SYNTHESIS OF AA2014 USING CACO3 AS A FOAMING AGENT BY LIQUID MELTING TECHNIQUE AND CHARACTERIZE THEIR MECHANICAL PROPERTIES

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CANDIDATE'S DECLERATION

I, RANDHIR KUMAR, Roll No. 2K12/PRD/16 student of M. Tech. (Mechanical Engineering), hereby declare that the dissertation titled "**Synthesis of AA2014 using CaCO3 as a Foaming Agent by Liquid Melting Technique and Characterize their Mechanical Properties**" in partial fulfillment of the requirement for the award of the degree of Master of Technology is an authentic work carried out by me under the supervision of Dr. A. K MADAN in Mechanical Engineering Department of Delhi Technological University.

The matter embodied in this report has not been submitted elsewhere for the award of any Degree.

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This is to certify that above statement made by the candidate is true to the best of my knowledge.

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ABSTRACT

Metal foam is revolutionary materials that exhibit different characteristics when compared to their solid material counterparts. Cellular structure of these materials provides the tool for the realization of optimal combination of properties. In the past, when a large dense metal contained any kind of pores, it was considered “defect” and therefore unsuitable for engineering purposes. In recent years, a great importance has been attached to a new class of engineering material, known as “Metallic Foam or Porous metals” as a result to their unique mechanical and physical properties. In my thesis, I have made aluminium foam of AA2014 alloy using CaCO3 as a Foaming Agent with different relative densities by Liquid Melting Technique. SEM is used for analysing of their cell wall and pores cavity. Elements and their intermetallic compounds distribution in cell wall and pores cavity are analysed by EDS technique. Finally I find out the relation between the quasi static compressive behaviour and plateau stress.

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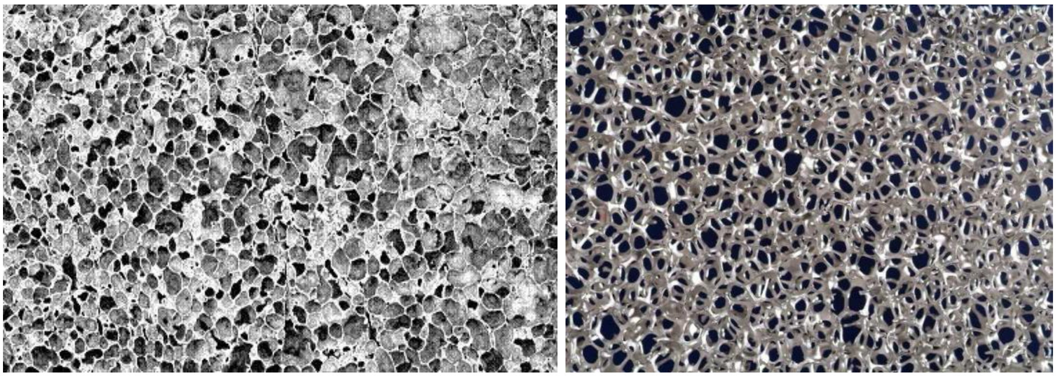
CHAPTER-1
Metallic foam

1.1 Introduction

Metallic foam is a kind of a new engineering material that has been developed from so many decades, which has cellular solid structure with unique combination of properties. Currently there is interest growing in use of honeycomb like metallic material in different application fields. It is a three dimensional array of gas pores within solid metal matrix. These materials are not perfectly characterized [1, 3].The foams structures possess light in weight, high strength and highly energy absorber. These structures are designated by important parameters relative density, cell size. Relative density is ratio of density of foam material to matrix material. Cell means pore size of foam. The foams having either pore interlinked with each other (Closed Cell) [2] or they separated by thin metal layer (Open cell). In open cell metal is present only at the edges of the cells but in closed cell, each cell is isolated by metal layer with every other cell.



Closed cell

Open cell

Fig. 1.Open and closed cell foam (Web reference)

1.2 Production methods of cellular metallic materials

There are many ways to manufacture cellular metallic materials. Some methods are similar to techniques used for foaming aqueous or polymer liquids, whereas others are specially designed by taking advantage of characteristic properties of metals such as their sintering activity or the fact that they can be electrically deposited.

The various methods can be classified according to the state the metal is processed This defines four ‘‘families’’ of processes summarised in Fig. 2, each one corresponding to one of the states of matter: one can start

(i) From liquid metal,
(ii) From solid metal in powdered form,
(iii) From metal vapour or gaseous metallic compounds,
(iv) From a metal ion solution.

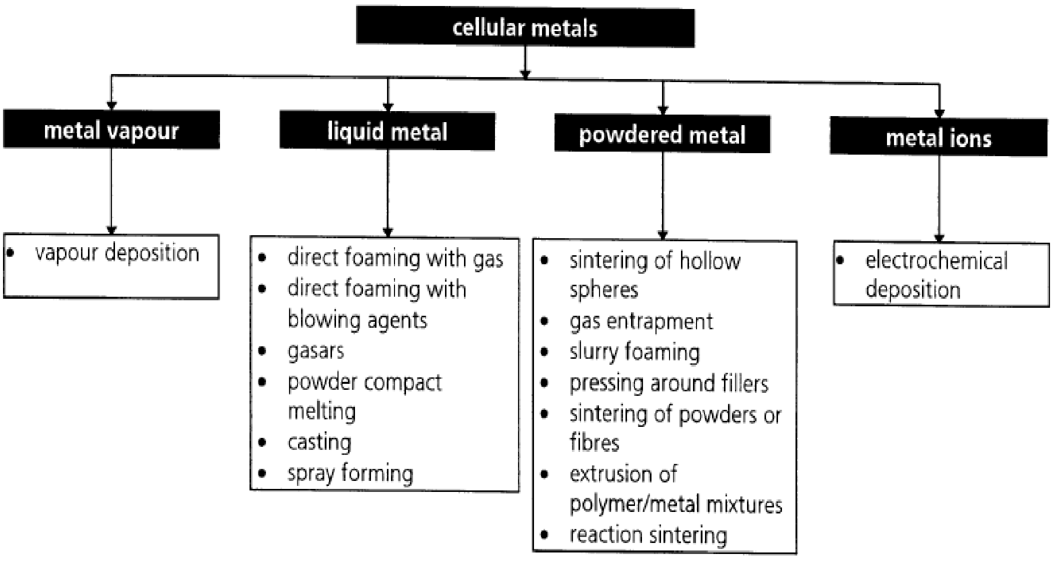


Fig. 2.Overview of the various ‘‘families’’ of production methods for cellular metallic materials

1.2.1 Vapour deposition

Metal vapour in a vacuum chamber can be produced and the vapour allowed condensing on the cold precursor. The condensed metal coats the surface of the polymer precursor and forms a film of a certain thickness characterised by the density of the vapour and the exposure time. One way to carry out this process is by arc vapour deposition [4]. After cooling, the polymer can be removed by thermal or chemical treatment and the same kind of material with hollow struts is obtained.

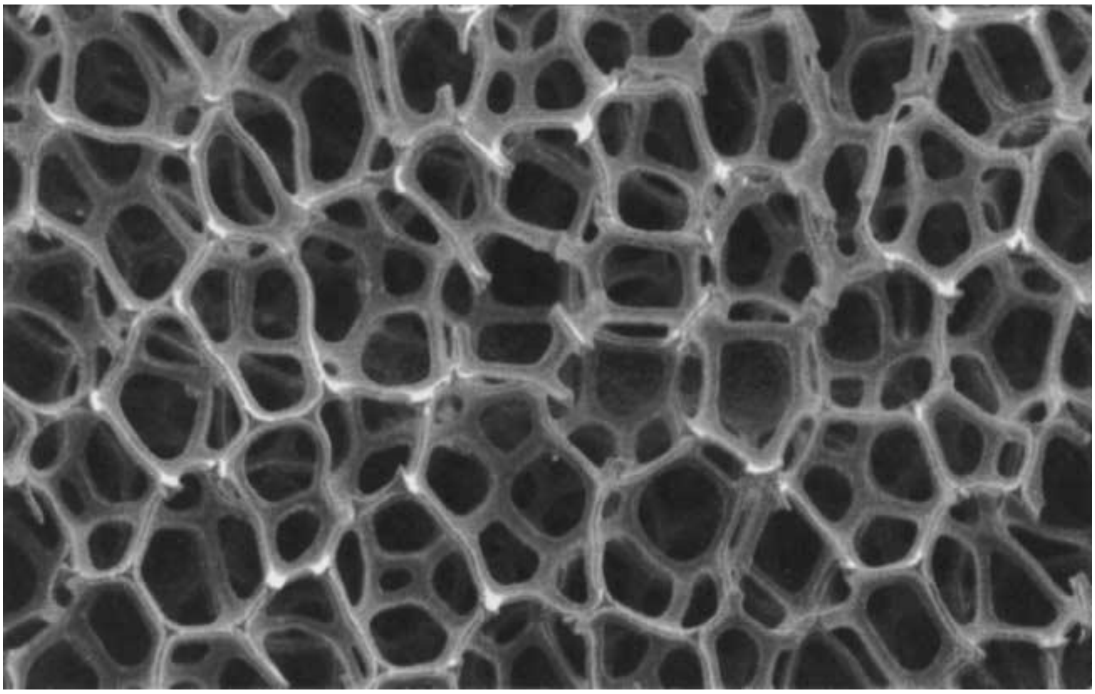


Fig. 3.‘‘Incofoam’’ sample made via Vapour deposition (20 ppi) [4].

1.2.2 Direct foaming with gas

According to this process as depicted in schematically form in Fig. 4, silicon carbide, aluminium oxide or magnesium oxide particles are used to enhance the viscosity of the melt. Therefore, the first step requires the preparation of an aluminium melt containing one of these substances. The liquid melt is foamed in a second step by injecting gases (air, nitrogen, argon) into it using specially designed rotating impellers or vibrating nozzles . The resulting solid foam is in principle as long as desired, as wide as the vessel containing the liquid metal allows it, and typically 10 cm thick.

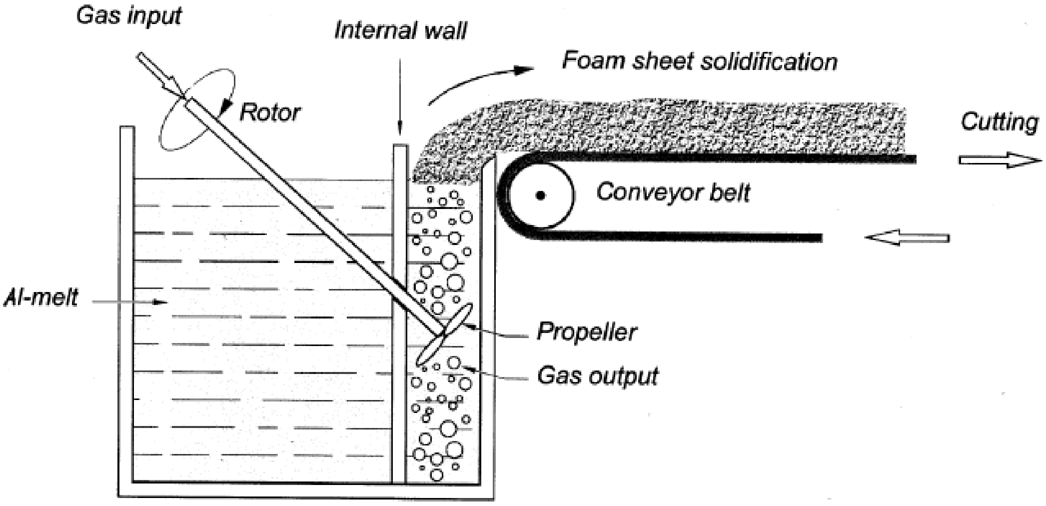


Fig. 4.Direct foaming of melts by gas injection [5].

The volume fraction of the reinforcing particles typically ranges from 10 to 20% and the mean particle size from 5 to 20 mm [6,7]. The selection of particle size and content has been carried out empirically. Too high or too low contents or particle sizes create the problems addressed in Fig. 5.

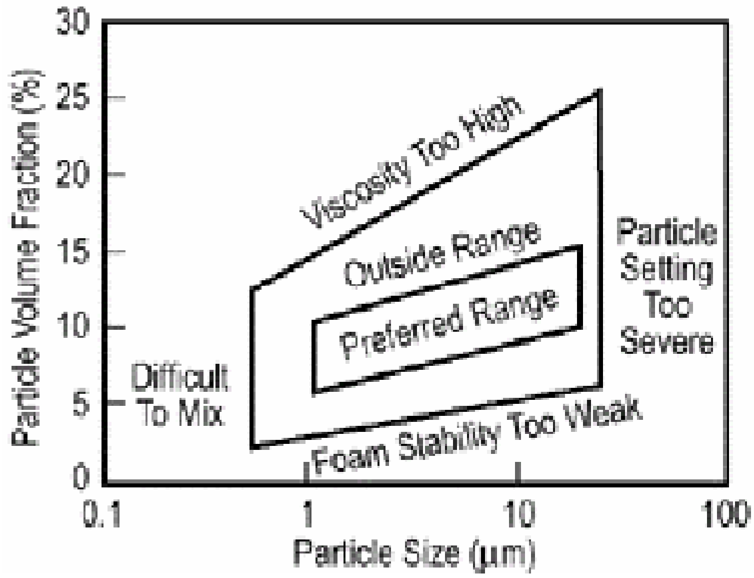


Fig. 5.Preferable particle volume fraction and particle size range of stabilizing powders[6]

1.2.3 Foaming with blowing agents.

A second alternative way for foaming melts directly is to add a blowing agent to the melt instead of blowing gas into it [7-9,10-12]. The blowing agent decomposes under the influence of heat and releases gas which then propels the foaming process. This is explained in Fig. 6 for a modern version of the process [13] In this technique, calcium metal is added to an aluminium melt at 680_C. The melt is stirred for several minutes during which its viscosity continuously increases by a factor of up to five [14], owing to the formation of calcium oxide (CaO), calcium–aluminium oxide (CaAl2O4) or perhaps even Al4Ca intermetallic which thicken the liquid metal [38,331]. Fig. 7 shows the effect of stirring on the viscosity of aluminium melts with various calcium additions.

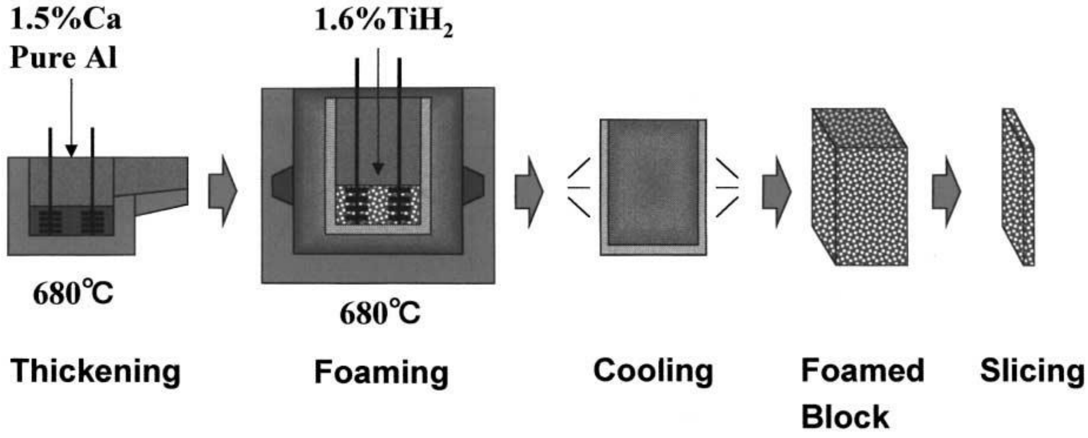


Fig. 6.Direct foaming of melts with blowing agents (‘‘Alporas’’-process) [14].

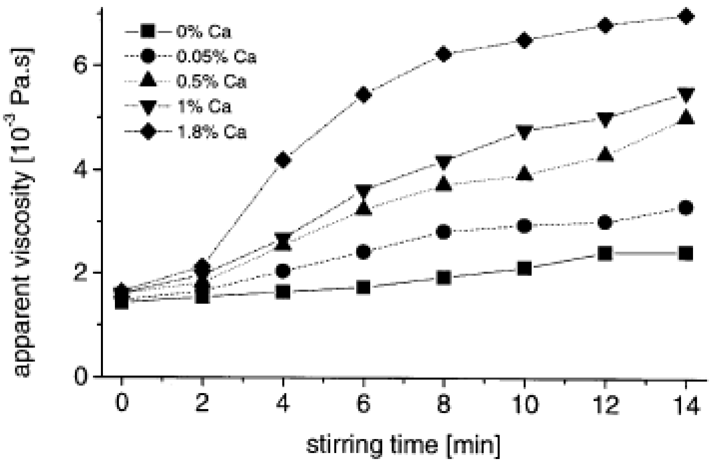


Fig. 7.Influence of stirring time on the viscosity of an aluminium melt after admixture of calcium metal [15].

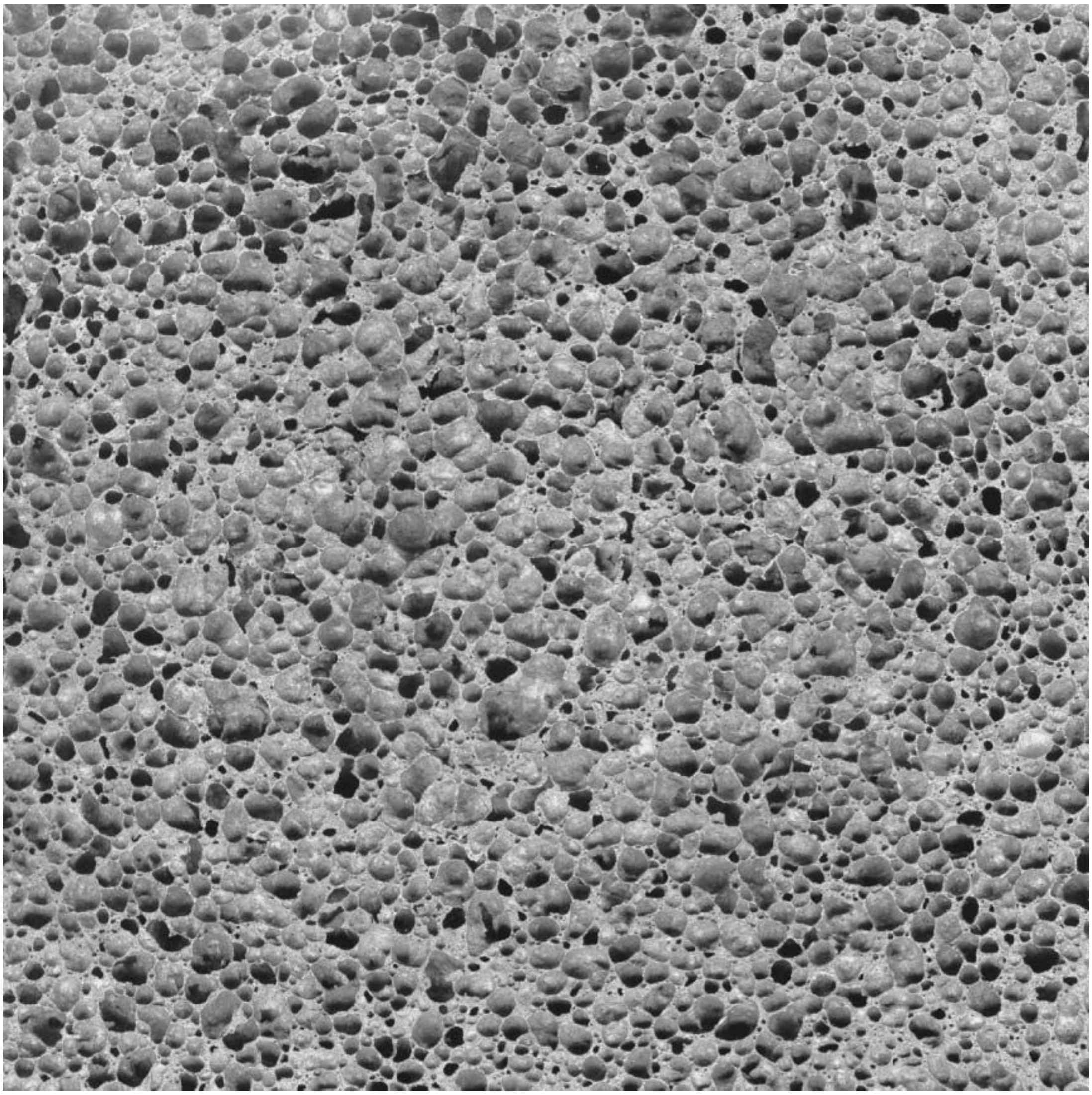


Fig. 8.Pore structure of aluminium foamed by adding TiH_2. Section shown is 80 _ 80 mm^2 in size [15].

1.2.4 Solid–gas eutectic solidification (‘‘gasars’’)

A method developed about a decade ago [16] exploits the fact that some liquid metals form a eutectic system with hydrogen gas. By melting one of these metals in a hydrogen atmosphere under high pressure (up to 50 atm), one obtains a homogeneous melt charged with hydrogen. If one then lowers temperature, the melt will eventually undergo a eutectic transition to a heterogeneous two-phase system, ‘‘solid gas’’. If the composition of the system is sufficiently close to the eutectic concentration, there will be a segregation reaction at one temperature. Because the eutectic composition depends on the system pressure, the external pressure and the hydrogen content must be co-ordinated. Removal of heat from the melt causes directional solidification. As the solidification front advances through the liquid, typically at velocities ranging from 0.05 to 5 mm/s, the hydrogen content near the solidification plane increases and gas bubbles are formed.

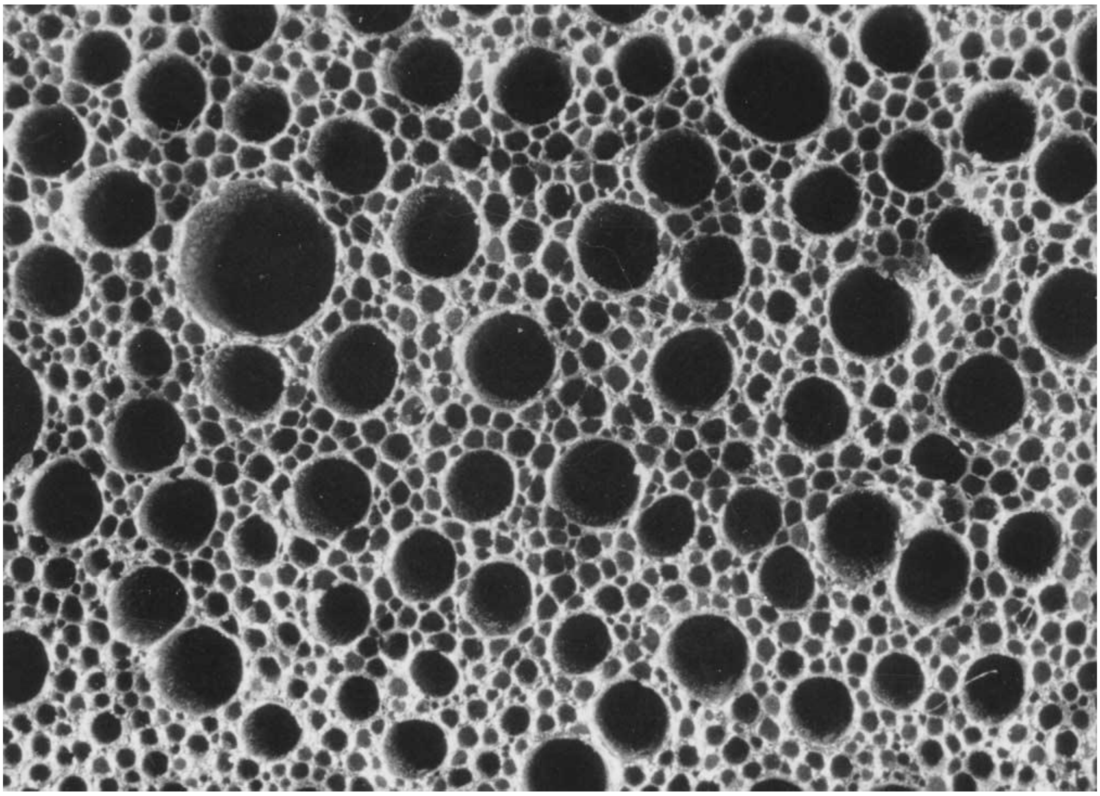


Fig. 9.Pore structure of a ‘‘gasar’’. Surface normal to direction of pores is shown [17].

1.2.5 Powder compact melting technique

The production process begins with the mixing of metal powders — elementary metal powders, alloy powder s or metal powder blends — with a blowing agent, after which the mix is compacted to yield a dense, semi-finished product (see diagram in Fig. 10). In principle, the compaction can be done by any technique that ensures that the blowing agent is embedded into the metal matrix without any notable residual open porosity. Examples of such compaction methods are hot uniaxial or iso-static compression, rod extrusion or powder rolling [18]. Which compaction method is chosen depends on the required shape of the precursor material. However, extrusion seems to be the most economical method at the moment and is therefore the preferred way [19]. Rectangular profiles with various cross-sections are usually made from which thin sheets can then be obtained by rolling Heat treatment at temperatures near the melting point of the matrix material is the next step. The blowing agent, which is homogeneously distributed within the dense metallic matrix, decomposes. The released gas forces the compacted precursor material to expand, thus forming its highly porous structure. The time needed for full expansion depends on temperature and the size of the precursor and ranges from a few seconds to several minutes.

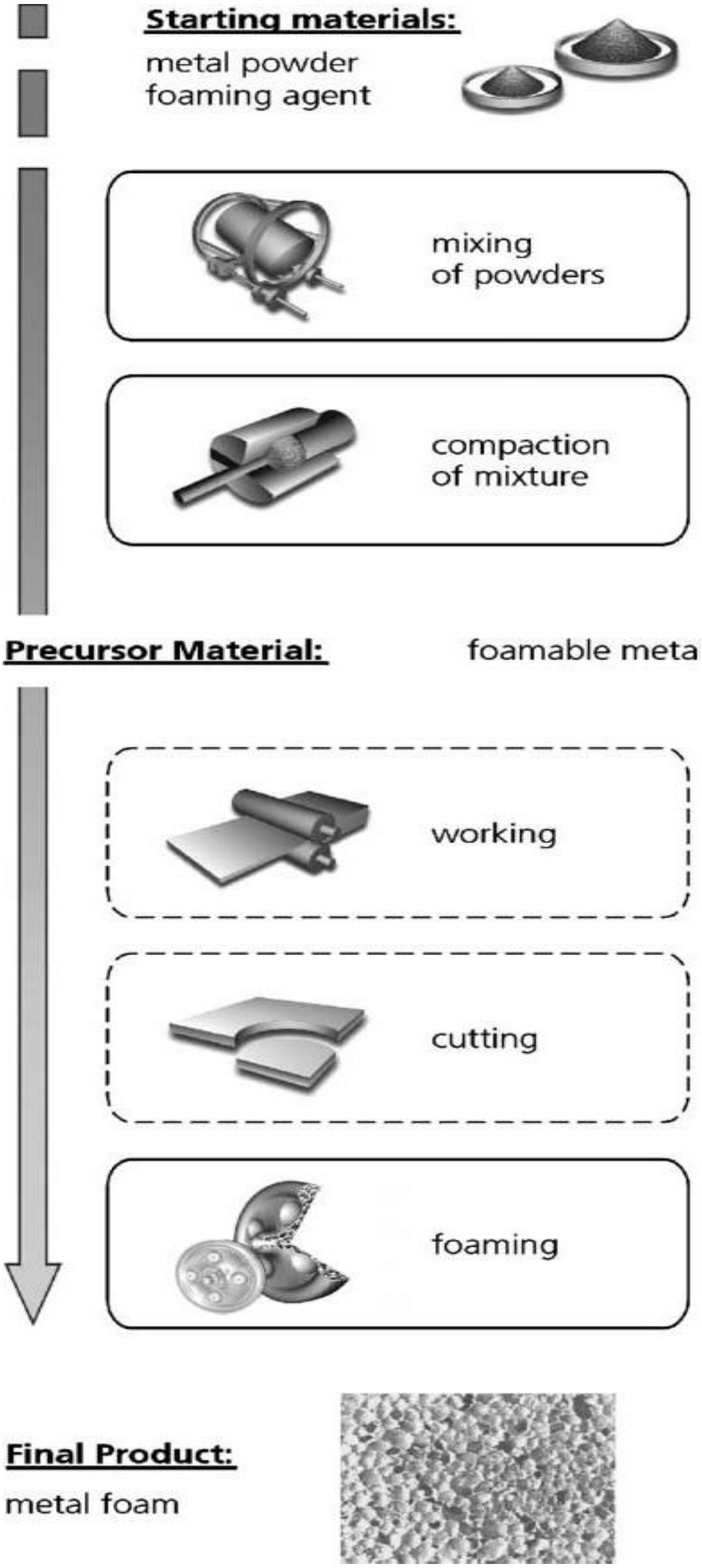


Fig. 10.Powder compact melting process [19].

1.2.6 Casting methods

Foams can be manufactured from molten metal without directly foaming the metal. This is shown in the schematical description of Fig. 11. According to this process, polymer foam, e.g. polyurethane foam, is used as a starting point. If the polymer foam has closed pores, it has to be transformed into an open porous one by a reticulation treatment. The resulting polymer foam with open cells is then filled with slurry of sufficiently heat resistant material, e.g. a mixture of mullite, phenolic resin and calcium carbonate [20] or simple plaster [21]. After curing the polymer foam is removed by thermal treatment and molten metal is cast into the resulting open voids which replicate the original polymer foam structure.

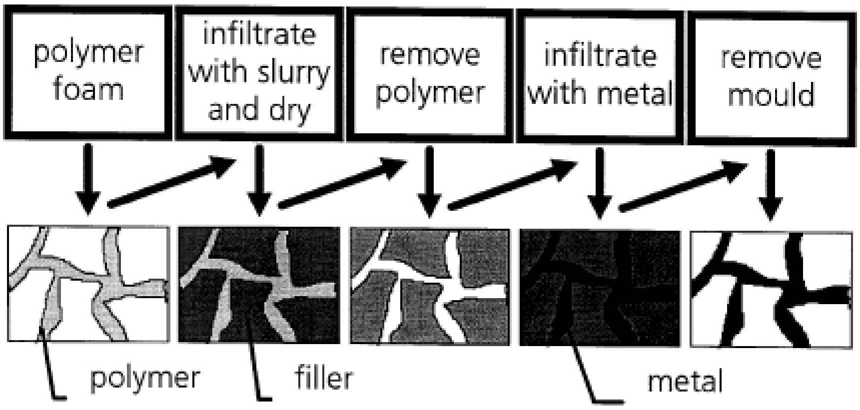


Fig. 11. Production of cellular metals by investment casting

1.2.7 Spray forming (‘‘Osprey process’’)

Spray forming is a method which allows for processing a variety of different metals and alloys. Metallic melt is continuously atomised and a spray of fast flying small metal droplets is created. The droplets are collected on a substrate where they grow to a dense deposit in a given shape, e.g. a billet, sheet or tube, provided the process parameters are appropriately chosen.

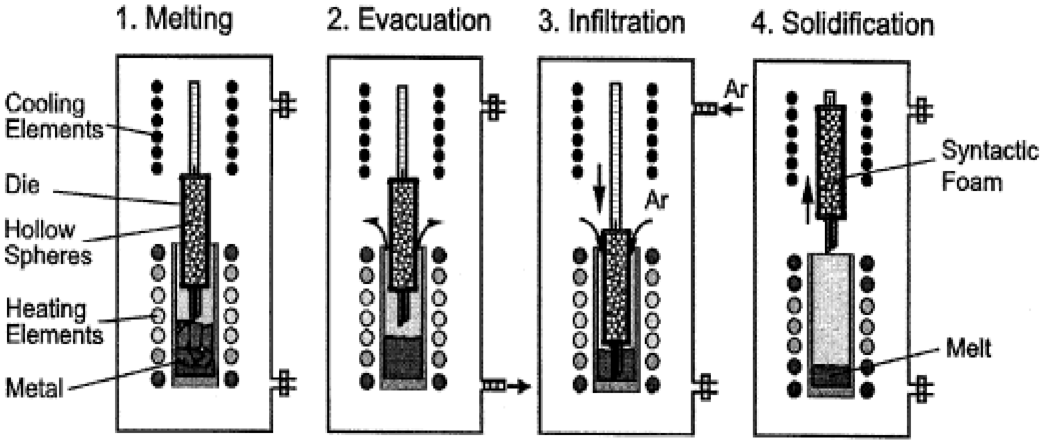


Fig. 12.Process steps for making syntactic foams [22].

1.2.8 Sintering of metal powders and fibres

In general, the production of porous structures consists of various steps: powder fractioning and preparation, compaction or moulding, and sintering [23]. Loose pack or gravity sintering is mostly used for bronze (Cu89Sn11). Sinter temperatures are around 820_C, and porosities between 20 and 50% can be achieved, whereas strengths are comparatively low. One such material is shown in Fig. 25.

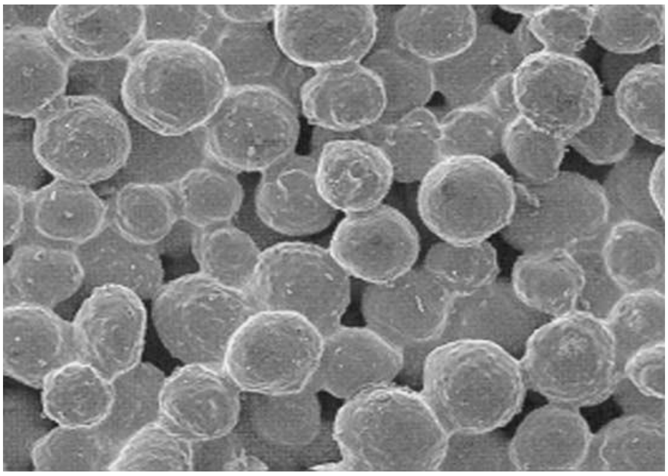


Fig. 13.Porous sintered bronze made from particles with about 100 mm diameter [24].

1.2.9 Gas entrapment technique

In this, powders are compressed to a dense precursor material. During compaction gas is allowed to be entrapped in the material [25]. Heating the precursor material in a second step then leads to metal expansion due to the internal pressure created by the entrapped gas. The expansion takes place in the solid state and is therefore not an actual foaming but rather a solid state creep process.

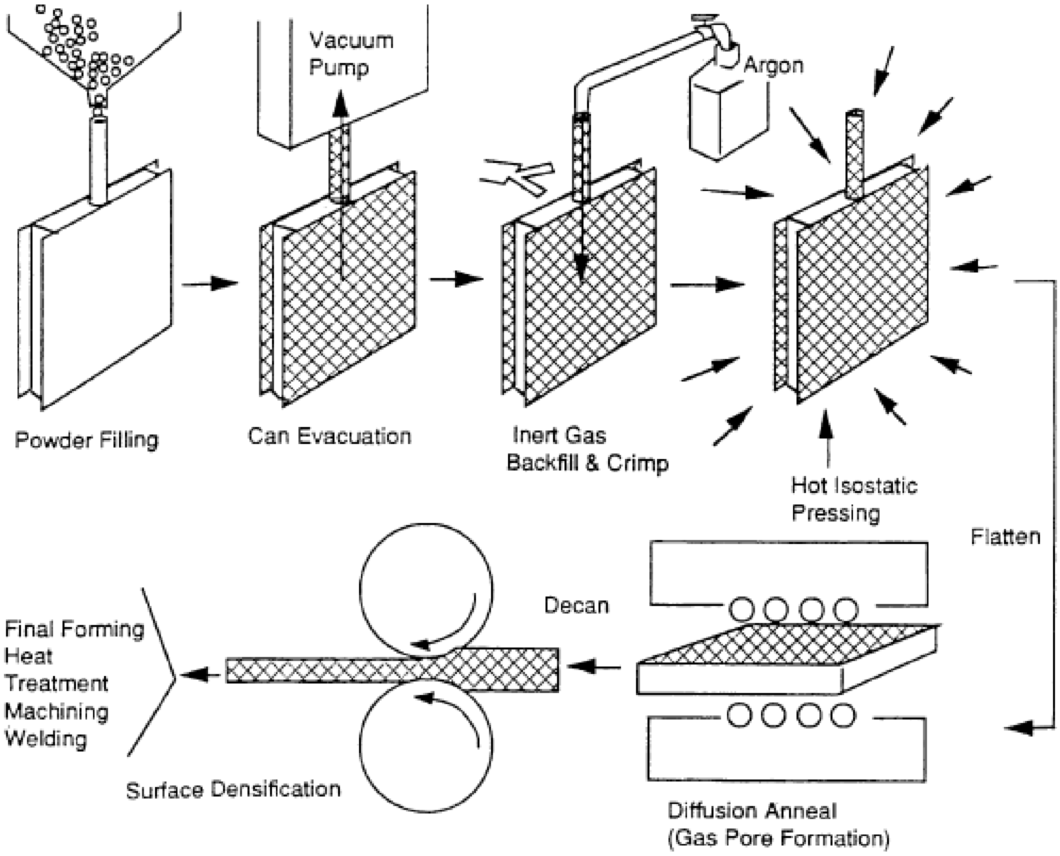


Fig. 14.Gas entrapment technique [26].

1.2.10 Foaming of slurries

Metallic foams can also be produced by preparing slurry of metal powders, blowing agents and some reactive additives. The slurry is poured into a mould after mixing and left there at elevated temperatures. Under the influence of the additives and the blowing agent, the slurry turns viscous and starts to expand as gas begins to evolve. If sufficient stabilising measures have been taken, the expanded slurry can be preserved and dried completely after which it is sintered to yield a metal foam with considerable strength.

1.2.11 Cellular metals based on space-holding fillers

The metal powder is either filled into a ‘‘dry’’ bulk of fillers [27], or a suitable solvent [28] or even an organic binder [29] maybe used to mix the space holders and the metal powders. The filled bulk is then either simply compacted at room temperature or, if the space holders are heat resistant, pressed at elevated temperatures to improve compaction and to start sintering processes between the metal powder particles. In both cases, a composite is obtained which consists of a metal matrix with embedded filler granules. If the metal content is sufficiently low, it is possible to remove the space holder material almost completely in a further process step because the network formed by the filler material is interconnected. This can be done by thermal treatment, leaching, or by use of an aqueous solvent. A final sintering step can be applied to further densify the porous metallic network.

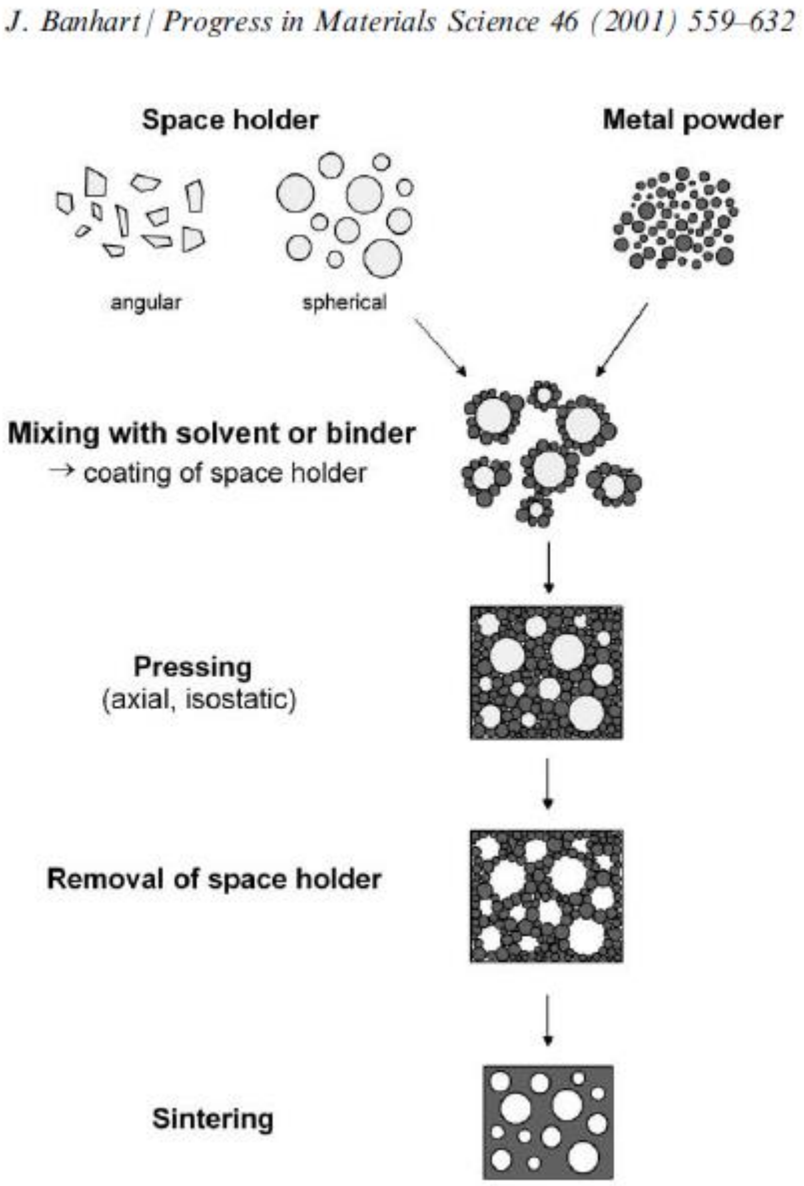


Fig. 15.Space holder technique for making porous metallic structures from metal powders [28]

1.2.12 Metallic hollow sphere structures

Hollow spheres made of copper, nickel, steel or titanium can be used to create highly porous structures by bonding the individual spheres together by sintering.

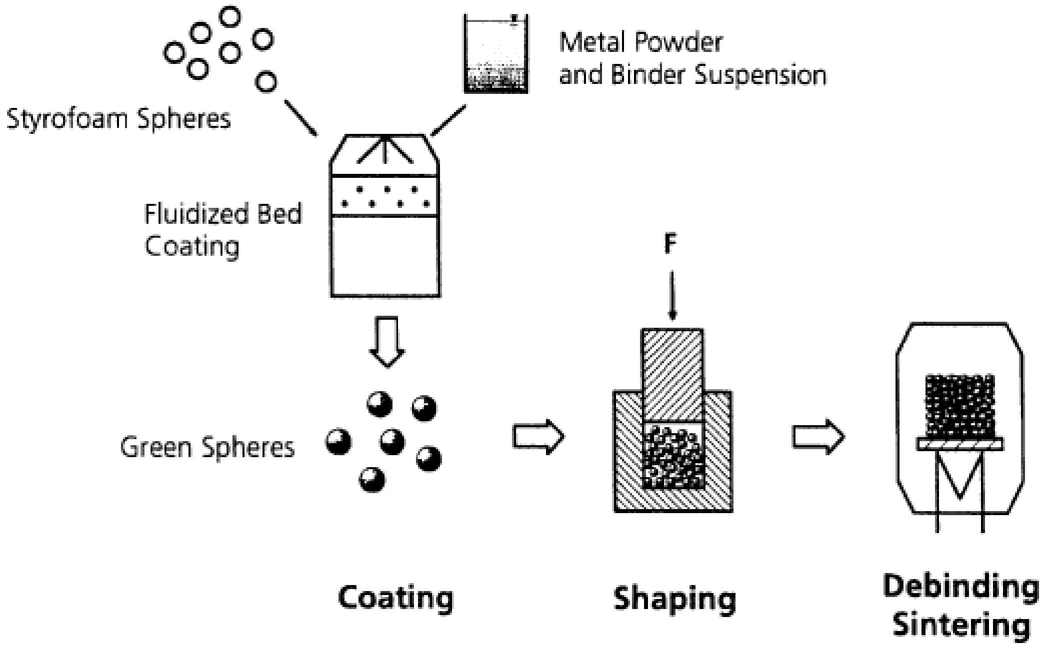


Fig. 16.Styrofoam coating process for making hollow sphere structures [29].

Closed structures can be obtained by filling the interstices between the spheres with metal powder followed by a sintering treatment [30]. Thin walled spheres are sufficient in this case. Sandwich type structures can be manufactured in a straightforward way by sintering the bulk of hollow spheres between two face sheets, thus creating a bonding not only between the spheres but also between the face sheets and the spheres

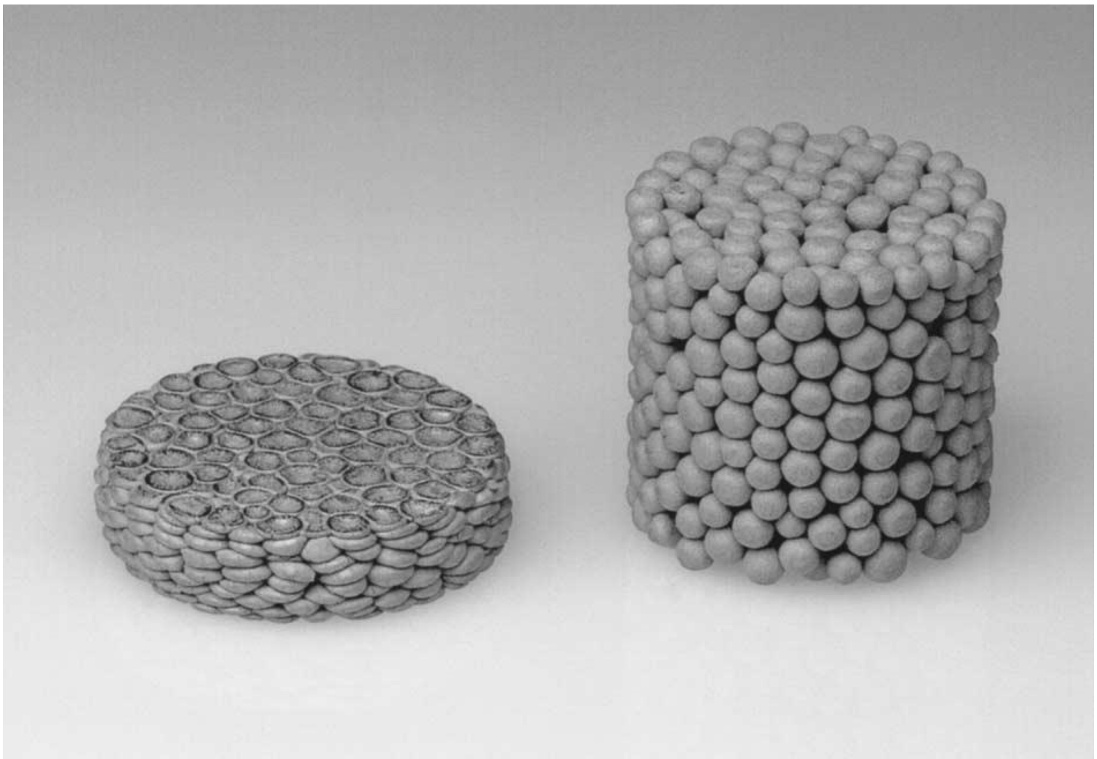


Fig. 17.Open hollow sphere structure made from stainless steel spheres by sintering: after and before axial deformation. Diameter of parts is about 20 mm [31]

1.2.13 Metal powder/binder methods

Mixtures of metal powders and polymer binders can be pressed or extruded and then heat treated to produce porous materials and components [32]. Although no space holding fillers are used, porosities up to 50% have been achieved. In a similar way, materials with oriented pores (baptised ‘‘micro-honeycombs’’) can be made [33] with channel diameters ranging from several microns to several millimetres and based on a variety of metals and alloys. The process steps required are explained in Fig. 18. Bimaterial rods are first prepared which have a core consisting of a mixture of a plastic binder with a volatile space holder and a shell of a metal powder/binder mixture. Next, bundles of such rods are pressed to a green part. This can either be done by extrusion of the bundles, yielding a green part of almost arbitrary cross-section, or by axial pressing to a green part of a complex shape. In a third step, the binder and the space holder are removed and the metal powder is consolidated by sintering. Fig.19 shows an example for a micro-honeycomb made of iron.

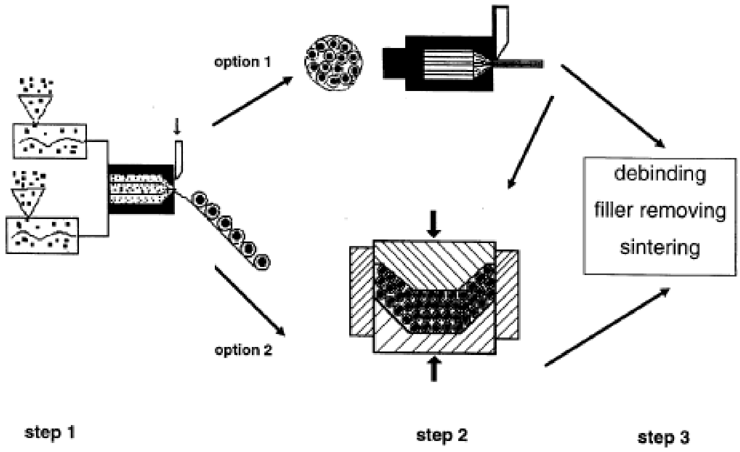


Fig. 18.Process for making cellular metals with oriented porosityfrom metal powders [33].

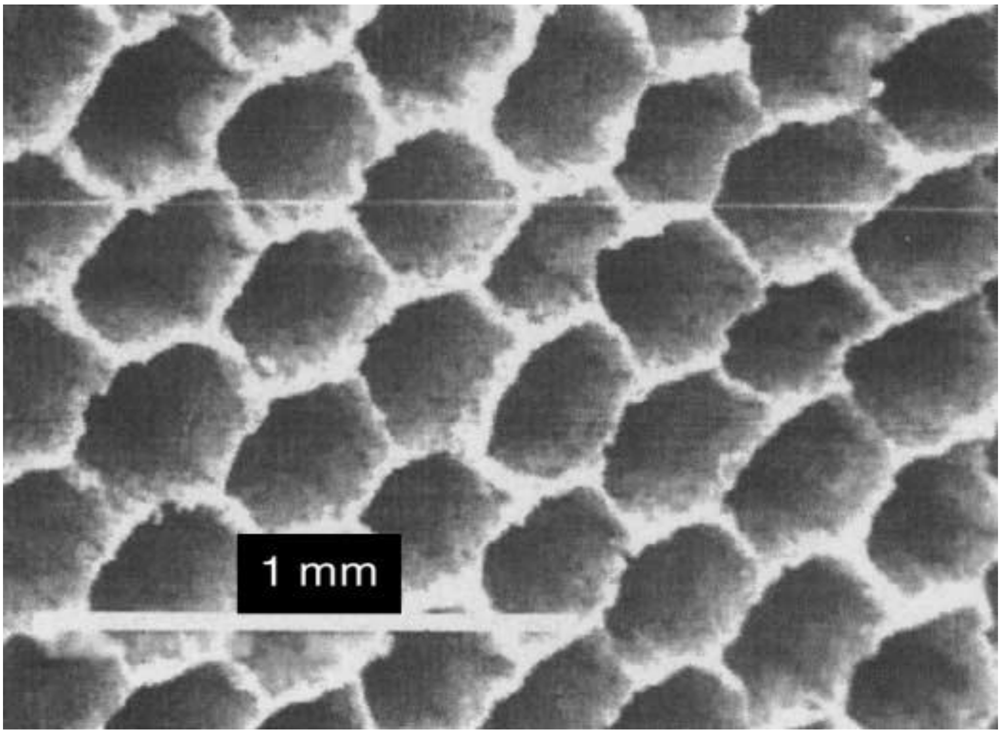


Fig. 19.Porous iron sample with oriented cells of hexagonal cross-section (86% porosity) [33]

1.2.14 Reaction sintering

Reaction sintering of metal powder mixtures such as Ti + Al, Fe + Al or Ti + Si is also known to yield porous structures [34]. This is due to different diffusion coefficients of the components of a multi-component system in each other.

1.2.15 Electro-deposition technique

Deposition techniques start from the ionic state of metals, i.e. a solution of ions in an electrolyte [35,36]. The metal is electrically deposited onto a polymeric foam with open cells which is later removed (see Fig. 20).

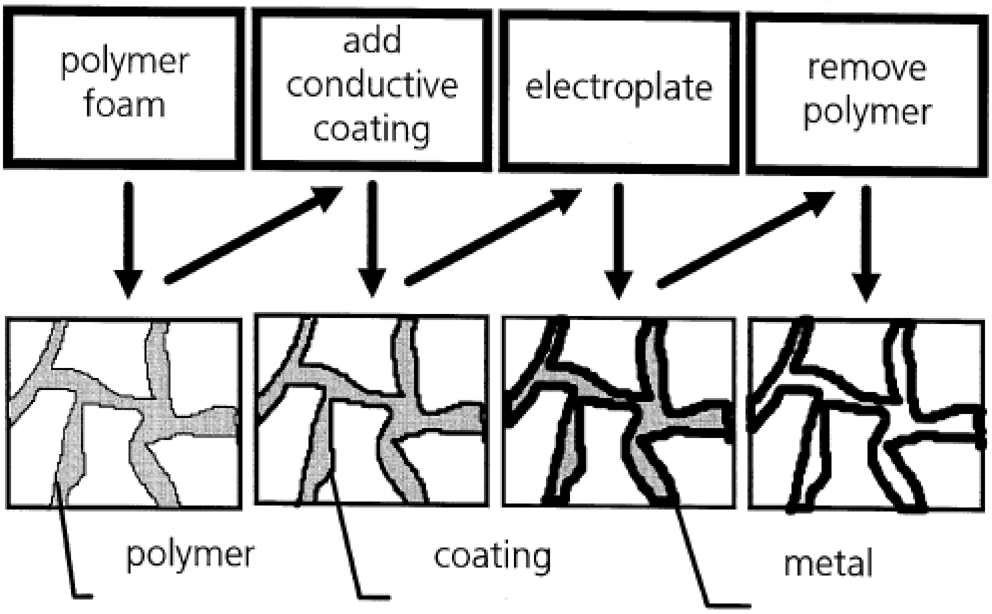


Fig. 20.Electro-deposition technique for making metal foam.

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1.2.16 Laser assisted aluminum foaming

This process is recently proposed by Kathuria [37]. The basic principle of laser assisted foaming is shown schematically in Figure 21. The precursor material with blowing agent, prepared by P/M process, is foamed by heating it up to its melting point by a high power laser beam irradiation. The uni-directional expansion of the foamable precursor material can be observed during the entire foaming process in the irradiation direction. The expansion in the other directions is relatively negligibly small.

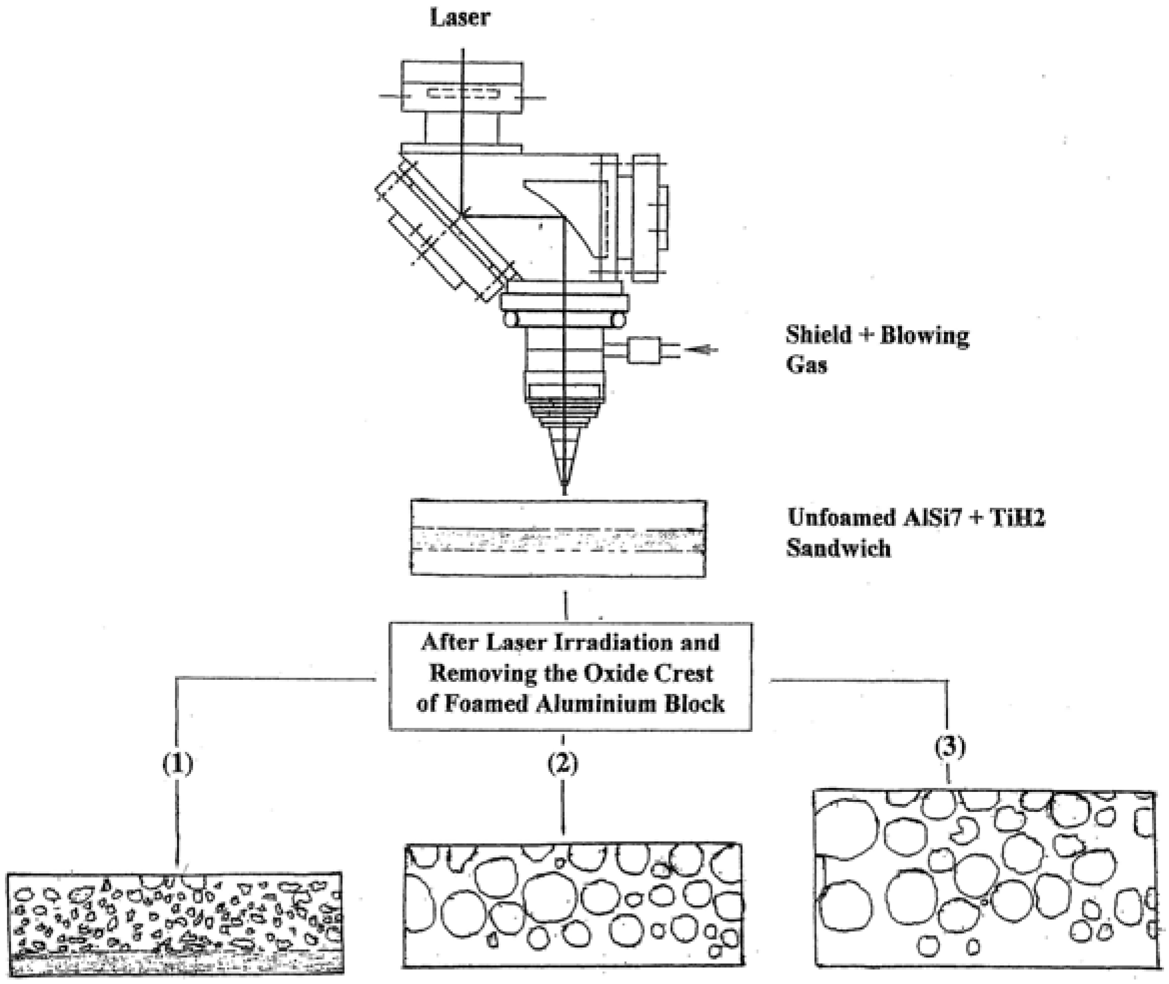

Fig. 21.The block diagram of laser assisted AlSi7 foaming for three processing speeds, in decreasing order (1) > (2) > (3) [37]

Besides H_2 evolution and foaming, the shield gas Ar is an additional help for the formation of the porosity and may also become trapped inside the solidified foam. In the conventional thermal melting process, the average temperature gradient of the interface varies as the bulk temperature is lower. This is accompanied by a slow cooling rate and hence a long time for the stabilization of the pores to occur. However, in the case of laser process the average temperature gradient of the interface is much higher, thus, a faster cooling rate results in the pore stabilization. Figure 10 also illustrates, as to how the processing speed could affect the cell morphology and the expansion ratio of the buildup foam.

The foamable Al-alloy sandwich samples fabricated according to the P/M procedure are used in this technique. Porous structures with relative densities of 0.33-0.39 and porosity of (61-67%) can be fabricated by using this method.

1.3 Stress- strain behaviour of metal foam

Metal foam possesses both uniaxial tensile as well as compressive behaviour.Figure-22 shows the stress strain curve.

During compression, it is characterized by plateau [38-4]. Plateau means at a constant stress material compressed with large strain. It shows linear elastic behaviour within elastic limit. First peak of plateau means cells start to collapse, the stress corresponding to this point is known as plastic collapse or plateau stress [41-45]. At a large strain value all the pores touch to each other that point is densification point ε_d.

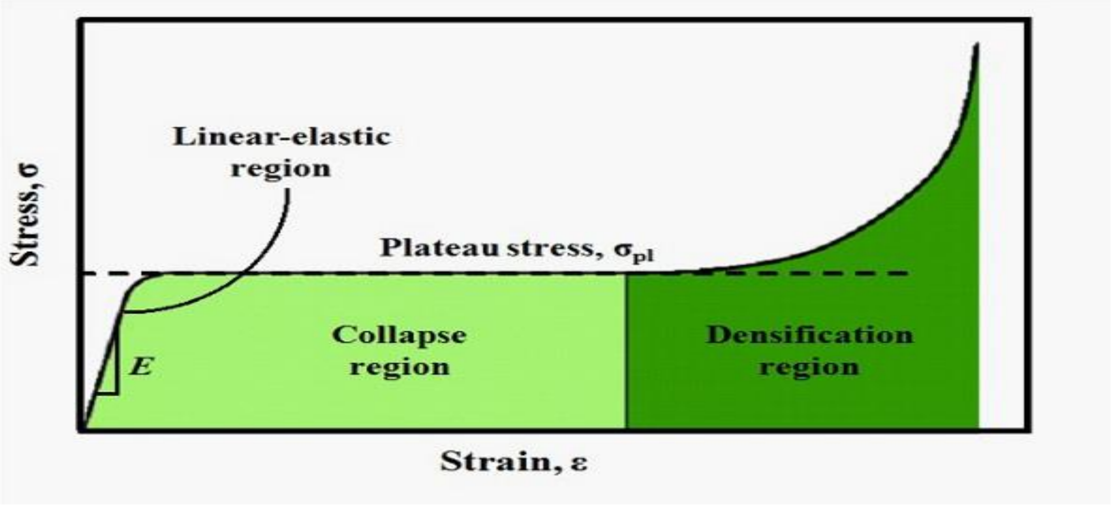

Fig. 22.Typical stress strain curve for metal foam in compression [44]

1.4 Applications

These foams have combined physical and mechanical properties [45]. Foams can be used in aerospace application because of their low density and high strength.

Foam has potential to absorb impact energy when a vehicle crashes either against another vehicle. Because it effectively absorbs impact and energy dissipates during deformation of material [3]. Thus, they can be used automobile vehicles and aircrafts where high impact absorption is needed. Also they can be used as crash barriers and in blast mitigators to absorb impact.

They can be used in automotive, railway and aerospace industries where weight reduction and improvement in comfort is requirement.

They can be used as electronic component packaging, cores for structural sandwich panels, and sound and energy absorption appliances. Because metallic foams have high structural efficiency at low cost.

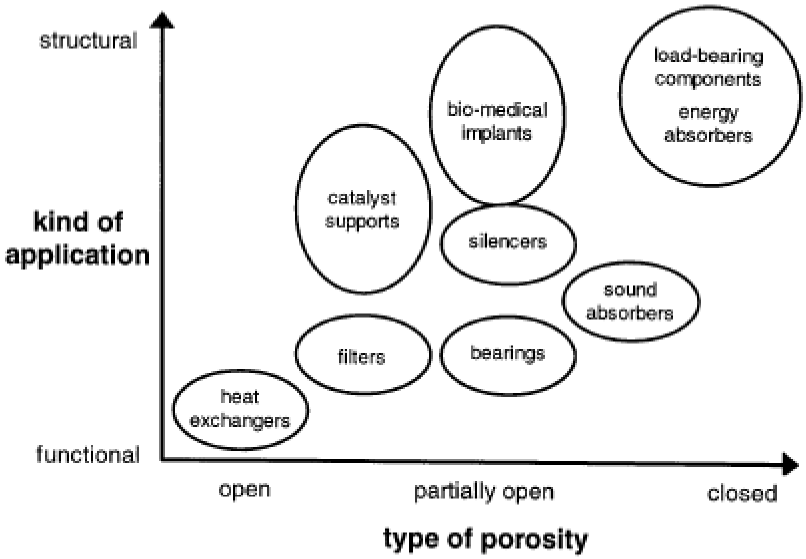

Fig. 23. Applications of cellular metals grouped according to the degree of ‘‘openness’’ needed and whether the application is more functional or structural[45].

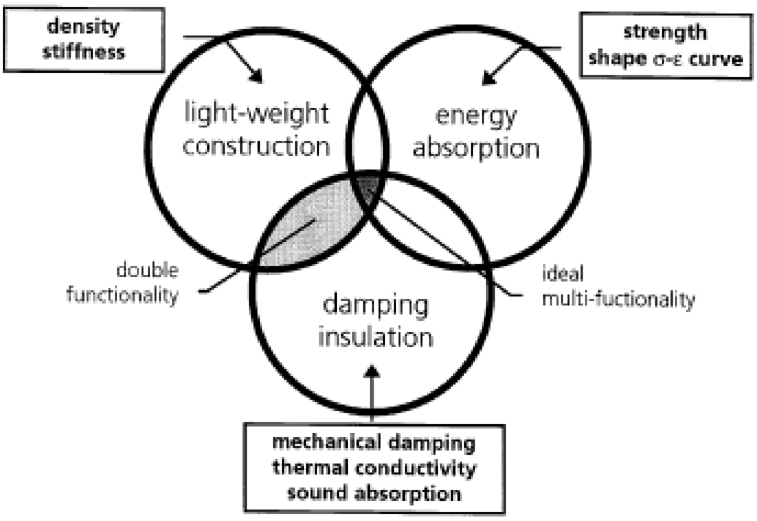

Fig. 24.Main automotive application fields of structural metal foams[46]

In Fig. 24 summarises the three application fields for metal foams, mostly aluminium foams, in the automotive industry. The inner circles represent the three fields which have to be distinguished and the outer boxes illustrate the foam properties which are responsible for the advantage in the given field. An ideal application would be a part which served as a light-weight panel, absorbed energy in crash situations and carried sound or heat absorbing functions (intersection of the three circles in Fig. 24). Such multifunctional applications are, of course, difficult to find and one often would be satisfied with finding a two-fold application where, e.g., a structural light-weight panel served as a sound absorber at the same time.

CHAPTER-2
Literature review

2.1 Introduction

In the present work only closed cell aluminium metal foam (Alporas) is synthesized and characterized. For this need to discuss different manufacturing route and properties are discussed.

2.2 Manufacturing of alporas metal foam

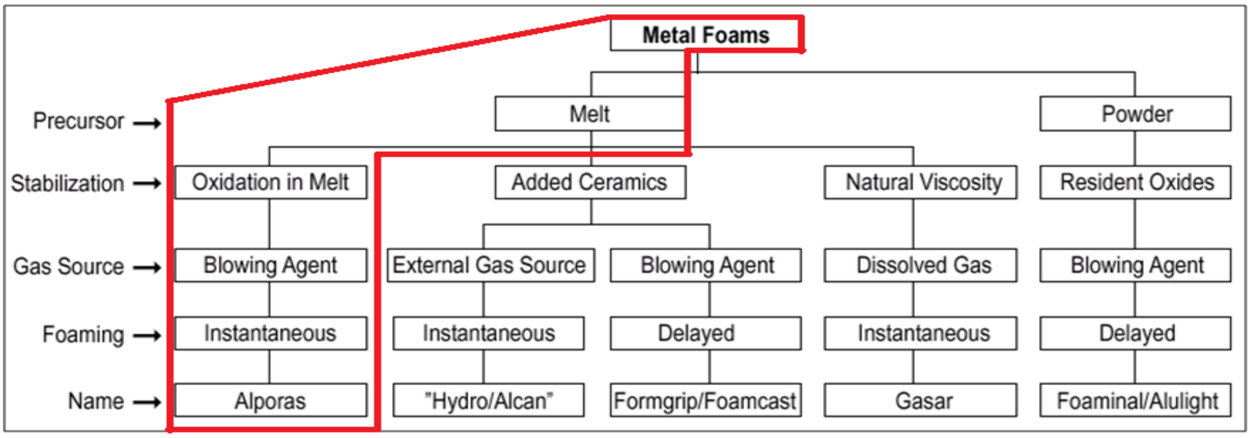

Fig.25. Different methods of foam making, [28]

2.2.1 Stirring of a foaming agent into molten alloy

In this method blowing agent (as $CaCO_3$, TiH_2, etc.) is added to molten metal (Al alloy)[46,47]. It is stirred so that blowing agent uniformly mixes within molten metal and decomposes due to heat and liberates gas. The gas is entrapped in molten melt which produce ALPORAS^{TM} foam [48,49]. In 1951, John C. Elliott proposes to use TiH_2 or ZrH_2 as blowing agent.

Viscosity is important parameter to control the structure of foam. For stabilization of melt mostly calcium granules are added to molten metal. This forms $AlCaO_x$ and some compound which increases the viscosity of molten metal [52,53]. Due to Stirring of molten metal which increase availability large amount of oxygen can increase the apparent viscosity by forming aluminium oxide which is acts as a stabilizing agent. Apparent viscosity of the molten metal increase as stirring time increases [51].

To obtain uniform pore structure of foam, optimum viscosity required prior to adding foaming agent. Higher viscosity of molten metal reduces the formation of pores and lower viscosity results in bubbles get away through the molten metal (no trapping of gases)[54].

2.2.2 CACO3 blowing agent

a. It always compared with TiH_2 as another commercially used foaming agent because of its low cost and safe to use.

b. he decomposition temperature is higher than melting point of parent foam material. Not require any of pre-treatment (heating) to prevent premature gas.

c. Decomposition product itself and the products obtained by reaction with Al alloy are stabilizing products. Sometimes, not require to add extra thickening agent to increase the viscosity of molten metal.

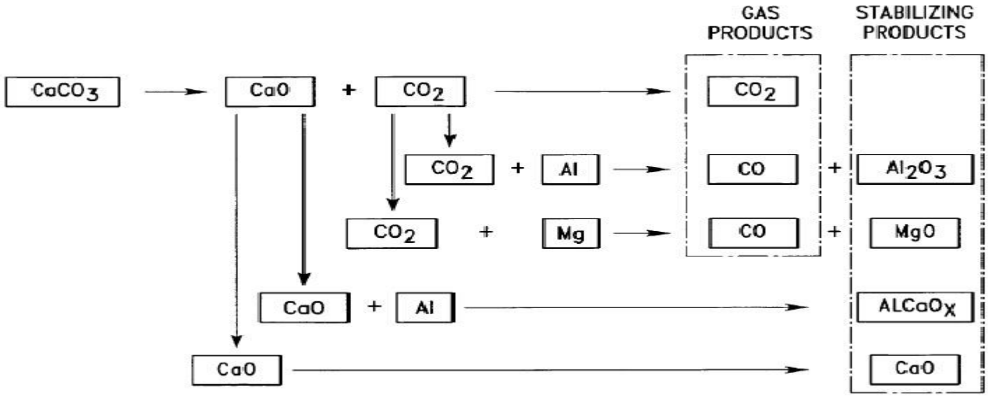

Fig. 26. Stabilizing products by decomposition of CaCO3[26]

d. Density of both foaming agent and alloy are nearly equal, helps to produce uniform density foam.
e. Higher melting point of foaming agent as compared with base foam metal Al alloy, this becomes foam production costly and also demands more and more stabilization.

2.3 Properties of metal foams

There are number parameters influences on properties of metal foam such as parent material of foam, type of structure- closed cell or open cell, relative density, pore size, etc.

a. Low density
b. High energy absorption during compression
c. Good vibration and sound absorption
d. Thermal resistant, non- flammable
e. Electrically conductive
f. Moisture resistant
g. Non toxic

2.4 Motivation and objective of the present investigation

2.4.1 Motivation

Compressive behaviour and energy absorption characteristics of alporas aluminium alloy AA2014 foam manufactured by liquid melting technique using $CaCO_3$ faming agent are not reported in any literature.

Aluminium alloy 2014 has ability to heat treated. The heat treatment effect on mechanical properties of this alloy foam is not reported in any literature.$CaCO_3$ is commercially available, cheap source of foaming agent as compared with TiH_2[35].

Alporas foam shows sensitivity at different strain rate. The strain rate sensitivity of this aluminium alloy foam is not reported in any literature [56,57].

2.4.2 Objectives

a. Synthesis of closed cell alporas aluminium alloy AA2014 foam using liquid meting technique.
b. Characterization of foam at different strain rate to show sensitivity
c. Compression behavior of alporas foam

CHAPTER-3
Experimental technique

3.1 Introduction

This chapter gives detailed experimental technique and procedures used for synthesis and their characterization of closed cell Alporas metal foam.

3.2 Synthesis of closed cell aluminium alloy AA 2014 alporas foam

The AA 2014aluminium alloy alporas foam was synthesized by liquid melting technique using $CaCO_3$ as a foaming agent.

a. Selection of material
b. Details of furnace used for foaming
c. Selection of Furnace Temperature
d. Addition of calcium carbonate and Calcium
e. Solidification of foam
f. Parameters taken for successful foaming
g. Cutting of foams for making samples

3.2.1 Material selection

AA 2014 aluminium alloy is parent metal used to manufacture the alloy foam. This is the alloy of 2000 aluminium metal series, having Cu is main alloying element present in this material. It is also called aluminium copper alloy [54]. It has high compressive strength and ability to heat treated. Chemical composition of this alloy is shown in table -1.

The behaviour of this type of alporas foam is sensitive to strain rate is not reported in any literature. This foam is studied at different strain rate. Fatigue and creep behaviour of this alloy foam is not reported in the literature.

The AA2014 is procured from a local vendor and is analyzed by spectroscopy. The chemical composition was analyzed.

	Cu	**Si**	**Mg**	**Fe**	**Mn**	**Al and other**
Present	4.63	1.09	0.63	0.26	0.88	Remainder
Standard	3.9-5.0	0.5-1.2	0.2-0.8	0.7 max	0.4-1.2	Remainder

Table 1-Chemical composition of AA 2014 (in wt %)

The chemical composition AA 2014 available in literature [54] and it is compared with present.

3.2.2 Details of furnace used for foaming

Furnace designed by khan (2011) for aluminium foam production is being used for foaming [39]. The capacity of furnace is 1 kg of aluminium. There is a melt stirring facility attached to furnace by removable motorized stirrer. It has a digital controller for temperature control in the furnace. The furnace consists of heating chamber, which is an alumina muffle of 200 mm × 200 mm × 300 mm with door size 150 mm × 150 mm. It is heated by electrical resistance wire. The furnace is insulated by asbestos sheet from all sides. Small opening is provided to insert the stirrer. Stirrer motor is fixed on bracket, which has maximum speed 1200 rpm and that motor along with bracket can be move up and down as required. A graphite crucible is used to melt aluminum. The top portion is covered by glass wool to trap the heat loss.

Fig. 27. Furnace used for making aluminium foam[39]

3.2.3 Crucible used for foaming

Graphite crucible is used for aluminium foam preparation. It has diameter of 150 mm at the top and 100 mm at bottom with height of crucible 200 mm. The crucible can handle 1kg of molten aluminium for foaming

3.2.4 Selection of furnace temperature

The temperature in the furnace is decided from melting points of alloy or foaming agent.

The calcium carbonate procured from market, whose details are-

Sigma Aldrich, calcium carbonate powder, product no. 239216, ACS reagent, ≥99.0%

The complete decomposition temperature of CaCO3 was found out to be around 800°C[58].This decomposition temperature is verified by safety data sheet given by $CaCO_3$of Sigma Aldrich Company.

Melting point of Aluminium alloy-650 °C (web reference)

Therefore, the melting point of foaming agent calcium carbonate (complete decomposition temp.) is higher than aluminium alloy. Thus, temperature of the furnace decided to for manufacturing of above foam is 900 °C.

3.2.5 Foaming by calcium carbonate and addition of calcium

Calcium carbonate powder decomposes due to heating produces CO_2 gases and CaO. It is an endothermic reaction.

$$CaCO_3\ (\text{Solid}) \xrightarrow{\blacktriangle} CaO\ (\text{Solid}) + CO_2\ (\text{Gas})$$

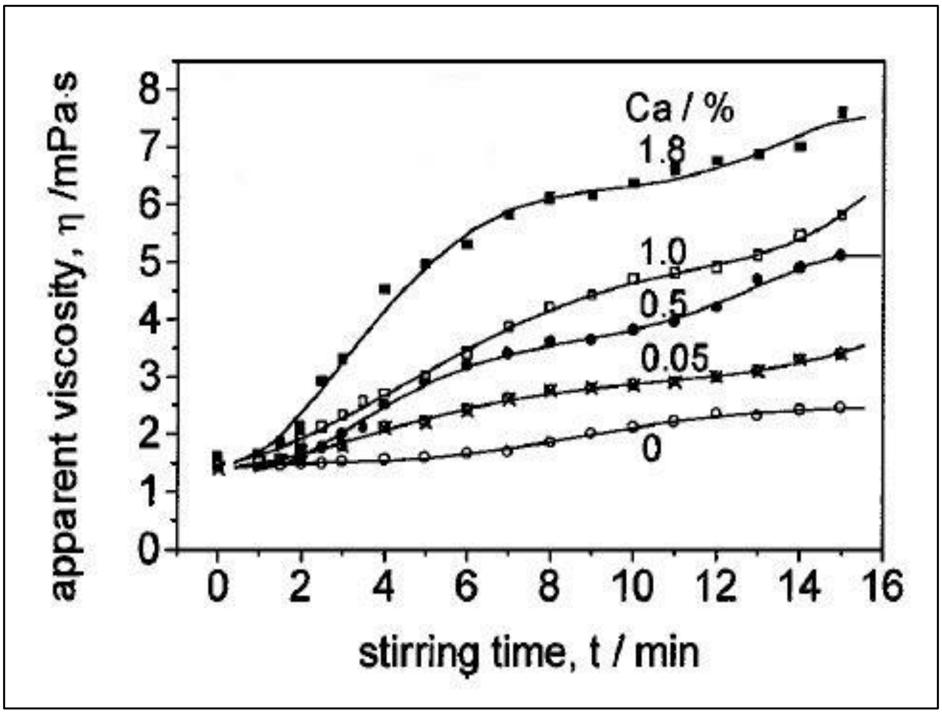

Fig. 28.Variation of Ca and stirring time with apparent viscosity [52]

In the closed cell aluminium foam, this CaO present cell walls and cell contains CO_2 gas. For addition of calcium carbonate powder, aluminium foil is used so that it should not float on the top of molten metal.

Calcium granules, Sigma Aldrich, product no.215147 procured and it is mainly used to maintain proper viscosity by producing number of stabilizing products as shown below.

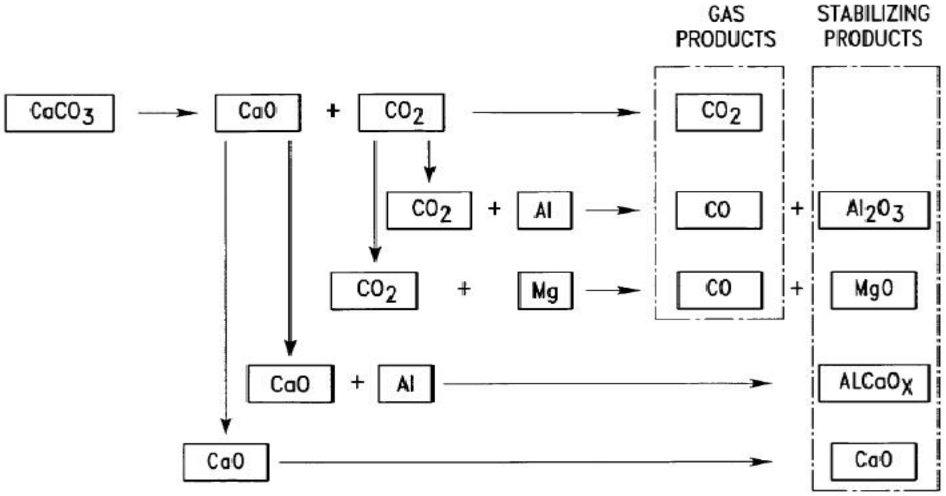

Fig. 29. Stabilizing products by decomposition of $CaCO_3$[47]

3.2.6 Stirring of AA2014 molten metal

For manufacturing of aluminium foams, Ca granules as melt thickening agent and $CaCO_3$ powder as gaseous source were added. The stirrer is required for making proper distribution to get homogeneous melt after addition of Ca granules and $CaCO_3$ powder. The graphite stirrer was used to stir molten metal. It avoids diffusion any stirrer composition elements into the aluminium alloy melt

3.2.7 Solidification of foam

Once the foaming is completed crucible containing foam is quenched directly into the water. To avoid damage due to water if enters into the pores, crucible is immersed inside the water. After cooling of foam, the foam is taken out of crucible for analysis.

Fig. 30. Foams developed

3.2.8 Parameters taken for successful alporas aluminium alloy AA2014 foam

In the beginning there are number of examples of failure. Initially few experiments were conducted which shows foams failure in figure 31. These experiments finally lead to optimal set of parameters for gives good quality of foams.

Fig. 31.Few failure experiment foams result

.

Aluminium alloy 2014	
Stirring time	15 min
Amount of calcium granules	0 - 0.3 wt % AA
Amount of calcium carbonate powder	3 - 5 wt % AA
Stirring speed	1200 rpm
Foaming time	2 min

Table 2-Parameters taken for successful foaming

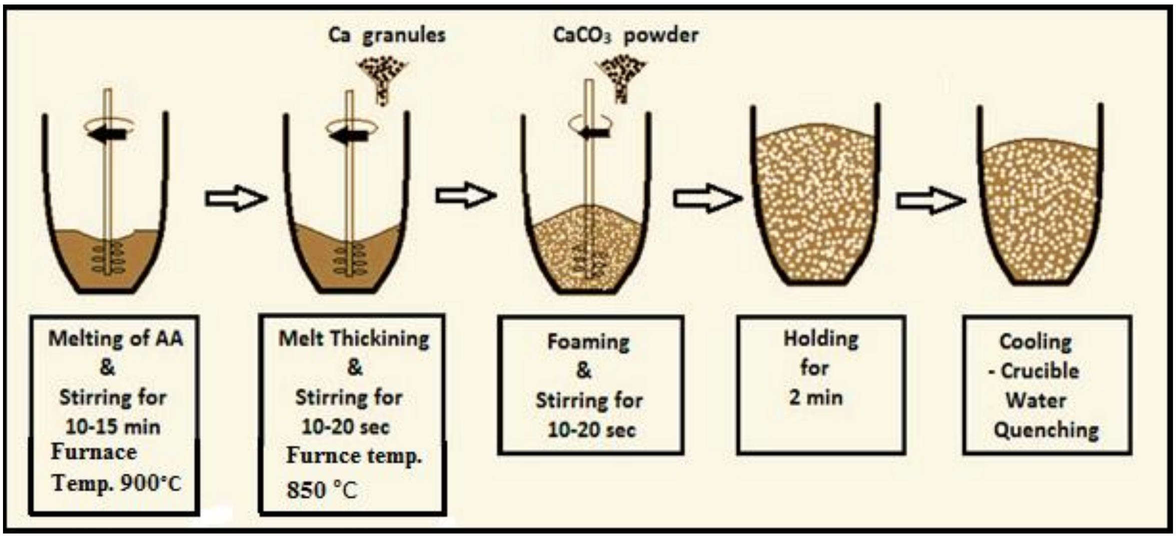

Fig. 32.Aluminium alloy 2014 foaming process by liquid melting technique using CaCO3 as a foaming agent with ‘Ca’ granules as a stabilizing agent

3.2.9 Cutting of foams

Small hand saw is used to cut foam to minimize the damage to the structure of foam (cell damage). To make samples to the perfect size of the foam, little amount of grinding is used. For static and intermediate compression

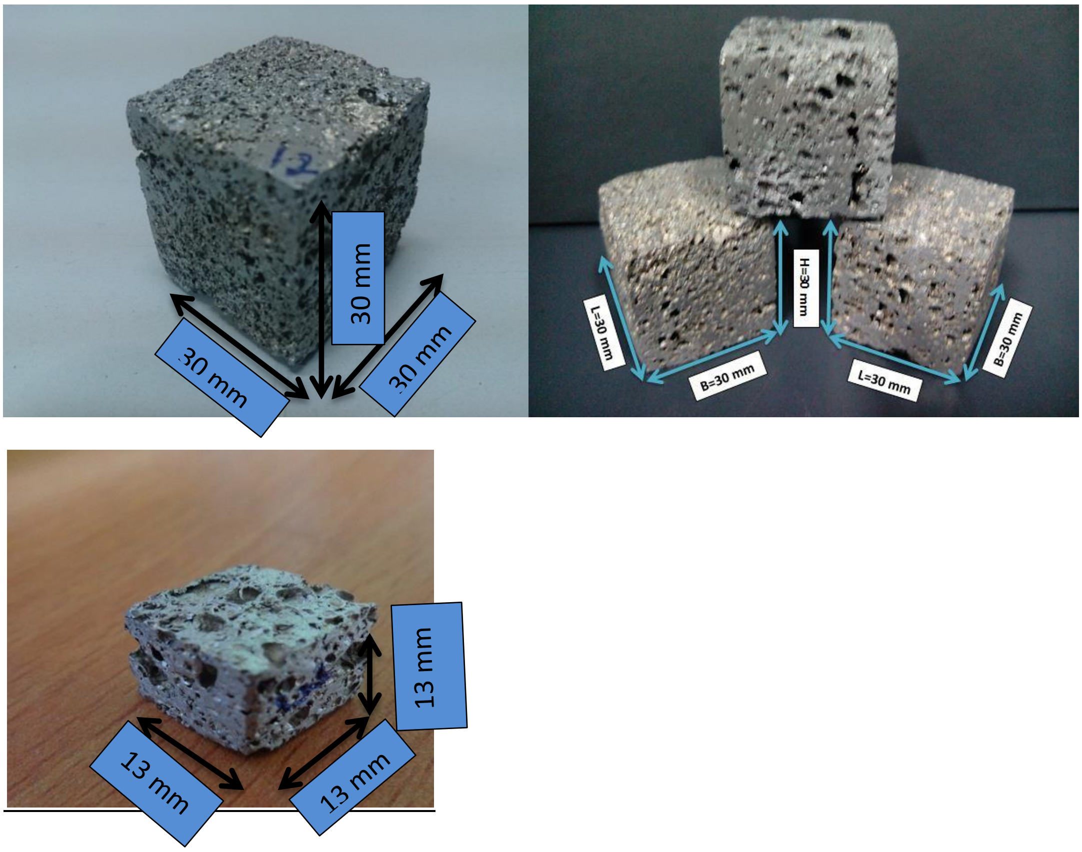

Fig. 33.Aluminium foam samples for testing

3.3 Quasi static compression

The aluminium alporas foams were tested in compression at quasi-static rate on MTS 810 material tests system. This material test system is versatile, multipurpose servo hydraulic testing system for static and dynamic loading conditions can test a wide range of materials in tension or compression. The load capacity is having in the range 25 KN to 250 KN. It has ability to test the materials ranging in strength from plastic to aluminium and composite to steel. A large test space is available to accommodate standard, medium and large size specimens, grips, fixtures and environmental subsystem. It has capability to perform a wide range of testing tensile, compression to high cycle fatigue, fracture mechanics and durability of component.

An integral actuator design, stiff, low-mass crossheads, and special force transducers deliver superior axial and lateral stiffness. Precision-machined columns and actuator rods, and laser-guided factory alignment ensure unprecedented alignment accuracy. Highly accurate MTS load cells exhibit low hysteresis and long-term stability. Linear Variable Differential Transducers mounted co-axially with actuators deliver precise actuator position measurement.

Quasi static compression tests were conducted on alporasaluminium foam samples at a strain rate of 2.7×10^{-4}/s. The size of the sample was $30 \times 30 \times 30$ mm^3.

Fig. 34.MTS 810 material test system used for quasi static compression

CHAPTER-4
Mechanical behaviour

4.1 Introduction

In this chapter we discuss the mechanical behaviour of alporas aluminium alloy AA2014 foams, which synthesized by liquid foaming technique using $CaCO_3$ as a gas blowing agent.

4.2 Analysis of foam under compression behaviour

Compressive behaviour of alporas foams are studied strain rate from $2.7 \times 10^{-4}s^{-1}$to$700s^{-1}$. The foams are studied at very slow rate (quasi static process), dynamic process- intermediate and high strain rate.

4.2.1 Pore Size Measurement

The relative density of foams is obtained by measuring weight of alporas foam sample and it is divided by product of density and volume of AA2014 base metal

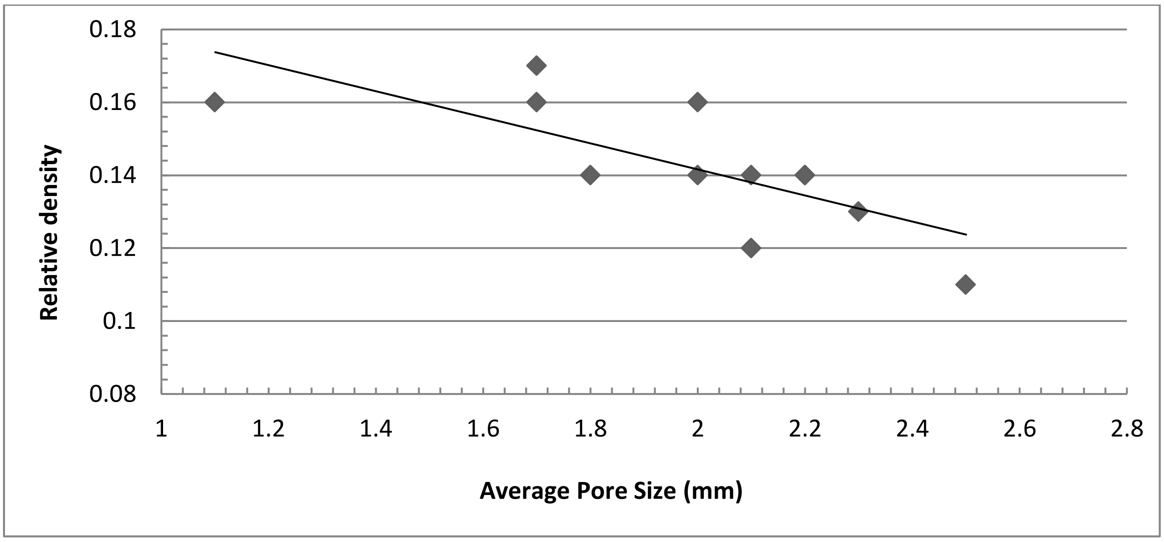

Fig. 35. Variation of relative density and pore size

The average pore size of closed cell AA2014 alporas foam is obtained by measuring number of pores in unit length. From figure 35, it is clear that as pore size of foam sample increases the relative density decreases

4.2.2 Scanning electron microscopy and energy dispersive system result

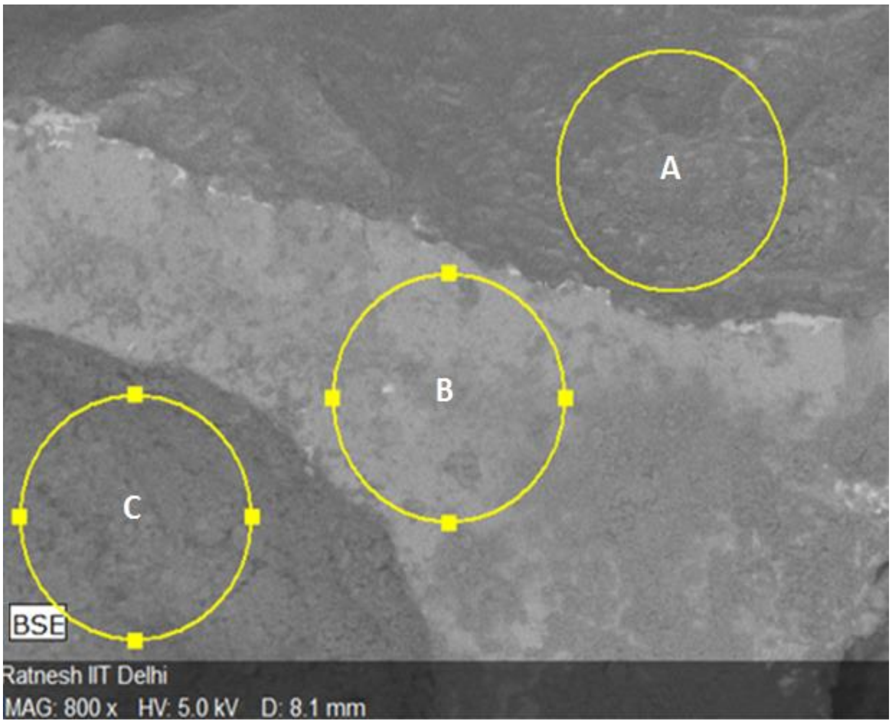

Fig. 36. Back scattered SEM image of cell wall

EDS Pattern and Mass Percentage at A, B, C areas in SEM Image of cell wall & of Present Alloying Elements in AA2014 Alporas Foam

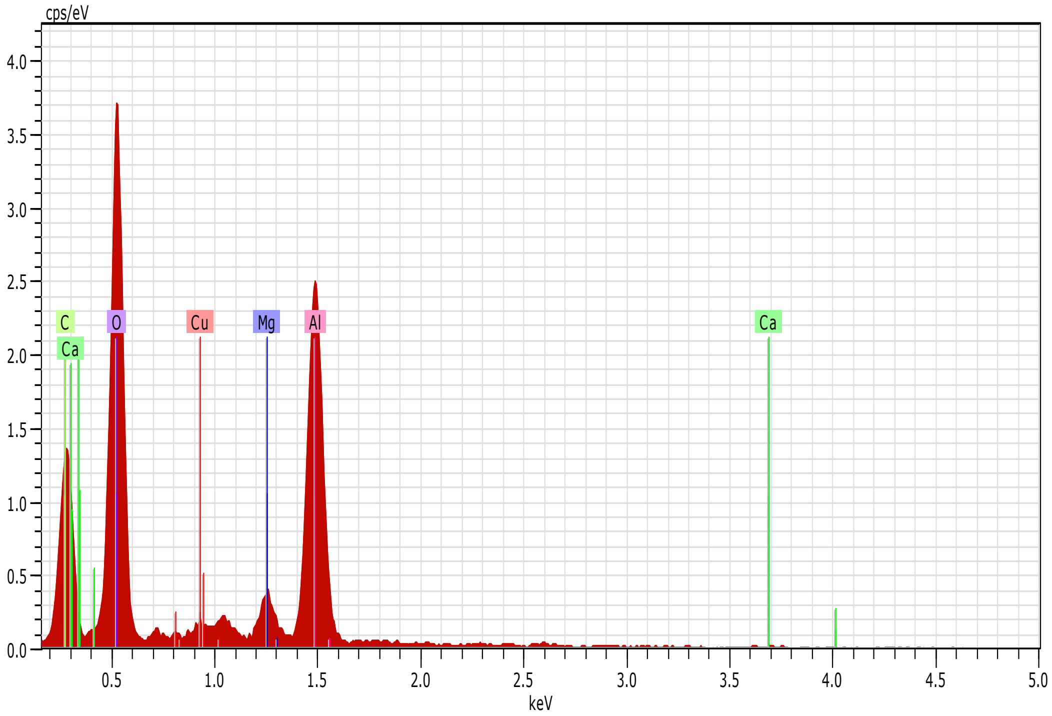

Fig. 37.EDS pattern of AA 2014 at area 'A'

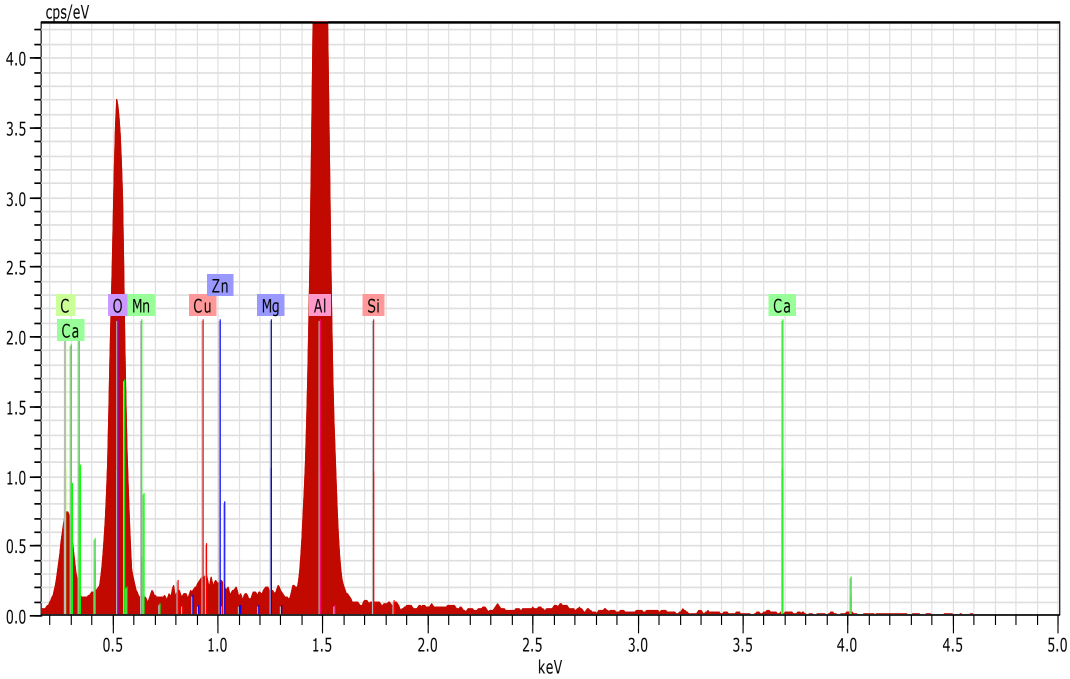

Fig. 38.EDS pattern for AA2014 at area ‘B’

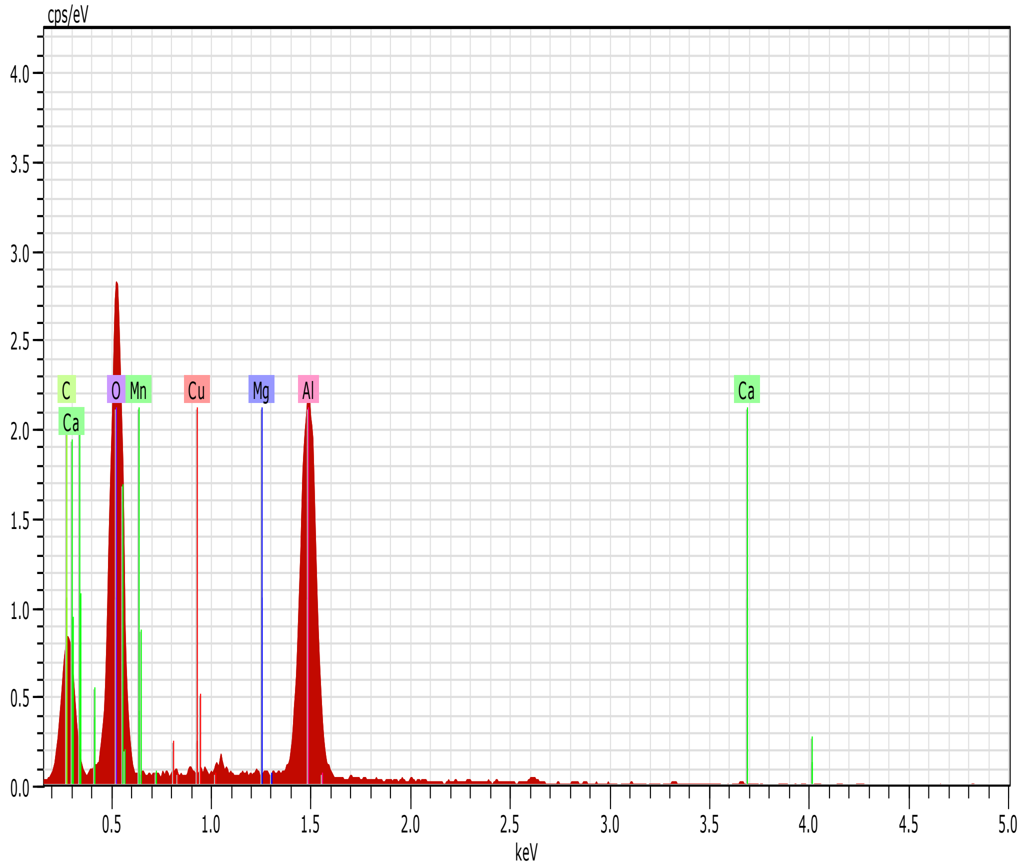

Fig. 39.EDS pattern for AA2014 a ‘C’ position

From figures 37,38, 39 it can be seen that at A, B, C areas i.e. within pores significant peaks of Ca, O_2, Al, C are seen, which may be CaO,Al_2O_3, Al_4C_3, Al_2Ca, etc. Within cell wall area, Cu, Mg, Mn, Zn and Si small peaks are seen which may be intermetallic compounds of Al-Cu, $MgAl_2O_4$, etc

4.2.3 Quasi static compression test

MTS 810 material test system was used for quasi static compression test. The specimen size for performing this test was square base of 30×30 mm^2 and 30mm in height. The cross head speed set was 0.5 mm/min. this corresponds to 2.7×10^{-4} s^{-1}.

The test rate was set kept 1 mm/min. The relative densities of the foam samples were in the range 0.1 to 0.16.

The stress strain curve for closed cell alporas aluminium alloy AA2014 foam with different relative density is shown in fig27.

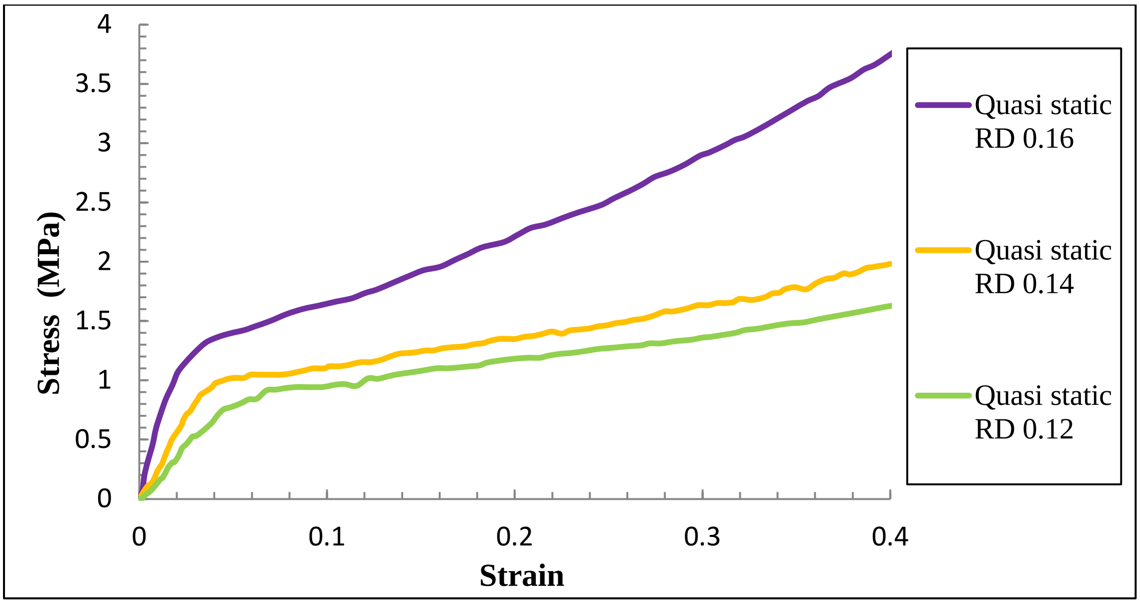

Fig. 40.Stress strain curve for different relative density foams

From the figure, we can observe as relative density increases the stress increases

.

4.2.3.1 Plateau stress

Gibson and Ashby- equation for plateau stress considering a simple cubic model.

$$\frac{\sigma_{plateau}}{\sigma_{ys}} = 0.3\ (\varphi\frac{\rho_f}{\rho_m})^{3/2} + 0.4\ (1-\varphi)(\frac{\rho_f}{\rho_m}) + (\frac{P-P_l}{\sigma_{ys}})$$

Where, $\sigma_{plateau}$ is plateau stress, σ_{ys} is yield stress of foam parent material, φ is amount of material contained in cell edges. For closed cell foam value is equal to 1. ρ_f/ρ_m is the ratio of density of foam to density matrix material. P is inside pressure and P_l is liquid metal pressure.

First term indicates plastic bending of edges, 2nd term denotes stretching of cell walls, 3rd denotes effect of gas pressure.

For ideal closed cell foam i.e. at φ=1 and neglecting the effect gas pressure equation becomes

$$\frac{\sigma_{plateau}}{\sigma_{ys}}=0.3\ (\varphi\frac{\rho_f}{\rho_m})^{3/2}$$

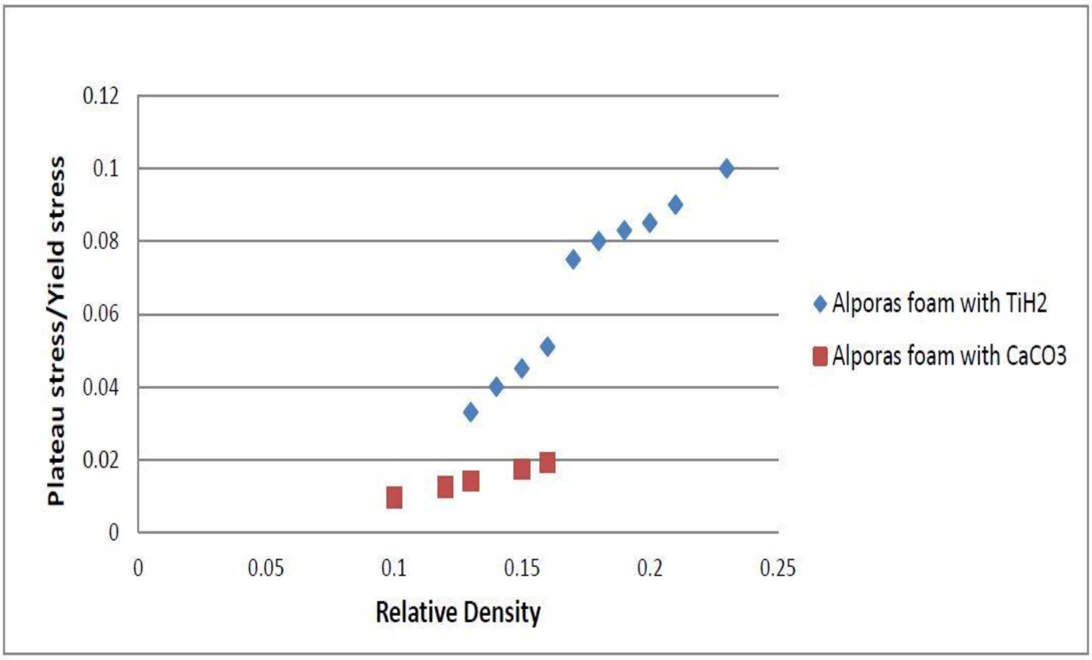

Fig. 41.Comparison of alporas aluminium foams made by TiH_2 and $CaCO_3$

4.2.3.2 Energy absorption capacity

The energy absorption capacity of alporas AA2014 foam of different relative densities up to strain rate of 40% is shown in figure. The energy absorbed by the material upto specific strain is called energy absorption capacity.

It is calculated as

$$E = \int_0^{\mathcal{E}} \sigma \, d\mathcal{E}$$

This is the area under stress strain curve.

Where, E- energy absorption capacity in MJ/m^3, Ɛ is strain up to 40%, σ is stress in N/mm^2 or MPa.

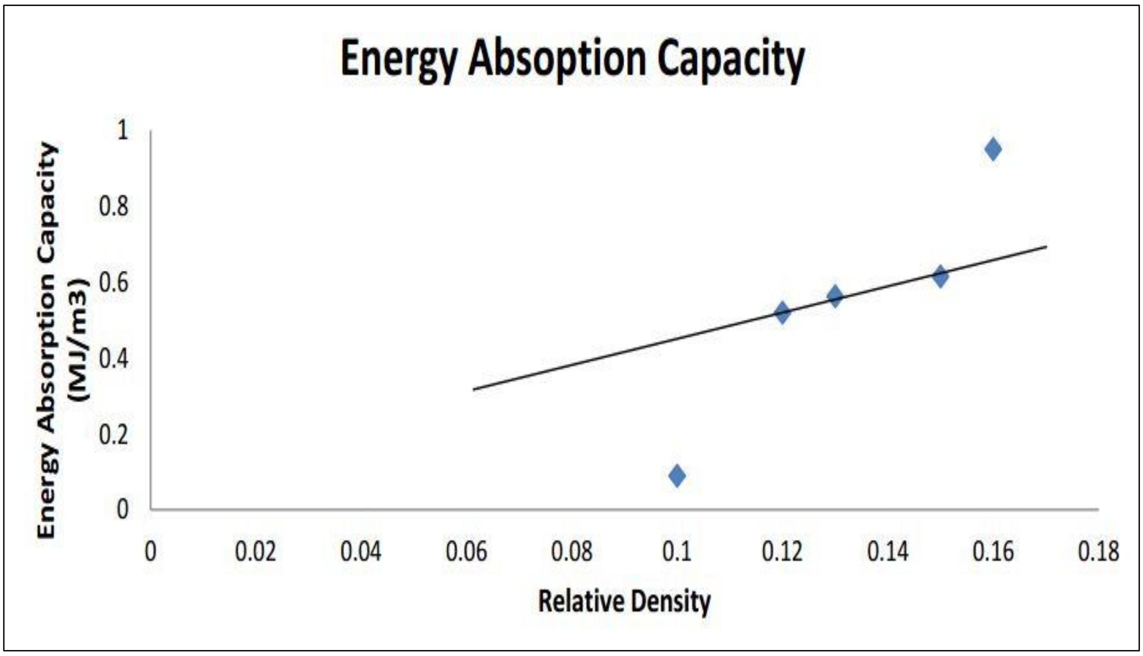

Fig. 42.Energy absorption capacity vs. relative density

From the figure it is clearly observed that, energy absorption capacity increases as relative density of foam increases. It is also say that energy absorption capacity increases as plateau stress increases.

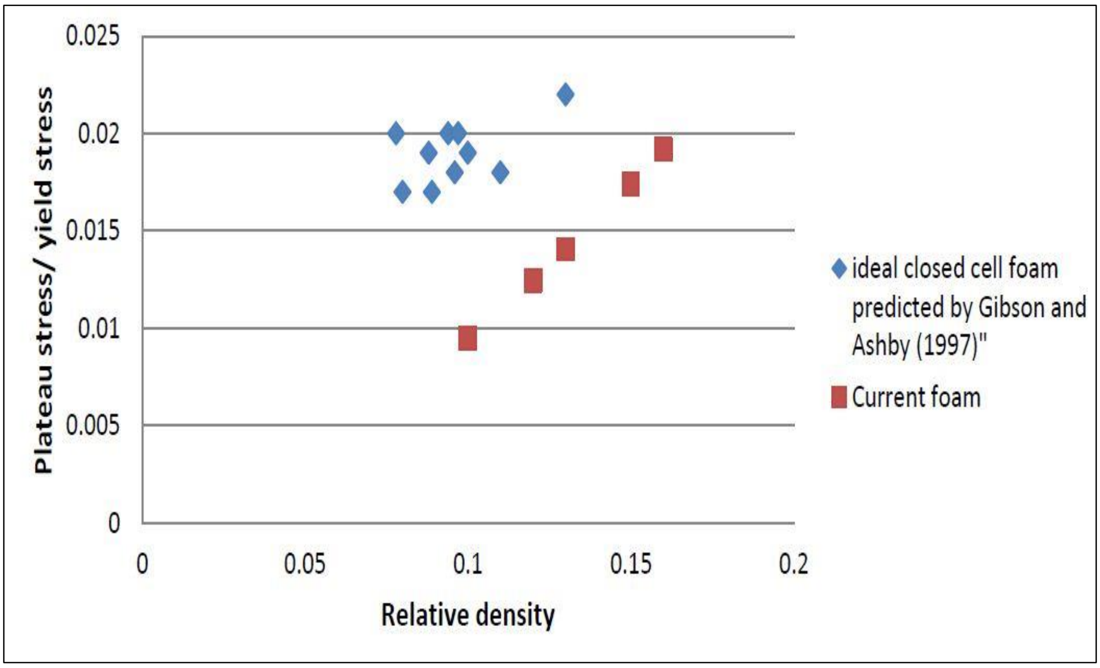

Fig. 43.Comparison between ideal closed cell foam predicted by Gibson and Ashby (1997) and current foam

CHAPTER-5

5.1Conclusion

Alporas aluminium alloy AA 2014 foam has been manufactured with different relative densities by liquid melting technique using $CaCO_3$ as a foaming agent (CO_2 gas source).

The foams developed with relative density vary from 0.12 to 0.16 and cell sizes of foams were approximately 1 to 2.5 mm. The cell size of foams increases with decrease in relative density.

Cell wall and porse cavity are analysed by SEM . EDS patterns shows that within pores significant peaks of Ca, O_2, Al, C are seen, which may be CaO,Al_2O_3, Al_4C_3, Al_2Ca, etc. Within cell wall area, Cu, Mg, Mn, Zn and Si small peaks are seen which may be intermetallic compounds of Al-Cu, $MgAl_2O_4$, etc

The quasi static compressive behaviour is analyzed and it is found that as the relative density increases plateau stress increases. The energy absorption capacity of metal foam is the area under stress strain curve, is increases as relative density increases.

As the relative density increases the pore size decreases so, maximum fraction of material present inside the cell walls of foam as decreases the relative density. The energy absorption capacity increases as the plateau stress increases.

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