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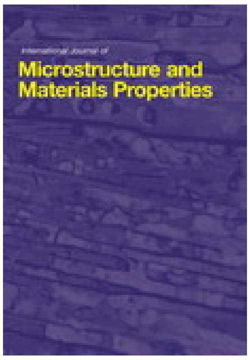

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Determination of porosity and microstructure studies of wax-based Aluminium metal foam

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Abstract: Aluminium metal foams nowadays are popularly used because of their unique feature of high stiffness concerning low density in the order of 10–15% of the bulk Aluminium material. In this paper, Aluminium metal foam is developed using the powder metallurgy technique. The elements used in the composition are Aluminium metal powder and a foaming agent as a wax powder (3–9%). The porosity is calculated using the Archimedes principle and achieved a good percentage of porosity in the specimen with a blowing agent as wax powder and achieved maximum porosity of 60.41%. The Microstructure study has been done on the prepared specimens to check the uniform distribution of porosity on the entire specimen and to check if any foreign chemical factor is incorporated. It is found that there is no adequate result in the prepared specimen.

Keywords: Aluminium metal foam; wax powder; powder metallurgy technique; porosity; microstructure studies.

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1 Introduction

Aluminium foams are developed by techniques like the Melting gas injection method, powder metallurgy technique, casting process, melting using a foaming agent, etc. The critical component of all methods is the effect of properties of the material; thus, for this many examples of optimising the method and characterisation because of its complexity and hazards (Aida et al., 2017; Paknezhad et al., 2017). Aluminium foam has unique properties: high strength-to-weight ratio, lightweight, exceptionally high stiffness & energy absorbing capability, which are used in the aerospace and automobile industry. The metal foam has also shown promising results in fatigue degradation during compression and tension (Rabiei et al., 2006). Foam is used as a solid material during minimum stress. It deforms in maximum stress for a specific limit of strain, it will become elastic, and this elastic deformation will no longer be recoverable (Szamel et al., 2014). Aluminium metal foams have unique properties because achieving these properties is challenging. Nowadays, there are so many methods; however, to get good results, it is necessary to select an appropriate technique. In this regard, the literature study shows that the powder metallurgy technique is the best to get good property results (Nourouzi et al., 2016). This technique is based on precursor incorporating the different foaming agents, concerning low production cost, good foam properties, and uniform porosity distribution.

By this technique, closed-cell foam fills the areas in the dense random collection by powder metallurgy technique to increase the properties like energy absorption and foam strength (Stöbener et al., 2008). The Aluminium metal foam is produced through the powder metallurgy technique. The main steps are first heating the mixture or powder. The foaming agent is inculpated as the foaming agent releases the gases into the molten Aluminium metal, due to which porosity is created in the specimen. This method creates porosity rapidly; within minutes, the foam is developed (Derekar et al., 2020). In this paper development of Aluminium metal foam has been done through the powder metallurgy technique using a foaming agent as the wax powder. The Archimedes principle calculates the porosity and density, and characterisation studies have been done to check the uniform porosity distribution on the prepared specimen.

The literature studies show many ways to develop Aluminium foam in each process. The main feature is a selection of typical morphology yield foam, alloy, or metal and the material's density limit. Aluminium metal foam has a wide range of applications, but the main limitations are getting uniform porosity distribution over the entire specimen and lacking good properties. For this reason, many researchers are suggested that by using the powder metallurgy technique, there is the possibility to get good uniform distribution and achieve properties (Báez-Pimiento et al., 2015; Bucher et al., 2016; Jang et al., 2010; Lázaro et al., 2014; Sun et al., 2015). Suppose we want to analyse through simulation any mechanical application. In that case, we must produce Aluminium metal foam by powder metallurgy technique because the highly high porosity and uniform distribution can be obtained (Mahadev et al., 2018). In literature studies, it was observed that the powder metallurgy technique prevents the spread of cracks over the surfaces and gives the uniform density of the prepared specimen. One research paper confirmed experimentally that foam produced using the Powder metallurgy technique has high porous connectivity and attain properties (Madgule et al., 2022).

In this regard, this research paper for producing Aluminium metal foam powder metallurgy technique is used with a foaming agent of wax powder. Foaming agent composition varies the percentage, with 3–9% of the base powder. Then porosity in each specimen was calculated using the Archimedes principle after the microstructure studies had been carried out on the prepared specimen.

Table 1 Application of metal foam based on porosity (see online version for colours)

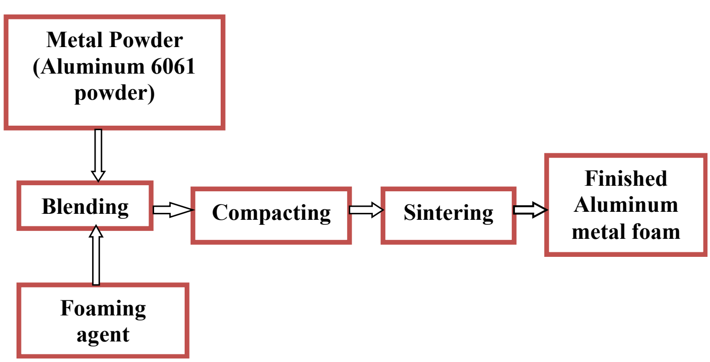
Open cell	Partially open	Closed cell
Heat Exchanger	Bearings	Load bearing components
Filters	Silencers	Energy absorbers
Catalyst supports	Bio-medial implants	sound absorber

2 Material and methods

2.1 Production of Aluminium metal foam by powder metallurgy technique

The specimen preparation uses the powder metallurgy technique, the base material used as an Aluminium powder (6061), and to form the porosity space holder used as wax powder. This wax powder foaming agent proportion is used 3–9% of the Aluminium powder. This proportion of this percentage is considered based on literature studies and trial and error by varying the variation in percentage and checking its quality, so in this regard, the 9% foaming agent gives the maximum percentage of porosity in the specimen. The following steps are most commonly used in the powder metallurgy route, as shown in Figure 1.

Figure 1 Flowchart of foam preparation by powder metallurgy (see online version for colours)

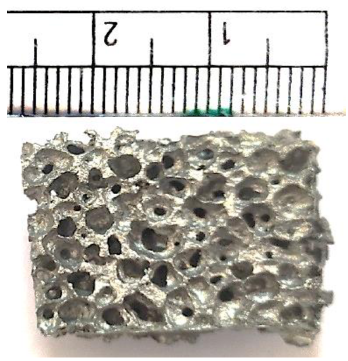


The production route followed while preparing Aluminium metal foams is the powder metallurgy route to achieve uniform porosity on the specimen. Initially, we blended

Aluminium powder (Al6061) and wax powder using a high-energy ball milling machine to get the form of a fine powder, the grain size of powder up to the size of 120 µm. Powder Aluminium and wax powder are appropriately blended in the stainless steel at a stirring speed of 1200 rpm to 1 min so that both constitute mixed properly. Then the blended powder is compacted in the die compaction, and the die is placed in the universal testing machine (UTM), where the compressive load is applied up to 30 KN. This process is used to ensure both particles are closely packed together. Compacting is necessary strength of the specimen is just sufficient to handle in the process to the sintering process (Pekkan et al., 2020).

The compaction process is called cold compaction. The final step in powder metallurgy is sintering. This process compacts the powder to have good integrity and strength. This is used in the heat treatment process. The temperature used in this process is below the melting point of the compacted specimen. The compacted specimen is placed in an Electric resistance furnace and sintered at a temperature of 400°C kept for a duration of 30 min. the cross-section of the prepared Aluminium foam specimen by powder metallurgy process is shown in Figure 2.

Figure 2 Specimen of Aluminium metal foam size 25 mm square (see online version for colours)



3 Results and discussion

3.1 Determination of percentage of porosity of Aluminium

The porosity is an important parameter because the material's density will decide the foam's quality. When the foam density decreases, it will increase the porosity. The one factor that increases the specimen's porosity will not help attain good properties. Still, the uniform porosity distribution in the entire specimen is essential. To find the porosity, the following procedure is used.

To find the porosity, the formulae are used.

Density and porosity are calculated by using the below formulae.

$$\text{Density of Foam} = \frac{\text{mass}}{\text{Volume of Foam}} \, {}^{g}\!/_{cc} \tag{1}$$

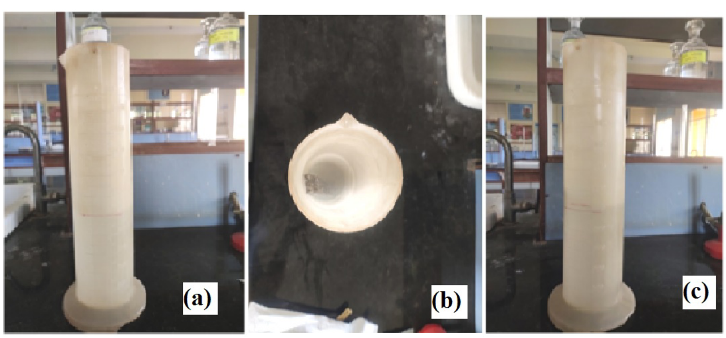
$$\text{Porosity}(\%) = \frac{\text{The density of Aluminum6061} - \text{Density of Foam in the specimen}}{\text{The density of Aluminum6061}} \times 100 \quad (2)$$

Initially, the step-by-step procedure is necessary to calculate the prepared metal foam specimen density. By the standard method, finding the density of irregular foam shapes is impossible. The Archimedes principle has been used to calculate the density of the metal foam, as shown in Figure 3(a)–(c).

- First, need to take Measuring Jar (MJ)
- Fill the distilled water into the Measuring Jar around 500 ml.
- Submerged the foam specimen into the 500 ml water and keep it in the jar for 2 min.
- Slowly, the water level increases, then record the new water level.
- The difference between the initial and final levels of distilled water is recorded. It will consider the actual volume in cc of Aluminium metal foam.
- The difference between the initial and final levels of distilled water is recorded, which is the actual volume in cc of the metal foam specimen.
- Weigh the prepared specimen of Aluminium metal foam in terms of grams. That is the mass of foam.

Table 2 results show that the effect of the blowing agent on the porosity as the percentage of wax powder increases, the porosity also increases. This shows that wax powder is the most suitable blowing agent in the powder metallurgy technique to achieve sufficient porosity in the specimen (Bassidi et al., 2017).

Figure 3 (a) Jar is filled with 500 ml; (b) specimen submerged into jar and (c) rise in water level (see online version for colours)



The range of percentage of porosity in any metal foam is about 9%, so this blowing agent achieved an excellent percentage of porosity.

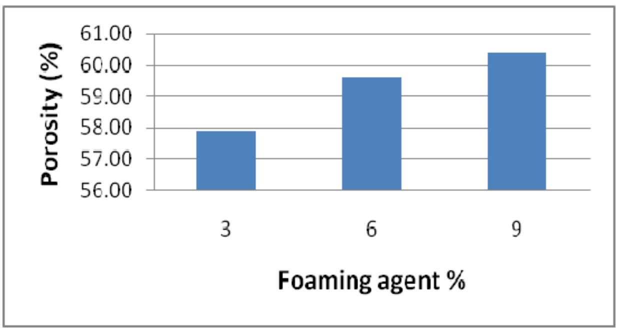
Figure 4 shows that the graph concerning foaming agent and porosity shows that as the percentage of the porosity increases, the porosity in the specimen also increases. Determining porosity is important in Aluminium metal foam because it can decide for which application it is suitable based on the percentage of porosity in the specimen. The Aluminium metal foam has broader energy and acoustic absorption application.

Table 2 The details of density and % of porosity are given below

Foaming agent Wax powder content (%)	*Initial vol. of water in Measuring Jar* (MJ) *in cc*	*Final vol. of water in Measuring Jar* (MJ) *in cc*	*Actual vol. of foam*	*Mass of specimen in g*	*The density of foam in g/cc*	*The density of Aluminium (6061) in g/cc*	*Porosity (%) in a specimen*
3	500	551	51	58	1.14	2.7	57.88
6	500	555	55	60	1.09	2.7	59.60
9	500	558	58	62	1.07	2.7	60.41

The maximum porosity in the specimen is also not good in terms of strength; it decreases the strength of the specimen. The optimum porosity of 40–60% in the specimen is the best result in terms of energy absorption and strength in the heat exchanger, silencer, etc. (Casas et al., 2020).

Figure 4 Effect of foaming agent on porosity (see online version for colours)



3.2 Discussion of obtained results

The maximum porosity obtained in the prepared specimen is about 60.41%, with a uniform porous structure and proper network connectivity between the porous structure. It is confirmed that the powder metallurgy process with a foaming agent of wax powder is the best technique for developing Aluminium-based metal foam. The porosity (40–60%) obtained in the specimen is the optimum porosity, and it is most suitable for structural and functional applications as a sound and energy absorber, lightweight material, mechanical damping capacity in a Heat exchanger, Bearings, Filters, Electrical vehicle batteries and bio-medical implants, etc. (Banhart, 2001).

4 Characterisation of Aluminium metal foam

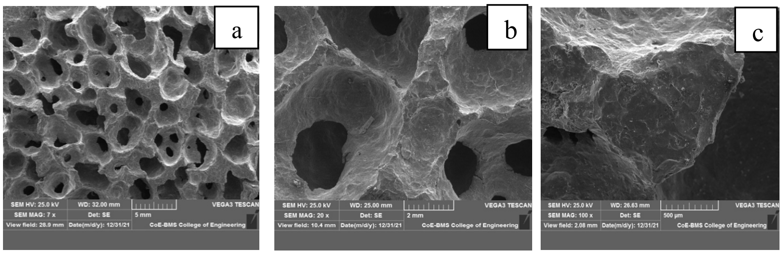
4.1 Microstructure studies on Aluminium metal foam with the foaming agent as wax powder

The above microstructure studies have been done through scanning electron microscopy (SEM), which gives evidence of the overall appearance and composition in the prepared specimen and also it gives the morphology of distribution and constituents of pores in the

Aluminium metal foam specimen prepared by powder metallurgy technique with the foaming agent as a wax powder (Xiao, 2022).

It can be observed in Figure 5(a)–(c) the porosity is formed, which leads the result of the dissolution of wax powder during the sintering process. Due to the powder metallurgy technique, the uniform distribution of porosity has been formed, as shown in Figure 5(a)–(c) due to this porosity which leads to the formation of the foams in the prepared specimen.

Figure 5 (a) SEM image of Aluminium metal foam foaming agent wax powder SEM MAG 7X; (b) SEM MAG 20X and (c) SEM MAG 100X



4.2 *Energy dispersive spectroscopy (EDS) studies on Aluminium metal foam with the foaming agent as wax powder*

Energy-dispersive X-ray Spectroscopy (EDS) gives the composition of the factors within the SEM image. Confirm the formation element in the prepared Aluminium metal foam specimen with foaming agent wax powder. Figure 7 shows that the evidence of the proper chemical composition is present in the prepared specimen; it confirms that there is no foreign adequate chemical composition remaining in the specimen. The highest peak in Figure 7 shows the maximum Aluminium content, and the remaining small peaks show another chemical composition as per the Al 6061 material (Wang et al., 2022).

Table 3 Details of chemical composition of the wax powder

Element	*Weight %*	*Atomic %*
C K	24.76	40.89
O K	9.83	12.18
MgK	0.66	0.53
AlK	60.04	44.13
SiK	0.47	0.33
CaK	3.01	1.49
TiK	0.13	0.05
FeK	1.09	0.39
NiK	0.00	0.00

The EDS test was conducted. At the same time, the different surface specimen area of 2 mm was focused on to ensure the proper result, as shown in Figures 6 and 7 shows the corresponding peaks. The details of EDX spectra value considered in weight and Atomic percentage are shown in Table 3. It shows no foreign chemical component in the specimen prepared by the wax-based foaming agent.

Figure 6 EDS area 2 mm selected on wax powder specimen (see online version for colours)

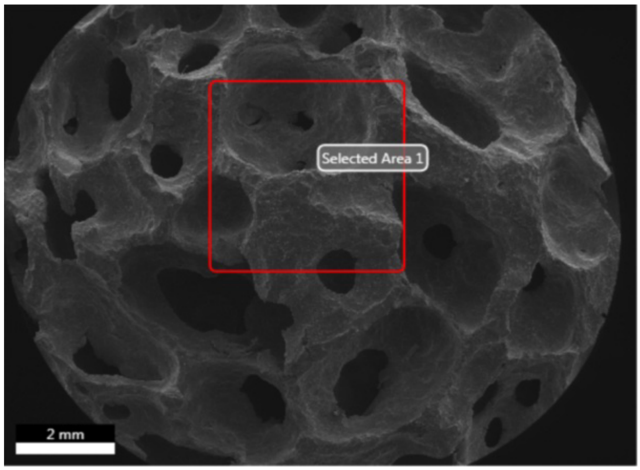
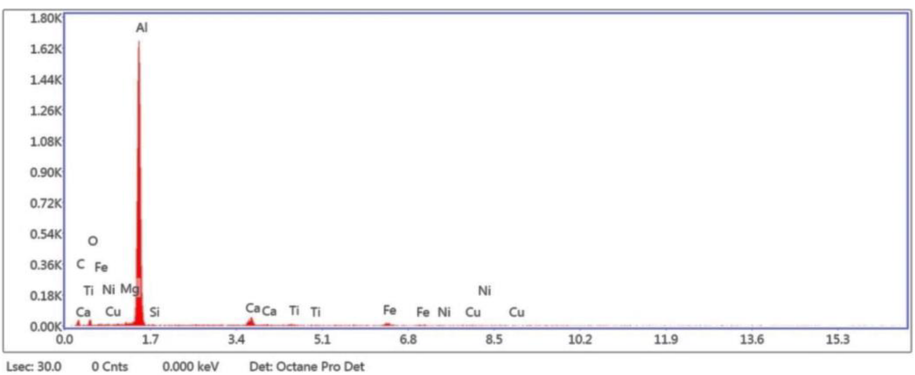


Figure 7 EDS qualitative analysis for the identification of wax-based foaming (see online version for colours)



4.3 X-ray diffraction (XRD) studies on Aluminium metal foam with the foaming agent as wax powder

An X-ray diffraction (XRD) study shows the crystallographic phases within the prepared specimen. This technique is carried out at room temperature, showing evidence that the prepared specimen (Agarwal et al., 2021) with a foaming agent as a wax powder (C3H6O3) shows the highest peak at 38 degrees, as shown in Figure 8. Table 4 shows that regarding the evidence that the specimen that presents the phases of Aluminium scores 10, and wax powder compound name trioxane, which is scores 2 as shown in the table. The powder metallurgy process used the foaming agent as a wax powder to produce a porous structure. Figure 8 highest peak confirms that wax powder (C3H6O3) is used. It is confirmed through an XRD test.

Figure 8 XRD analysis details of wax-based foaming agent (see online version for colours)

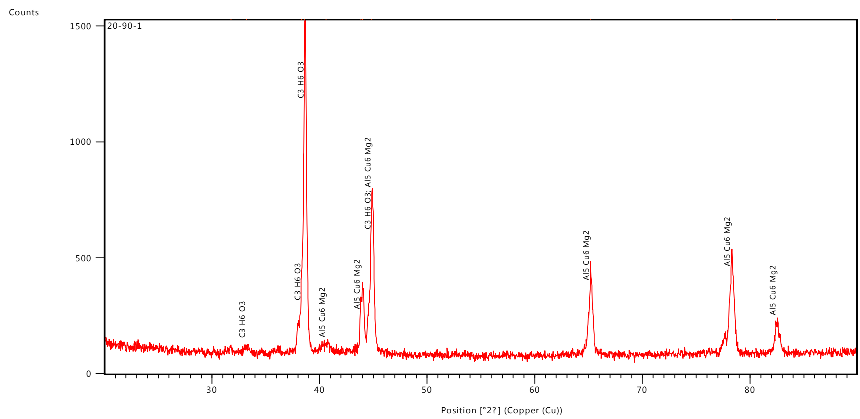


Table 4 Details of crystallographic phases in wax-based foaming

Visible	*Ref. Code*	*Score*	*Compound name*	*Displacement [°2Th.]*	*Scale factor*	*Chemical formula*
*	98–015–1343	2	Trioxane	0.000	3.937	C3 H6 O3
*	98–005–7694	10	Aluminium Copper Magnesium (5/6/2)	0.000	0.305	Al5 Cu6 Mg2

5 Conclusions

The Aluminium metal foam is successfully produced by powder metallurgy route using a foaming agent as a wax powder (3–9%). The accurate results towards the uniform distribution of porosity as evidence is confirmed in microstructure studies in this regard based on literature studies the which will attain good properties of Aluminium metal foam if the uniform distribution of porosity in the entire specimen. The percentage of porosity is calculated by Archimedes's principle and achieved a good percentage of porosity about as the percentage of blowing agent increases porosity in the specimen also increases and achieved sufficient percentage of porosity in the specimen, which gives accurate results in attaining the energy absorption property. The maximum porosity is achieved in the specimen prepared with a 9% foaming agent, about 60.41% porosity. The Microstructure studies have been done by scanning electron microscope (SEM) on the prepared specimen, showing the uniform porosity distribution on the entire specimen. Energy-dispersive X-Ray spectroscopy (EDS) analysis of foaming agent wax powder evidence that no foreign chemical elements are present in the prepared specimen. X-ray Diffraction (XRD) analysis has been carried out on all three specimens showing evidence of the chemical element of Wax powder. Finally, it is concluded that powder metallurgy is the best technique to achieve uniform distribution of porosity over the Aluminium metal foam specimen.

Disclosure statement

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