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Research Article

Production of Low Cost Aluminium Foams

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Abstract

Metallic foams offer interesting perspectives due to the combination of properties which are related to the metallic character on one hand and to the porous structure on the other hand. The production of foamed aluminium has long been considered difficult to achieve because of problems such as the low formability of the molten metal, the varying size of the cellular structures, and solidification shrinkage. Aluminium foams have become popular because of their properties such as high stiffness combined with very low density .Their cellular structure causes to show unique features, such as energy absorbing capacity, thermal properties and sound absorbing properties. With these properties the aluminium foams are being used in many applications like automobile, railways, aerospace, ship building, household and furniture etc. Methods for producing metal foams are many but obtaining repeatability in the properties is very difficult. The main challenge posed by the metal foam is that obtaining homogeneous porosity. Literature reveals that producing good quality aluminium foams, both open cell and closed cell costs very high. In the light of the above the present work focuses on producing the low cost aluminium foams with better quality using CaCO3 as foaming agent in the closed cell aluminum foam and polystyrene granules as space holders in open cell aluminium foam.

Keywords: *Aluminium foam, Porosity, Aluminium Sponge.*

1. Introduction

Metal foam is a cellular structure containing porosity. If there is porosity in the metal it is actually considered a defect, but here in the metal foam the porosities in the metals are created intentionally and the porosities should be homogeneous throughout the material. The term ‘‘foam’’ is not always properly used and shall therefore need to be defined. According to which lists the designations for all possible dispersions of one phase in a second one (where each phase can be in one of the three states of matter), foams are uniform dispersions of a gaseous phase in either a liquid or a solid .The single gas inclusions are separated from each other by portions of the liquid or solid, respectively. Thus the cells are entirely enclosed by the liquid or solid and are not interconnected. The term ‘‘foam’’ in its original sense is reserved for a dispersion of gas bubbles in a liquid. The morphology of such foams, however, can be preserved by letting the liquid solidify, thus obtaining what is called a ‘‘solid foam’’. When speaking of ‘‘metallic foams’’ one generally means a solid foam. Metallic foams, particularly those of aluminium, offer a great potential for applications in the automotive industry. Foams are light weight, energy absorbing and incombustible and have good sound absorbing properties. Other applications are also possible in engineering, building, household goods and the chemical industry.J.Banhart et al has reported the methods to produce closed cell aluminium foams have been known for a number of years and can be generally separated into two fundamental groups: (i) Foaming liquid metal (casting procedures) and (ii) Foaming metallic precursors (powder metallurgy-PM procedures). Bernd Friedrich at al has reported that Metal foams can be produced by lost wax casting or casting into moulds filled with place holders as for example polystyrene balls . Nowadays metal foams are finding wide range of applications in the world but there are some problems which are holding back the usage of these foams. Some of the main problems are obtaining the repeatability in the foam, controlling of the process parameters in production is of high risk, controlling pore size, and the production cost is very hig. In the present work attempt has been made to develop aluminium foam by open cell and closed cell method to get low density, greater strength, higher hardness and homogeneous porosity aluminium foams at very low production cost. The matrix metal used here in the production of aluminium foam is Al6061 owing to its better foamability. Both the open cell and closed cell aluminium foam are produced through liquid metallurgy route. In open cell aluminium foam polystyrene granules used as space holders and in closed cell aluminium foam CaCO3 as foaming agent.

2. Experimental Details

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2.1Production of Open cell aluminium foam using polystyrene granules as space holders

Open cell porous metal sponges can be manufactured by the Casting process in which a liquid material is usually poured into the mould, which contains hollow cavity of the desired shape and then allowed to solidify.

In the scope of above process, Al6061 alloy is melted in an electric resistance melting furnace at a temperature of 750 0C. Before melting the crucible in the furnace is coated with Graphite paste, which acts as a debonding agent and resists the diffusion of iron from the crucible in to liquid Al6061. After the metal is completely melted, the impurity present in the material is removed by using Scum powder. The required quantity of Scum powder is added into the molten metal, which will bring up all the impurities present in the molten metal to the surface and can be easily removed leaving the pure molten metal into the crucible. While melting Al6061, lots of dissolved gases will be present in the molten metal. Since we are producing porous material called Aluminium foam, the degassing process is eliminated in the casting procedure. By eliminating the degassing technique, we can enhance the porosity of the final casted product.

Preparation of Mould

Mould is coated with graphite paste for easy removal of casting. The polystyrene granules/ Space holders (90% volume of mould) are placed in the mould and molten metal is poured in to the mould at a temperature of 800^0C. The space between the granules is occupied by the molten aluminium. After solidification, the aluminium billet with polystyrene space holders present in it and is tapped and removed from the mouldbox.The obtained casting is placed in the furnace and heated to a temperature of 450^0c which is less than melting temperature of aluminium (660^0C) and more than melting temperature of polystyrene (240^0C). By doing this all the polystyrene granules present in the casted aluminium billet gets melted and it can be removed leaving only porous aluminiumin the casting.

Fig 2.1. Production of open cell aluminium foam.

2.2Production of closed cell aluminium foams using $CaCO_3$ as foaming agent

In production of closed cell aluminium foam, the foaming agent is directly added to the aluminium melt. Al6061 alloy is melted in an electric resistance melting furnace at a temperature of 7500C. The furnace is switched off for some time to reduce the melt temperature because the reinforcement of CaCo3 into the melt is easy when the molten metal is in semisolid state and then again the temperature is raised to 7000 C. Once this temperature is reached, the melt is stirred using a mechanical stirrer.

The Foaming agent decomposes under the influence of heat and releases gas which then propels the foaming process. After this, CaCO3 is added (typically 8wt %) which acts as a blowing agent as it releases gas. The melt is stirred for several minutes at approximately 200 rpm which thickens the liquid metal. The liquid metal with CaCo3 reinforced in the alloy is poured in the mould. Once the melt gets solidified the billet is placed in the furnace at 400 degree centigrade for 20 minutes and the billet starts expanding. Foaming of aluminium alloys and aluminium-based composites with CaCO3 blowing agent is caused by the thermal decomposition of calcium carbonate in contact with molten aluminium at temperatures above 700 °C. The foams produced this way - trade name Alporas – have a very uniform porous structure.

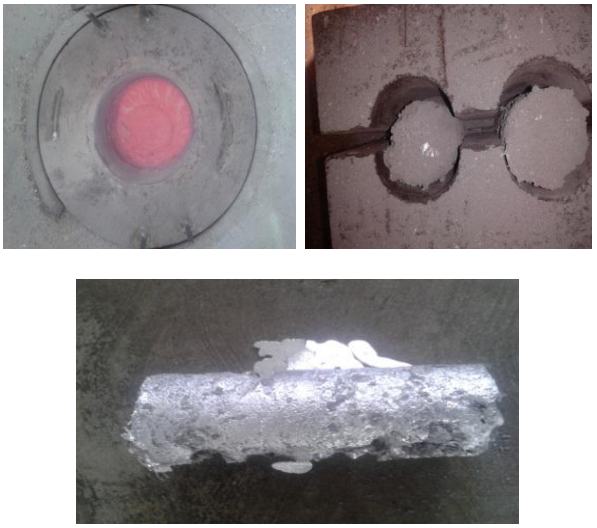


Fig 2.2. Production of closed cell aluminium foam.

Foaming of aluminium alloys with $CaCO_3$blowing agent is caused by the thermal decomposition of calcium carbonate in contact with molten aluminium at temperature above 7000C. The overall chemical reaction is complex, consisting of several successive reactions which lead to the formation of various solid (CaO, $Al2O_3$, Al4C3) and gaseous phases (CO_2, CO).

The decomposition of $CaCO_3$is usually described by
$CaCO_3=CaO(5)+CO_2(g)$ (1)

Theoretically, under normal atmospheric pressure the thermal decomposition of pure $CaCO_3$ is thermodynamically favorable only at temperatures above 9000 C. However, note that in the real system, chemical

conversion occurs at the interface of CaCO3and liquid or semi-solid aluminium. Hence, in order to investigate the real process of foaming additional chemical reactions should be also considered. Here only three possible ones are listed, although several others also reported.

$2Al(I)+3CO2(g)=Al2O3(s)+3CO(g)$ (2)

$8Al(I)+3CO2(g)=2Al2O3(g)+Al4C3(s)$ (3)

$6Al(I)+3C2(g)=2Al2O3(g)+Al4C3(s)$ (4)

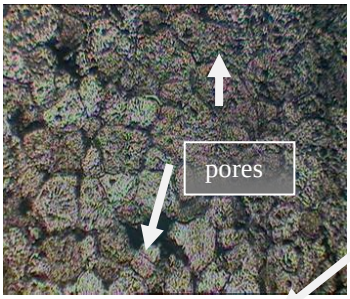
Reactions (2)-(4) are all thermodynamically favorable, even at temperatures significantly below the melting point of aluminium.

3) Results and Discussion

3.1 Microstructure Studies of Open Cell Aluminium Sponge

Figure 3.1(b) shows the microstructure of the developed aluminium foam using polystyrene granules as space holders. The microstructures clearly reveal that there is visible porosity in the developed cast aluminium sponge, whereas the parent material is completely free from porosity.

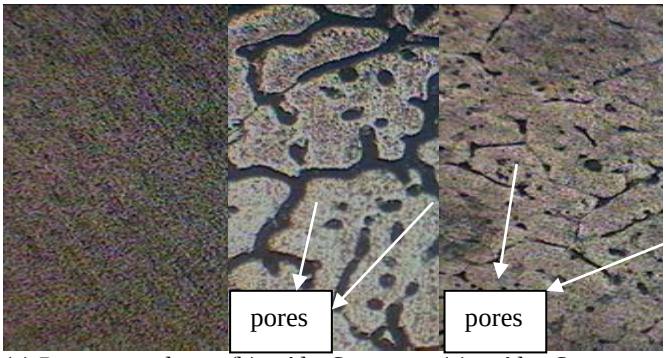
(a)Optical microscope image of parent metal



(b)Optical microscope image of open cell Sponge

Fig 3.1 Microstructure images of open cell Aluminium foam

3.2 Microstructure studies of Closed Cell Aluminium Sponge



(a) Parent metal (b) Al Sponge with8% $CaCO_3$ (c) Al Sponge with 10% $CaCO_3$

Fig 3.2 Microstructure images of closed cell Aluminium foam

Figure 3.2 Show the microstructure of developed aluminium foam using CaCO3 as foaming agent. The microstructures clearly reveal that there is visible porosity in the developed cast aluminium sponge, where as the parent material is completely free from porosity.

3.3 Density and porosity

Figure3. 3 reveal that there is a reduction in the density of the developed sponges when compared with base alloy. There is reduction in density of 19.12% and 21.17% is observed in closed cell Al-sponge and open cell Al-sponge respectively when compared Al6061 parent material. This can be attributed to the fact that the developed sponge processes higher porosities when compared with parent material.

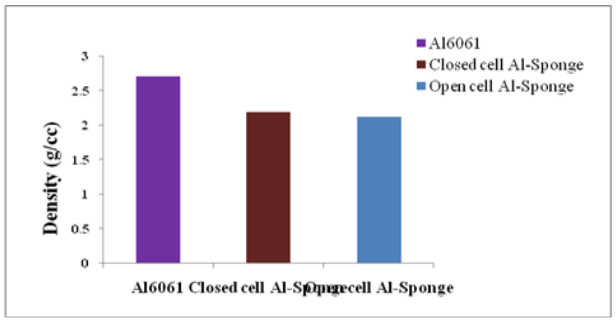


Fig3.3 Variation of densities in Al6061 parent metal and developed Al6061 sponges

Figure3.4 reveals that, when compared with base alloy there is a reduction in the densities of the developed sponges using 8wt%$CaCo_3$ and 10wt%$CaCo_3$ as foaming agent. This can be attributed to the fact that the developed sponge processes higher porosities when compared with parent material

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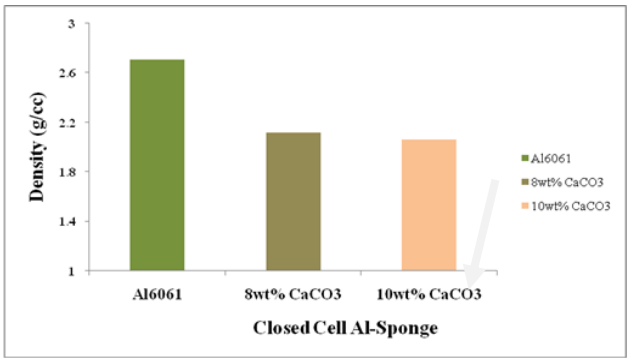

Fig 3.4 Variation of density in Al6061 parent metal and developed Al6061 sponge materials with varying percentage of $CaCO_3$

From the Fig 3.5, it is observed that the percentage porosity in open cell aluminium foam is 21.771% and closed cell aluminium foam is 19.18%. Considerable amount of porosity was achieved in both the open cell foam and closed cell foam.

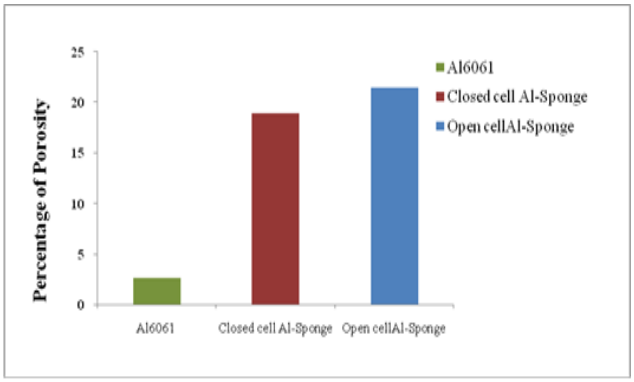

Fig 3.5 variation of porosity in Al6061 alloy and developed Al sponge

3.4 Micro hardness

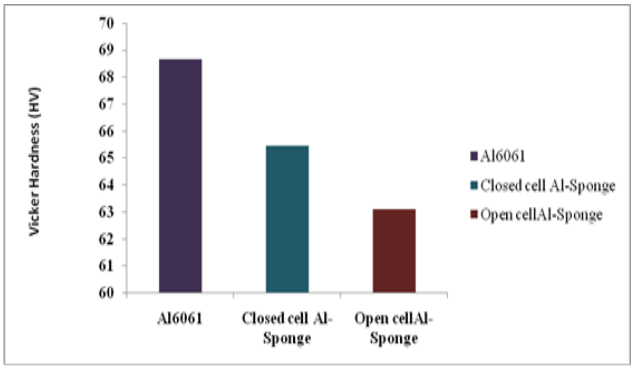

Fig 3.6 variation of Micro hardness in Al6061 parent metal and developed Al sponges

From the Fig 3.6, it is observed that there is marginal reduction in hardness of developed Al sponges when compared with Al6061 alloy.

3.5 Pin on Disk Wear Test

Table 3.1 Wear test results

Trial no	1	2	3
Initial weight w1 in gm	4.8	4.76	4.707
Final weight $w_2$in gm	4.76	4.707	4.675
Speed in rpm	500	400	300
Applied load in kg	1	2	3
Initial length L_1 in mm	27.6	27.2	26.8
Final length L2 in mm	27.2	26.8	26.4
Frictional force Fr (N)	1.66	1.93	1.98
Co-efficient of friction (μ)	0.338	0.196	0.134

The aluminium foam produced has a low coefficient of friction of 0.222 which implies that the material will have a low wear rate.

Effect of the applied load on coefficient of friction

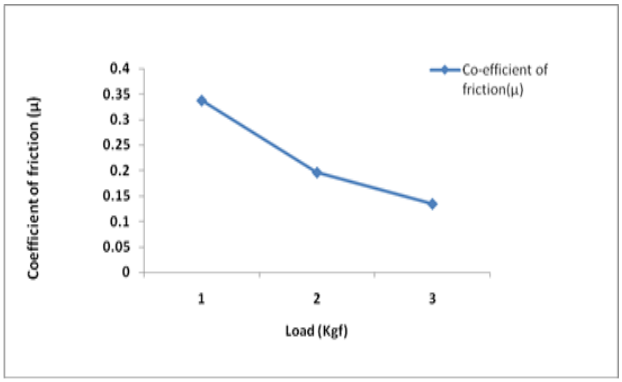

Fig 3.7 Variation of Coefficient of friction (μ) with applied load

Effect of speed on coefficient of friction

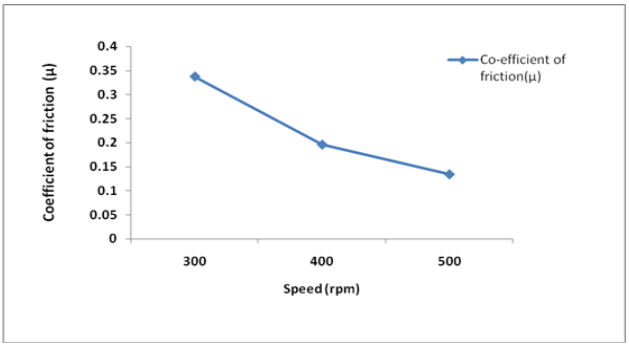

Fig 3.8 Variation of Coefficient of friction (μ) with speed

3.6 Corrosion Test

Factors affecting the rate of corrosion are environment, concentration, temperature, solution velocity. We followed weight loss technique in thismethod. The corrosion rate is determined by making use of the weight loss data of specimen in specific corroding environment.

The following expression is used to calculate the corrosion rate in terms of
C.R =534WL/ ρ AT
C.R = Corrosion rate in mils per year
WL =weight loss in grams
ρ = Density of the test material gm/cm^3
A=Area exposed in cm^2
T= Time (hours)
C.R=534×0.017/(2.19×72×24)
= 9.078/3782
C.R=0.0023 g/h

Fig 3.9 Corrosion Test Specimen

Conclusion

1) The Aluminium sponge is successfully produced economically by closed cell as well as open cell method in research laboratory with good quality.
2) Percentage porosity of 21.771% and is obtained for open cell Aluminum foam.
3) Percentage porosity of 19.18% and is obtained for closed cell Aluminium foam.
4) TiH_2powder as foaming agent is successfully replaced by commercial $CaCO_3$ powder in closed cell Aluminium sponge production.
5) Polystyrene granules as space holders are better utilized for open cell Aluminium sponge production.
6) From the experimental findings it is obvious that the properties of Aluminium sponge significantly depend on its porosity, which means that a desired property can be tailored by the sponge density.
7) The experimental findings prove that the microstructure and hardness of the Aluminium sponge conforms to required standards.
8) Production cost is reduced drastically.
9) Quality of the aluminium sponge is up to required standards.
10) Co-efficient of friction of the foam is considerably low which makes it fit for automotive applications.
11) The Corrosion and wear rate of produced Aluminium sponge is low.

Scope of Future Work

By utilizing the materials like polystyrene, $CaCO_3$we have made an attempt to obtain the Aluminium sponge with good foam structure. As the metal foam producing is challenging process, there is lot of scope in this area and in future using the experience from past experiments, utilizing the available resources effectively we can develop the Aluminium metal sponges with higher quality. Further the polystyrene granules as space holders in open cell sponges and $CaCO_3$ as foaming agent in closed cell aluminium sponges can be used in the powder metallurgy route and sponge can be produced.

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