

Fabrication Routes of Aluminium Metal Foams: A Review

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Abstract

Metal foams are cellular structures fabricated by gas filled pores in a metal matrix. Metal foams possess exceptional mechanical as well as physical properties. The low thermal conductivity property of metal foam makes them a great choice for flame arrestor materials and heat exchangers. High stiffness and impact absorbing capabilities of the metal foams are utilized in high-speed ballistic testing. Tensile strength and corrosion resistance properties of metal foams are exploited in orthopedic applications. Sound damping characteristics are used in automotive industry for sound damping applications. For stiffening of structures, metal foams are used because of their high stiffness. Aluminum metal foams find numerous applications in military, marine and automobile sector. Various processes for fabrication of Aluminum metal foam are discussed in this review. Metal foam manufacturing is problematic due to the existence of solid, liquid, and gaseous phases at various temperatures. Despite the different ways and procedures for producing foamed metals, the foamed metal nevertheless contains flaws and non-uniformities. To increase foam quality, researchers must investigate and comprehend the stability of foam in liquid metals, which will aid in the development of more dependable and repeatable foam metal manufacturing procedures. The best way for producing aluminum metal foam for mechanical applications is found in this review.

Keywords

Cellular structure of aluminum foam, production techniques, properties, analysis.

1. Introduction

The present world engineers are driven towards the fabrication of lightweight materials/alloys possessing specific properties to meet the sustainable development goals (SDGs) drafted by United Nations (UN) Hashmi et al. (2022). One such material is metal foam which is light weight and possess high strength to weight ratios, high specific stiffness, and considerably enhanced energy and sound absorption qualities that are used in the automobile and aerospace sectors. Ashby et al. (2020), Peng et al. (2019) Aluminium metal foams (AMF) have been synthesized using a number of fabrication routes such as Powder metallurgy, Friction Stir processing (FSP), injection gas melting, casting etc. Sreenivasa et al. (2018) the input parameters greatly influence the structure of the metal foam produced; open cell structure or close cell structure. A number of publications suggest that researchers have made attempts to optimize the input parameters. Each of the fabrication technique has merits and demerits. In this paper an attempt has been made to identify the best processing technique.

2. Literature Review

From the available literature various researchers have investigated the effect of different process parameters on the synthesis of metal foam. For instance, Paknezhada et al. (2017) studied the relationship between the temperature of the heated surface and the impact of the angle of inclination by employing the free convection heat transfer. The results showed the foamed plates have better heat transfer rate in comparison to without foamed plated. The maximum heat transfer was obtained when the foamed plated were kept in vertical direction. When the surfaces are vertical, the AFM acts as a heat sink thus lowering the surface temperature by up to sixteen degrees Celsius. Mirzaalia et al. (2016) fabricated two distinct types of aluminum foams having closed-cell structure by using the expansion of a blowing agent, one with an even dispersion of cells along its length and the other with a varying pore size along its length. According to his hypothesis, foam samples' having small structural radial asymmetry throughout their length improves their mechanical properties. In order to do this, he investigated the microscopic structural features of foam samples using micro-CT imaging, and then used monotonic compression tests to determine how these traits relate to the foam samples' macroscopic mechanical properties. In addition, he carried out numerical assessments for the elastic properties section and validated them using the results of the experiments. According to his research, the macroscopic mechanical properties of AMF having closed-cell structure were not significantly affected by porosity gradients. Further investigation into the mechanical properties of closed-cell

aluminum foams is being supported by the various findings. Manca et al. (2016) carried out an experimental examination of approaching jets in porous medium while assuming that steady heat flow from below is being produced by the fluid air that is heating the wall. The effectiveness of surfaces with and without foams is evaluated in this experiment using an energy performance ratio to compare pressure difference and heat transfer rates. According to preliminary experimental results, using a porous medium boosts heat transfer and effectively facilitates surface heat dissipation, but it also results in a rise in pressure drops. SF Aida et al. (2016) in his experimental on impinging jets used the wall which is uniformly heated from below. As a fluid material, air is employed. The experimental apparatus consists of a fun system, a test section, and a tube that condenses the test section into a circular segment. To investigate the efficiency of metal foam surfaces and to deduce the relationship between pressure drop and heat transfer rated an energy performance parameter was used in this study. According to preliminary experimental results, using a porous medium boosts heat transfer and effectively facilitates surface heat dissipation, but it also results in a rise in pressure drops, thin cell walled foam are known to fail when subjected to mechanical bending. Bucher et al. (2016) developed foam and bent it with Laser forming, which prevented the damage and collapse of cell walls. Three different geometrical models were developed to check which conforms to better numerical results. They used three different geometries which were equivalent geometry, Kelvin-based, and voxel geometry. It was concluded that voxel model could replicate the exact geometry of the foam, which accounts for precise temperature distributions and directions of the flow of heat.

3. Methods to develop Aluminum Metal Foam

Metal foams are porous metal structures designed for various purposes like defense applications and automotive sector. A number of metals like Magnesium, Aluminum, Nickel, Copper, etc. are used to develop foams, depending on the requirements. Some of the common methods of preparing metal foams are briefly discussed below.

3.1.1 Melts Foam by using blowing agents

In this method of forming metal foams, certain blowing agents are mixed into the molten metal to produce foaming from inside rather than an external driving factor. Calcium and Hydrides of some metals are added as thickening and foaming agents Elliott et al. (1965) respectively, both in minute quantities ranging from 1% to 2%. Kulshreshtha et al. (2020) when subjected to heat, the driving agents decompose to give metal and H₂ gas, which results in providing porosity to the cooled metal foam thereby produced. Stirring of the molten metal while the decomposition reaction progresses is favorable for uniformity in the thenceforth produced metal foam. Khare et al. (2021) once cooled down; metal foam with 89-93% porosity can be obtained.

3.1.2 Foam development by gas injection method

It is one of the most popular methods of development of metal foams owing to its simplicity and economical setup. Gas injection was patented by Ruch and Kirkevag in (1991) in this process; certain additives like Alumina, Magnesium Oxide, and Titanium Diboride etc. are added to the melting Aluminum in order to enhance the foaming action. Injection of the gas to the molten Aluminum is done by dedicated rotating impellers. The gas injected from the bottom surface moves upwards towards the surface, the porous Aluminum thereupon obtained is made to go through roller belts, which compress the hot porous Aluminum into rectangular blocks. Although dry air is preferred for the foaming effect, but inert gases, O₂, and water have also been used (Kulshreshtha et al. 2020). The mean size of the particles ranges from 5 to 20 μm .

3.2 Foam development with powders as foaming agents

In this method, a powdery blend of the foaming agent is mixed in the molten metal, which is usually a 0.4-0.6% of TiH₂. The first step is to heat the metal until its melting temperature, or upto the decomposition temperature of the foaming agent, whichever is higher. This leads to decomposition of the foaming agent and the release of H₂ gas, which leads to the development of porosity ranging between 60 to 85%. The most commonly used foaming metals under this process are the wrought Aluminum alloys of 1xxx, 2xxx and 6xxx series, and some cast alloys as well. Quality of the foam formed depends on several factors like fineness of the powder, base alloy material, cooling time, etc. (Sang et al. 1994).

3.3 Foam development by casting

Banhart and J. (2001) suggested casting is one such technique of producing metal foams which is preferred in case of foams with intricate shapes. With investment casting, metal foams can be prepared without the use of foaming agents. In this process; open cell foam like polyurethane is taken as a template and then filled with slurry of a

refractory material like Plaster of Paris, or mullite etc. When the slurry dries up, the polymer foam is eliminated by the application of adequate amount of heat. Rabiei and O'Neill (2005) this leaves us with the required cavity which just needs to be infiltrated with the molten metal. In order to ensure complete occupation of each and every corner of the cavity with the molten metal, the mould may be required to heat; application of pressure also helps achieve this. Once solidified, the mould is broken and the foam is obtained. Davydov et al. (2016) developed foam with remarkable compressive stress and energy absorption and has applications in aircraft structural members as well as prosthetics. The different steps that are generally used for development of metal foams by casting is shown in Figure. 1.

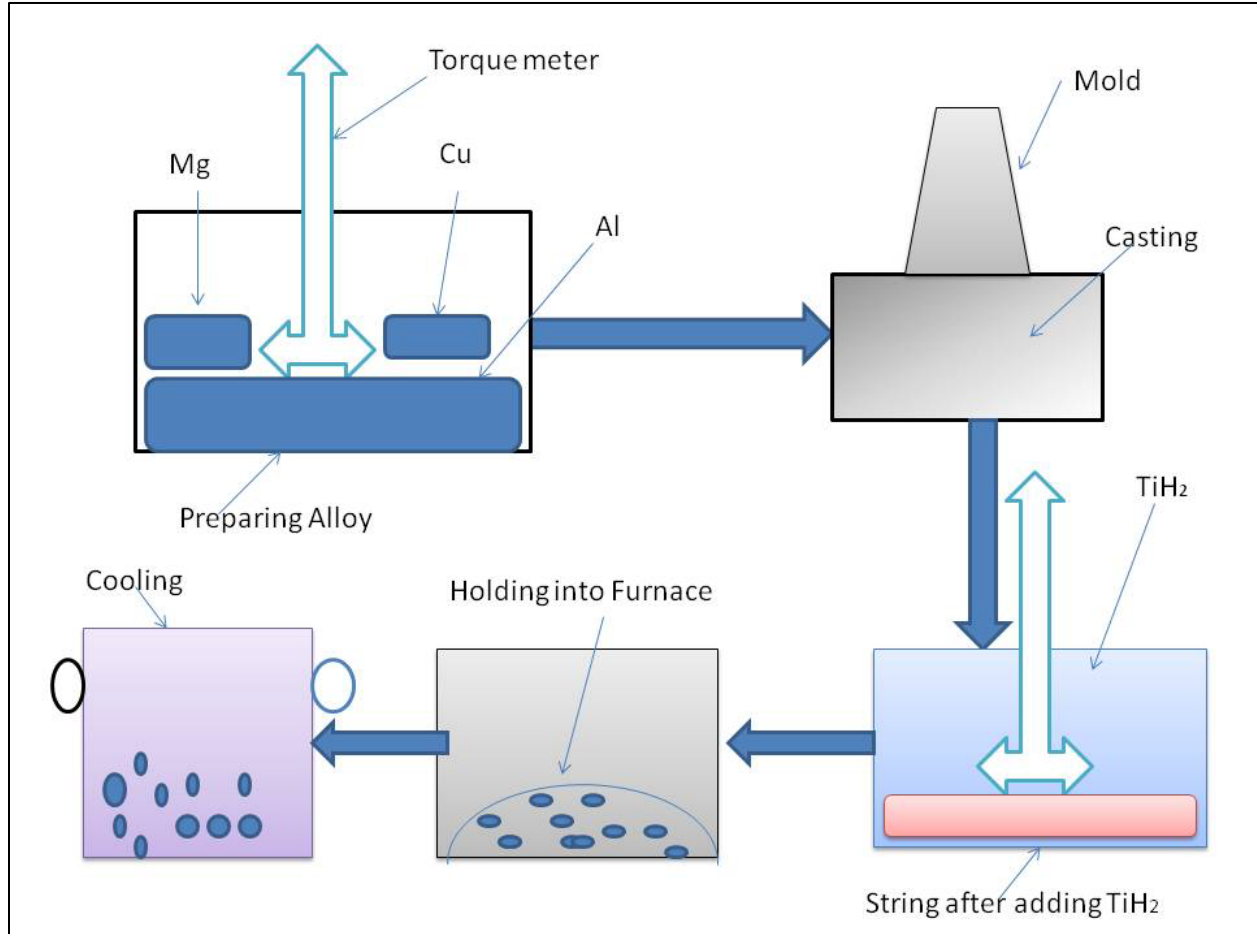


Figure. 1: Schematic showing different steps involved in casting route

3.4 Foam developed by Electro deposition Technique

Rabiei and O'Neill (2005) in this technique, polycarbonate filters (PCFs) are used for templating of the mould. The templates contain very fine pores of dimensions ranging from 5µm to 500nm. After dissolution of the oxide layer and substrate of Aluminum, one side of the template is coated with Copper, Gold or Silver to make it act as the cathode. When potential is applied, the flow of abrupt current leads to start of deposition of metal. Current decay is caused by the concentration changes in the pores and on the surface afterwards. After this fall, a gradual increase in current density is observed when the metal begins to overflow from the pores, and finally the deposition ceases to continue, and the foam is prepared.

3.5 Sand Ball production of Aluminum Metal Foam

Sreenivasa et al. (2018) porous aluminum leaf spring is fabricated by casting metal around sand balls. Sand balls are manufactured by the use of silica sand, bentonite blend and silica oil. Aluminum metal in liquid form is poured onto a matrix of sand balls. After this liquid aluminum metal attains solid state, it is isolated from the gating framework and using shot impacting, the sand balls are removed from the fabricated aluminum block.

3.6 Production of Aluminum Foam using Sodium chloride as a Space Holder

SF Aida et al. (2016) fabricated aluminum foam with sodium chloride acting as the space holding filler material. Further, in this study it is concluded that as the amount of sodium chloride increases, porosity increases which results in decrease in density of the fabricated foam. Isolated as well as interconnected pores are reported in this work. Razali et al. (2013) studied the relationship between the mechanical properties of aluminum foams and the density, porosity, compressive strength and energy absorption capabilities. The aluminum foam in this study was fabricated by conventional casting method combined with sodium chloride acting as the space holder. This study concluded that porosity in aluminum foams is inversely proportional to the compressive strength and directly proportional to the energy absorption capabilities. Rushdi et al. (2016) manufactured aluminum foam by the sintering dissolution process (SDP). SDP process involves mixing of aluminum powder and space holder particles which in this case is sodium chloride to produce a mixture that is homogeneous. After compaction, sintering was performed and warm water was used to remove the space holder particles. This study also concluded that the space holder particles have significant effect on the total porosity.

3.7 Development of Al foams by hot extrusion and foaming

Sinha et al. (2008). The process of fabricating metallic foam using powdered metal requires metal blending with foaming agent, compaction of the mixture, deforming of the mixture and the final step is foaming. The goal of the entire process is to form a highly dense precursor in which foaming can be done possessing uniform distribution of blowing agent. Shiomi et al. (2010) Aluminum foam was fabricated by extruding A6061 aluminum powder mixed with TiH₂ particles acting as the foaming agent into a die. This die is then heated above the melting point temperature of aluminum powder. The reported relative density of aluminum foam was 0.22. Aluminum foam was molded into a tube to form cylindrical aluminum foam. The reported relative density distribution inside the aluminum foam tube was 0.2-0.3. Aluminum foam present in the pipe, improves the energy-absorbing capabilities. The schematic of setup used for extrusion process is shown in Figure 2.

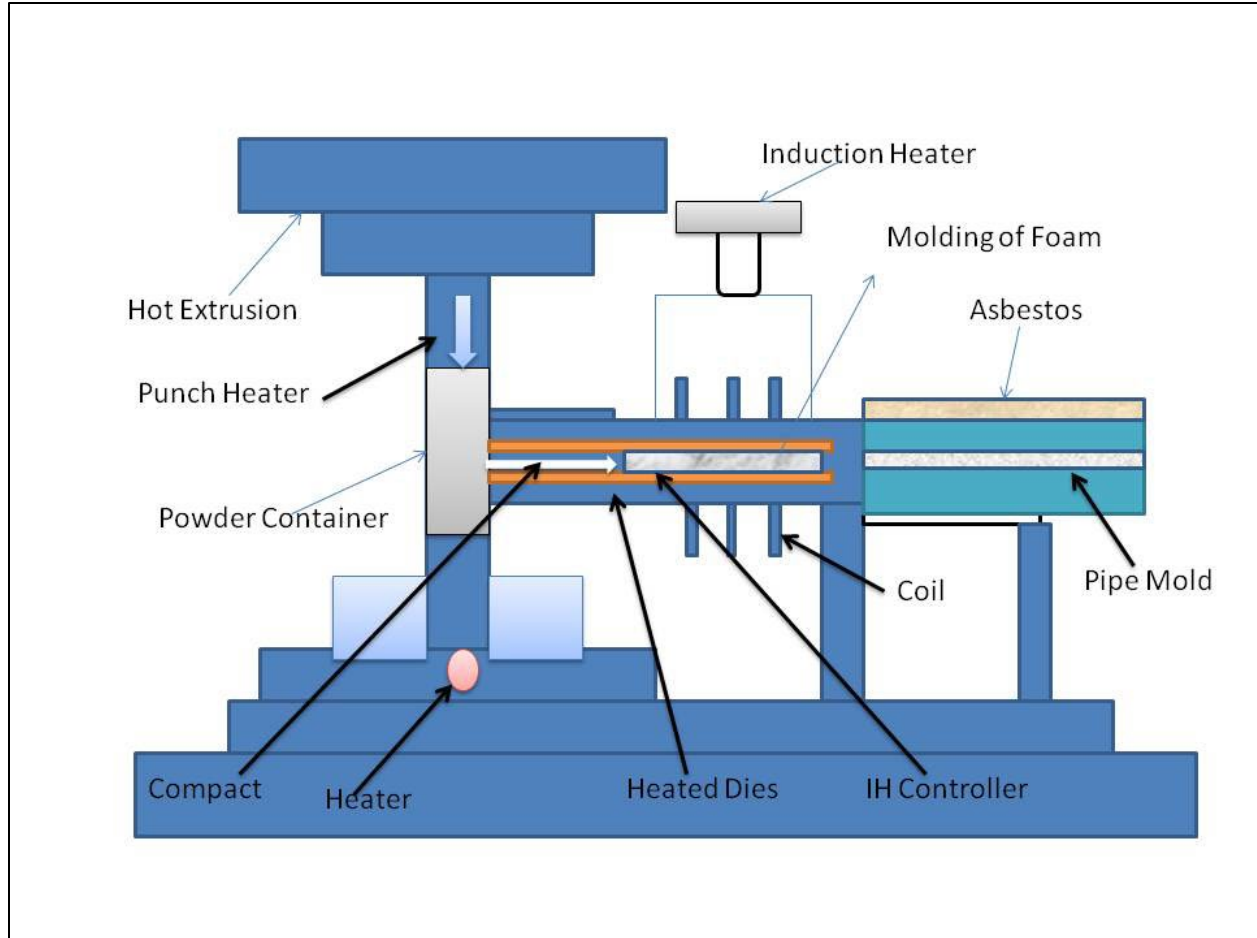


Figure. 2: Schematic of setup used for hot extrusion process

3.8 Fabrication of Al Foam by FSP

Friction stir processing (FSP) is an emerging, cost-effective technique which is employed in order to fabricate metal foam precursors using the bulk substrates. Shandley et al. (2020) used flame heating in order to localize foaming of AA5754 aluminum alloy and exploited multi-pass FSP technique to stir magnesium carbonate foaming agent in the bulk aluminum alloy. Material movement after every pass of FSP was also studied in this work. Hangai et al. (2011) fabricated functionally graded aluminum foam using A1050 which possesses low strength and high corrosion resistance with A6061 which possesses high strength. This work shows that FSP can be used to fabricate seamless functionally graded aluminum foam. Nisa et al. (2020) fabricated closed cell A6063 metal foam in which FSP technique was employed to disperse the foaming agent in the aluminum matrix. In this work mixing of foaming powder using FSP was analyzed using different characterization techniques. Pang et al. (2022) studied the effect of process parameters on the microstructures of aluminum foam precursor using optical microscope and scanning electronic microscope and concluded that the precursor formability is directly proportional to the deformation temperature. Microstructure characteristics and flow of material is also analyzed using experimental as well as numerical methods. The steps used to develop precursor using FSP route are elucidated in Figure 3.

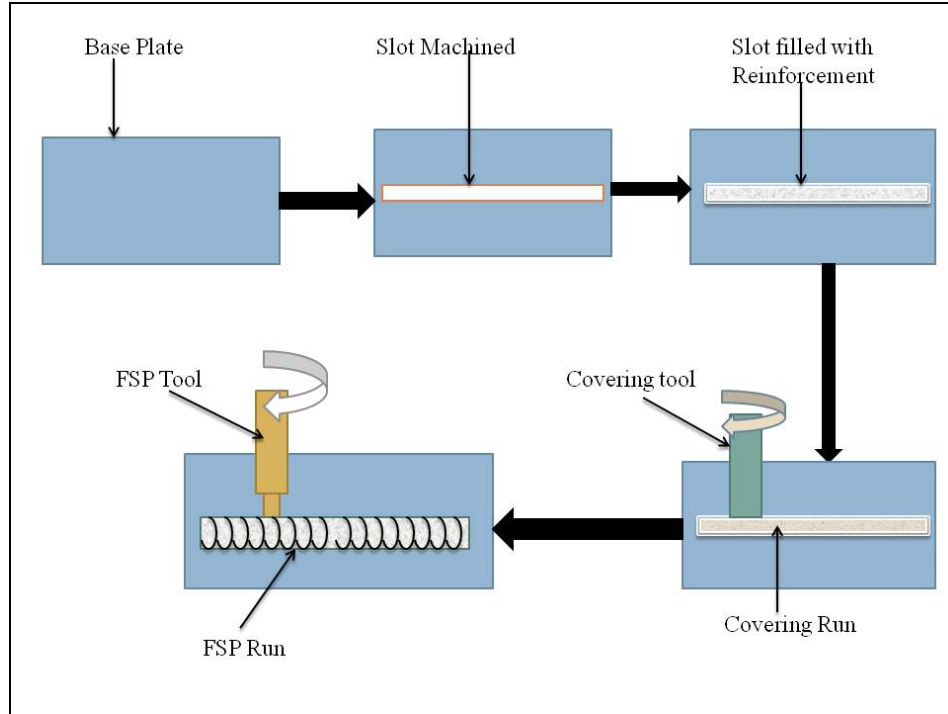


Figure 3. Schematic illustrating steps involved in fabrication of precursor by FSP route

4. Identification of a research gap and the scope of the current investigation

From the available literature, it is clear that various techniques have been used to develop metal foams. It has been found that the input parameters greatly influence the development of metal foam. Researchers have meticulously worked on these processes to find the optimum set of parameters that may be used to develop the metal foam as per the required applications.

The available routes developed for the fabrication of metal foams have some serious drawbacks. For instance, the metallic powders used in the fabrication of foams is generally expensive and results in macro-segregation. Also, the use of high-pressurized gas puts the life of the operator at risk and are highly time consuming.

Among the various fabrication routes developed, FSP offers a number of advantages over other manufacturing routes: First the process is quite simple and is not time consuming, secondly it eliminates the use of pressurized gas required in other fabrication techniques, thirdly the process is economical in nature. A lot of work has been done in this field. However, this field requires much more exploration in order to fully optimize the synthesizing process. The intricacies involving heterogeneous nature of the FSP forms non-uniform/distorted pores which may deteriorate the quality of the foam produced. These problems necessitated to look for strategies that will produce metal foams of excellent quality with improved pore formation uniformity.

5. Conclusion

This paper has thoroughly discussed the different fabrication routes. Powder metallurgy, investment casting, Friction stir processing, hot extrusion etc. can be used to fabricate the aluminium metal foams. The researchers are exploring each of these processes to find the optimal parameters.

The FSP is considered a better choice for the fabrication of metal foams as this process offers a number of advantages over other fabrication routes. Upon reviewing the available literature FSP offers a number of advantages over the other processes. As it is a cost effective and innocuous process. Additionally, this process eliminates the requirement of use of expensive metallic powders. In place of metallic powders commercially available plates are used for development of metallic foam.

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