and the presence of carbon in the binding agent are responsible for the formation of silicon carbide.

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