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Processing, Development, and Applications of Metal Foams – A Review

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Abstract

A new category of innovative materials in the category of environmentally friendly materials is known as metallic foams or Metfoams. These materials belong to the class of cellular materials that have low densities as well as unique mechanical, electrical, thermal, and acoustic characteristics. When many of these characteristics are integrated in applications, they show excellent promise for market penetration. Numerous processing methods for both open and closed-cell morphologies have been developed as a result of recent technical advancements in the field of metallic foams. This essay examines the typical method of producing metal foams. Based on metal characteristics, various methods for producing metal foams are discussed.

Keywords: *Metal Foams, Cellular Materials, Advanced Materials, Properties.*

1. Introduction

Metals with a lot of pores are known as metal foams. Metal has a great strength, is robust, and is very lightweight due to its pore structure. Because they contain pores, metal foams have distinct physical and mechanical characteristics. High specific strength-to-weight ratios, high gas permeabilities, high thermal conductivities, and potent energy and sound absorption properties are a few examples of extraordinary characteristics.. Cellular materials are widely employed in daily life and have a variety of uses, including cushioning, insulating, dampening, building, and filtering. Very porous materials are also known for their great stiffness and extremely low specific weight. As a result, cellular materials are commonly used in construction in nature. (e.g. woods and bones). [1,2]

Contrary to more traditional technical materials like polymers, ceramics, or glass, even metals and metallic alloys may be formed into cellular solids or metal foams. This is a fact that is less commonly known. Metal foams have been created in order to do this. It is well known that solid metallic foams, particularly those made of lightweight metals, can combine a variety of fascinating qualities, such as strong compression strengths and favorable energy absorption properties, or high stiffness and low specific weight.[1]. Even metals and metallic alloys may be produced into cellular solids or metal foams, in contrast to more conventional technological materials like polymers, ceramics, or glass. This information is less widely known. Metal foams have been produced to do this. It is well known that solid metallic foams, particularly those made of lightweight metals, can combine a variety of fascinating qualities, such as strong compression strengths and favorable energy absorption properties, or high stiffness and low specific weight. [2,4]

Between 40% and 90% of the metal foams' structure is permeable. Aluminum (Al), Nickel (Ni), Magnesium (Mg), Titanium (Ti), Copper (Cu), Gold (Au), Steel, and Stainless Steel alloys have been used up until this point in the production of metal foams. It is possible to create metal foams with open or closed cells. Extremely low density, high specific stiffness, good resistance to electromagnetic waves and impact, excellent heat insulation, superb sound absorption, fire resistance, recyclable, and other benefits are only a few of the advantages of metal foams. The properties of the base material affect the properties of metal foams, the relative density, the cell topology, and the production process. When establishing the attributes, it is essential to distinguish between the characteristics of the base material and those of the metal foam.[3, 4 & 7]. Beyond this, structure, particularly anisotropy and cell flaws, has an impact on the properties of foam. Cells can have varying sizes and unusual shapes. The mechanical characteristics of foam are frequently reduced due to frequently damaged cell walls, and porosity can vary by 10% or more. Metal foam's main characteristics are as follows: High compression strengths, good energy absorption, low thermal conductivity, and low density.

The four primary techniques for creating foam metals are ion deposition, vapour deposition, production in the liquid state, and production in the solid state. The physical and chemical qualities of the metal utilised must be taken into account while choosing the process for producing metal foams and porous metals. For instance, low melting point aluminum can be processed in liquid form, whereas high melting point metals like steel and titanium must be created in solid form. High temperatures can lead to undesirable chemical reactions. To produce metal foams with good physical qualities and mechanical properties, the production methods and processing factors are still being thoroughly and in-depth examined. [3,4].

1.1 Types of Metal foams

The metallic foams are divided into two categories based on their applications:

a- Structural applications
b- Functional applications

Metallic foams are frequently employed for structural purposes. Metallic foams have the following benefits in structural applications:

- Due to their ability to absorb significant amounts of energy under minimal stress, metallic foams are perfect for use in energy dissipation devices. Furthermore, they do not contribute excessive weight to the structure due to their low specific weight.

- Metallic foams can be utilised as stiffeners in the members because of their high stiffness-to-weight ratio, which results in little changes to the structure's overall mass.

- Some metal foam varieties, including steel foams, exhibit signs of weldability to other steel components.

- Metal foams can be used in place of metals in the constructions, resulting in members with the same weight but much reduced local slenderness ratios. This is one advantage of employing steel foams for improving ductility as opposed to alternative techniques like shape memory alloys.

The structural application categorization of metallic foams is,

-Metallic closed-cell foams: The majority of recent efforts to build metallic closed-cell foams foams have been directed toward nonferrous metals like foams based on aluminium alloys. This is mostly due to aluminum's low melting point, simple production, and the advantageous mass-specific mechanical properties of aluminium foams. However, efforts to create foams from other metals, Research, and development are still going on for materials like steel, gold, and superplastic zinc.

-Iron-based materials: Steel has been explored as an alternative to aluminium foams since it is generally more affordable and has greater strength and energy absorption capacity.

-Metal-based foam composites: Metal foams have novel applications for modifying the characteristics of other materials. Combinations like those with aluminium foam and glass-fiber reinforced polymer, aluminium alloy sheets, and composites with aluminium foam spheres joined together with polymeric glue show that there is still room for advancement.

-Amorphous metallic foams: In addition to decreasing density, amorphous metals with pores have much higher compressive ductility than those without pores, with cellular designs having values as high as 80%. This is explained by shear-band disruption induced by individual pores at low porosities and stable plastic bending generated by thin struts at higher porosities.

-Metallic hollow spheres: Hollow spheres have been used in composites and syntactic structures for structural applications. One of the newest materials in this class is made of hollow Cu2O and NiO nanoparticles, which are produced by oxidising Cu and Ni nanoparticles.

-Wire mesh structures: The "Wire-Woven BulkKagome (WBK) truss" Recently, a manufacturing technique for multi-layered Kagome truss periodic structures was created. Based on a six-way assemblage of helical wires, the structure was created. The uniform, periodic, and extremely permeable structures. They also possess positive particular qualities.

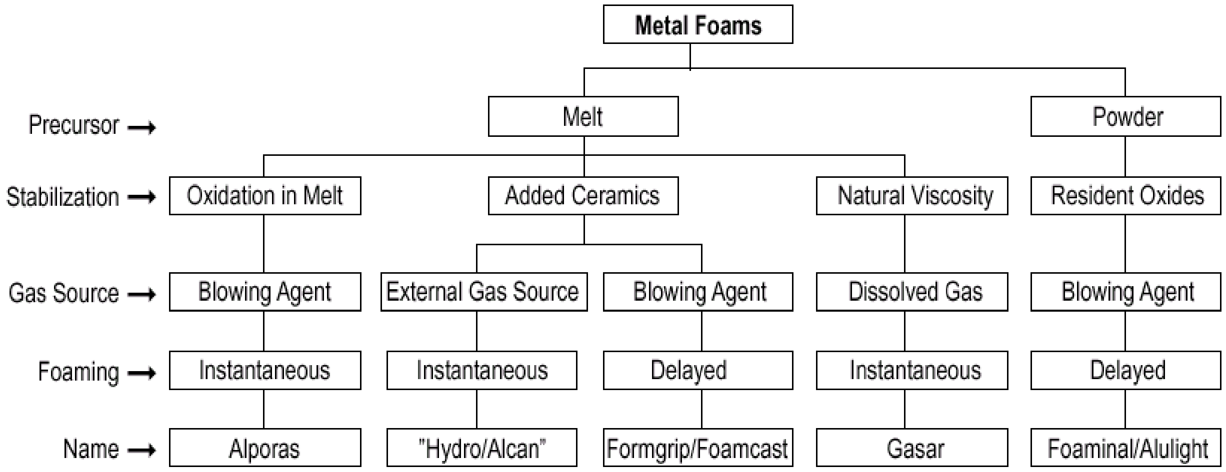

Figure 1: Different types of Metal Foams

2. Processing Methodologies:

Metallic melts may foam under specific circumstances when gas bubbles are added to the liquid. Gas bubbles produced in a metallic melt frequently rise to the surface quickly as a result of the strong buoyancy forces in the high-density liquid. This rise can be reduced by raising the molten metal's viscosity. components for alloying or fine ceramic powders can be added to form stabilising particles, or alternative methods can be used. Metallic melts can froth in three different ways either pushing gas that has previously been dissolved in the liquid metal to precipitate, by creating in-situ gas generation in the liquid, or by introducing gas from an external source into the liquid metal.

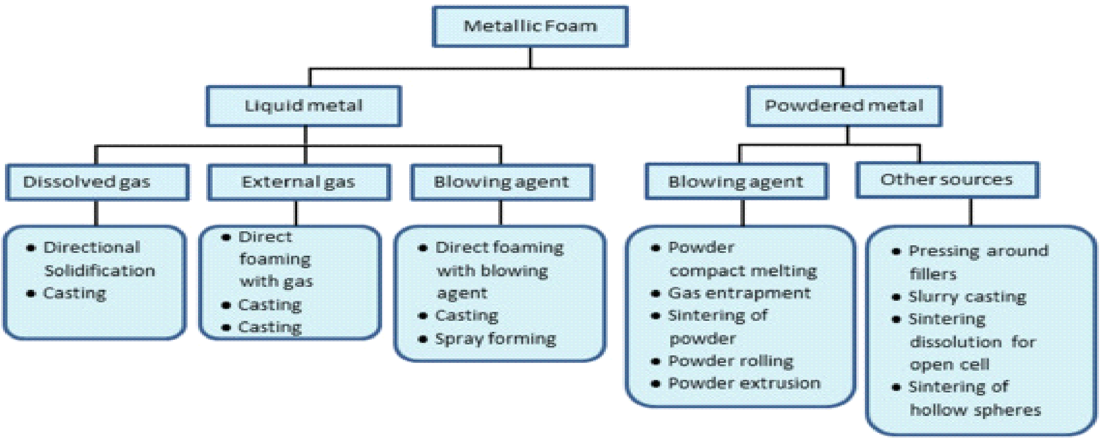

Figure 2: Different processing methods of metal foams

2.1 Gas Injection for the Foaming of Melts (Hydro/Alcan)

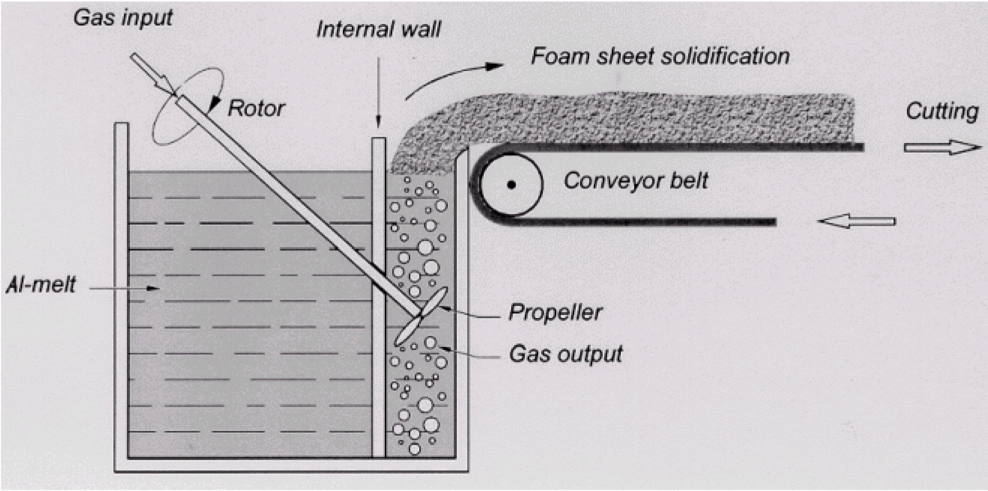

Figure 3: Gas injection method of metal foam processing

The first technique created for foams made of aluminium is this one. Figure 3 shows the foaming of melts caused by gas injection. The metal is heated until it melts, at which time the metal becomes molten. After that, binders and stabilisers like silicon carbide and aluminium oxide are added to the molten metal. The next step is to introduce gas into the molten metal to create a gas bubble. A specially made rotary or vibrating nozzle can be used to inject air, nitrogen, or argon during the gas injection process. The gas bubbles will create metal foams as they float on top of the molten metal. As depicted in Figure 3, the conveyor belt will drain the created metal foams. In order to achieve the correct thickness and density, according to Banhart, It's crucial to carefully control process variables such nozzle vibration frequency, conveyor speed, and gas injection pressure. Using this technique, large numbers of metal foams and pores may be produced.[5, 6].

2.2 Using blowing agents to create foam

A blowing agent can be used to directly make foam rather than blowing gas into metal melts. When heated, blowing agents will deteriorate, producing gas that will cause molten metal to froth. This technique was created and patented in 1986 at Amagasaki, Japan's Shinko Wire Company, Ltd. The foaming procedure with blowing agents is depicted in Figure 4. Beginning with the melting of aluminium at 680 degrees Celsius To make calcium more viscous, molten aluminium is poured to it. Due to its strong affinity for electrons, calcium can be used to thicken melts by forming calcium oxide and calcium-aluminum oxide. The melt is subsequently given a blowing agent, titanium hydride(TiH_2)

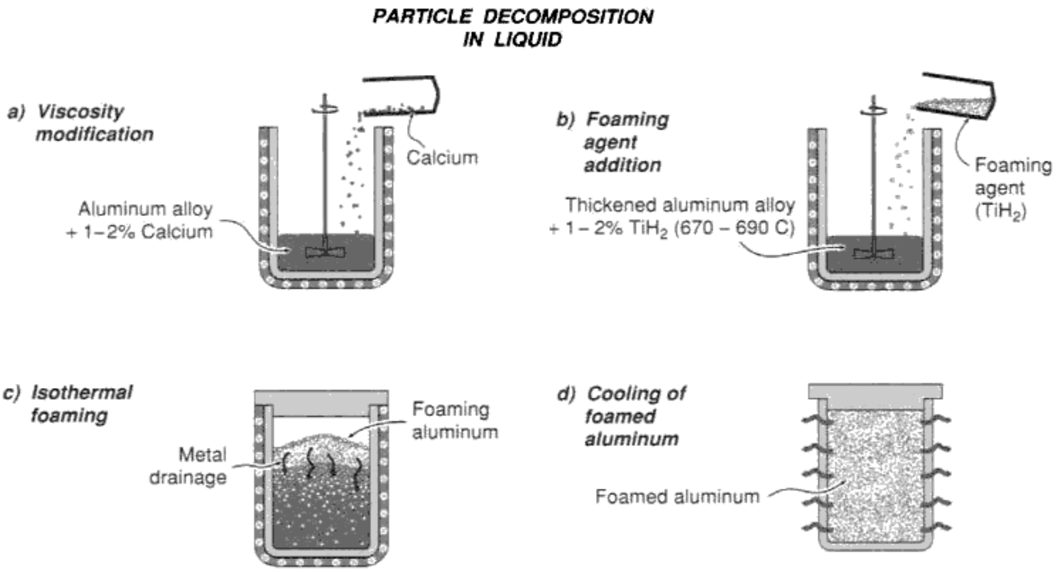

Figure 4: Blowing agent type of foaming technique.

The melt will grow to fill the mold as the titanium hydride breaks down and releases hydrogen. The aluminum foam block is removed from the mold after cooling, and the production processes are repeated. The operation is finished in around 15 minutes. The trade name ALPORAS is applied to the metal foams created using this process. This technique may quickly create foam that is comparatively uniform, but it is challenging to manage the size and shape of the pores.

2.3 Casting Techniques

Indirect liquid-state processing techniques include casting processes. Researchers can use polymer foams or space holders to cast metal foams. Figure 5 illustrates the use of polymer foam in metal casting. To fill polymer foam, a slurry with outstanding heat resistance is employed. The polymer foam is eliminated by heat treatment after drying. Then, molten metal is poured into the freshly made mold. The molten metal is poured into the mold, which is then opened once it has cooled. Figure 5 depicts the casting process using the space holder material. Typically, granular organic or inorganic materials are utilised as space fillers. After the space holder has been set up at the mold, the molten metal is first poured into the mold. After cooling and hardening, the filler material is removed using a solvent or heat treatment. The size and shape of the space holder can be easily changed to influence the pore morphology. However, highly reactive metals like titanium are still not a good fit for this method [8, 9, 10].

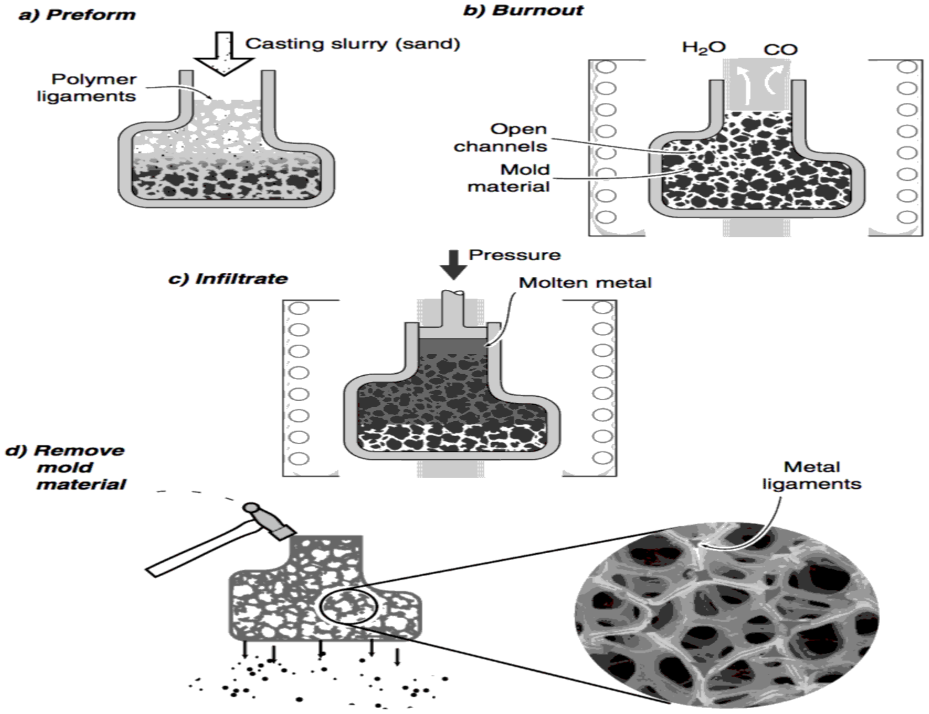

Figure 5: Casting method type of metal foam processing technique

2.4 Powder Compact Melting Technique

This method was created by the Fraunhofer Institute in Bremen, Germany. Metal powder is used as the initial component of this process. NeverthelessSince it foams while melting, it is still considered manufacturing because it is in a liquid state. The blowing agent is first combined with the metal powder. Extrusion or compression are used to compress the mixture. In order for the blowing agent to degrade, heat treatment is carried out at a temperature close to that of metal melting. The components will get larger as a result of the gases, and the molten metal will develop pores. The kind and makeup of the blowing agent can be changed to alter the metal foam's density. This method, however, is not suitable for metals with high melting temperatures, and is difficult to regulate the form of the pore due to the high cost of processing.[11,12]

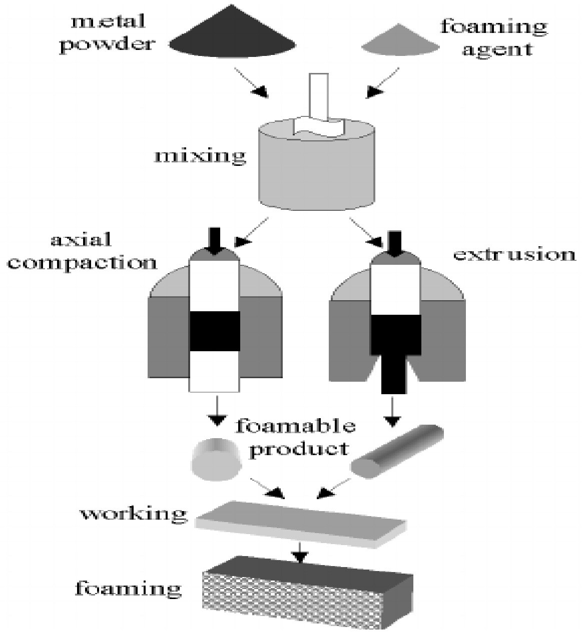

Figure 7: Powder compacting type of Metal foam technique.

2.5 Metallic Hollow Sphere Sintering

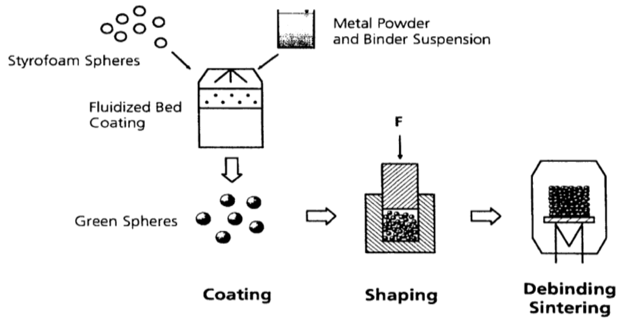

Figure 8: Metallic hollow sphere sintering technique

Sintering with loose metal powder is comparable to this process. Sintering is carried out on hollow spherical powder, which is the difference. Metal foams are created when hollow metal spheres that are sintered interact with one another. Different techniques are used to create metal hollow spheres. The easiest way is to chemically place the metal onto a polymer spherical. The coating was carried out by the researcher using binders and metal powder coating. After coating, the metal spheres are sintered and the polymer spheres are separated by debinding. Using coaxial nozzles, metal powder slurries may also be blown into microspheres to make hollow metal spheres. Metal powder will be displaced into the spaces between the spheres to create the closed pore structure. Metal foams with consistent pore size distribution may be created by metallic hollow spherical sintering. Using this approach, a variety of metal powders, including titanium alloys, may be treated.

2.6 Gas Entrapment Method:

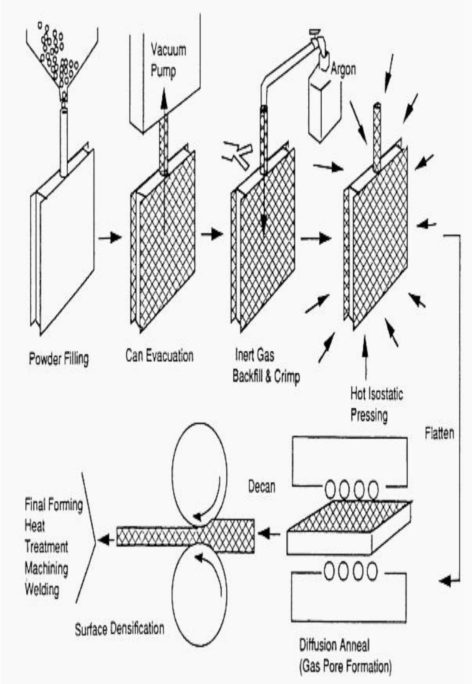

Figure 9: Metal foam technique for gas trapping

Metal foams can be created by gas entrapment without the need of blowing agents or melting metals. Metal powder is originally put into a vacuum container(as seen in Figure 9). After that, argon gas is pumped into the container at a pressure of 3-5 atm. Argon gas is subsequently confined inside the encapsulated metal powder after being exposed to heated isostatic pressing [12]. By annealing, the compressed material is processed in accordance with the necessary specifications. It typically takes 6 to 24 hours to complete the annealing process, which is done at 0.6 times the metal's melting temperature. Argon gas expands throughout the heat treatment, lowering its internal pressure until the equilibrium between pressure and part strength is reached.

2.7 Space Holder Method:

Metal foams with controlled pore morphology can be created using a space holder. Because metal foams' pore size and form can be easily customised, this approach has attracted a lot of scientific interest. The production of metal foams using the space holder method is shown in Figure 10. Metal powder is first combined with the space-holding substance. Salts, polymeric compounds, or ceramic particles could all be used as space fillers. In order to boost the part's strength, binders are typically added to the mixture in amounts between 1% and 2%. Injection moulding or compression moulding the mixture produces the desired pieces. [13] The space-holding substance is then dissolved or heated out after compression. Connected pores are created when spacer material is removed. The newly formed pores might either be open or closed. Finally, the green body is sintered to improve its structural durability.

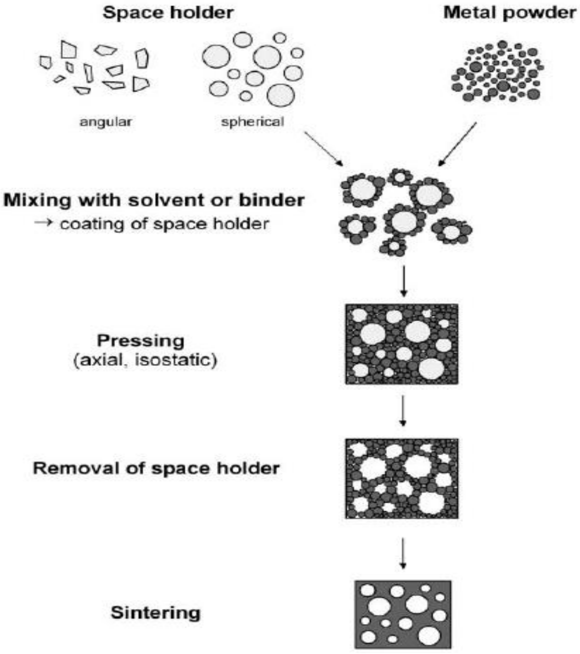

Figure 10: Space Holder method of Metal foam technique.

3. Applications

Since they were originally created, metal foams have piqued the interest of the automobile industry, which finds them suited for their needs. Additionally, the shipbuilding, aircraft, and civil engineering industries also have potential applications.

Examples of lightweight structures include shipping containers, construction materials, filling hollow materials to minimise buckling, and builder staging. Sandwich cores include an elevator cab, a door, a heavy-duty pallet, a panel-replacing honeycomb, and an aircraft pallet. Drop ceiling and floor made of panels. Mechanical damping is the cornerstone of any rotational apparatus or loudspeaker. Prosthetics like dental implants are considered biomedical items. A machine casing with enhanced sound and vibration dampening is utilized as a sound barrier for highways, an overhead bridge, and tunnels.

As impedance converters for ultrasonic sources, closed-cell foams are the best choice for acoustic control. In addition to various filtering and separation processes, filters can be used to clean recycled polymer melts, separate water from airlines, filter filthy oil, remove yeast from beer, and filter diesel fumes. Thermally separated containers include cooking pans. The buoyancy of ships and boats. Football players' shinbone guards are a necessary piece of playing equipment. Posh furniture, clocks, and lamps: examples of interior design and the arts.

Few general applications of metal foam structures are,

- Features, as well as for lightweight and impact-absorbing car parts
- The open variety is perfect for heat exchange, high-temperature filtration and catalysis, medical equipment, and absorption of vibration and sound.
- The open variety is suitable for practical uses like filtration and dewatering
- Load-bearing is required for structural applications using the closed variant.
- Prosthetics composed of foam metal are attached to the animals utilised in investigations.
- Strong metal foams are effective impact energy absorbers with great capacity.
- Excellent stiffness-to-weight ratio for light structures under bending loads
- Compared to solid sheets with an identical mass per unit area, foamed planets have higher natural flexural vibration frequencies.
- Metal foams with open cells can absorb sound.
- Open-cell foams for fluid and gas filtration at high temperatures.
- For anodes, cathodes, caustics evaporators, heat shields, chemical and food processing machinery, as well as electronic and aerospace applications, high-purity nickel is used.

4. Conclusions

In the last decade, a variety of novel metal foaming processes have been developed, resulting in a diverse spectrum of distinct forms of this interesting material. Metallic foams, as innovative materials developed by engineering, are now employed in a wide range of industrial applications such as lightweight constructions, biomedical implants, filters, electrodes, catalysts, heat exchangers, and so on. It is possible to produce both open and closed pore morphologies. Cost reduction is another critical concern in today's advances. The common solutions include using less expensive starting materials, skipping or combining processing steps, and decreasing scrap during production. This material engineering project aims to achieve integrated solutions that ensure metallic foams can be manufactured inexpensively with the needed quality and repeatability, and that their integration into engineering systems makes full advantage of their unique property range. The pore morphology is affected by the processing parameters of each procedure.

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