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Role of visual examination and microstructure examination in development of Al-Si Alloy Foam

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ABSTRACT

Aluminium foams are two phase systems which are not thermodynamically stable. These consists of large gas volume which is dispersed in small liquid or solid volume. The porosity in the foam may be spherical or polyhedral depending upon the foaming agent, concentration of foaming agent, temperature and method of foaming process. Pouring temperature has significant influence on the quality and microstructure of the casting of LM2 Al-Si alloy. The main objective of the research is to investigate the effect of pouring temperature, section thickness and melt treatment on the microstructure. Lower pouring temperature was found to produce finer microstructure casting. A novel method of centrifugal foam casting can be used for solid and hollow components having cylindrical cross sections. In this paper Titanium hydride and Lithium aluminium hydride are used as forming agents and different concentrations and temperatures are studied for the effect on pore generation and microscopic distribution. Visual examinations and Optical metallography can be used as basic decision-making steps in the development of foam manufacturing to check the percentage of porosity as a preliminary confirmation method.

Keywords: Al-Si Alloy, Foaming agents, Foaming Process, Metal foam, Powder metallurgy

INTRODUCTION

Metal foams are important group of materials having applications in structural, mechanical, acoustic, thermal and domestic applications.[1] The clarity in the material's definition need following considerations.

1) Cellular materials refer to metals and alloys having large volume of porosity.
2) Metal sponges are highly porous materials with complex and interconnected porosity where porosity cannot be identified as well-defined cells.
3) Metal foams are porous metals produced with processes where foaming takes place.

The precise definition of foam may be 'uniform dispersion of gaseous phase, either in liquid or in solid' after solidification, this state is preserved and true 'solid foam' is obtained.[1] Powder Metallurgy is widely used foam manufacturing process since 1990, on large scale for pure Aluminium 99.9% and alloys like $AlSi_{12}$, $AlSi_8Mg_4$, $AlSi_6Cu_4$, $AlSi_7$, $AlSi_9$, $Al_{6.5}Si$, $AlCu_{13}Mg_4$, $AlSi_9Mg_3$, $AlSi_9Mg_5$, and $AlSi_8Mg_4$. In various theoretical and experimental studies, these compositions are used to find effects of parameters

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on manufacturing.[2] Foaming agents are added in various amounts along with other stabilizers.[3]

Aluminum and its alloy[4] foams are gaining importance due to lower melting temperatures, lower densities, and ease of manufacturing by variety of techniques.[5] Aluminum foams are light in weight, good strength to weight ratio, good anticorrosive properties, and aesthetic in appearance.[6] Open grain and close grain Aluminum foams are mostly used in Automotive, Aerospace, Building & Construction, Healthcare and Energy industries.[7–10] Currently, there are six methods of used for commercial manufacturing of metal foam.[11,12]

Bubbling Gas in molten alloy[13]: In this method foams are made by injecting gas bubbles into molten aluminum. It can produce high porous foam having large pore size. It is a low cost method as compared with power compact and Alporas method.

Stirring of foaming agent in molten alloy[14]: It is also called as 'Alporas' method. Metal powders and blowing agents are mixed at 680^0C to 720^0C and stirred for 6 minutes to increase viscosity. Due to decomposition of blowing agent gas gets released which causes the foaming process.

Consolidation of metal powder with particulate foam powder[15]: To produce aluminum foam, aluminum powder or alloys of aluminum are mixed with foam agents and compacted. The foaming agent gets uniformly distributed in foam obtained. The density of metal foam depends on foaming parameters and agents.

Vapor phase deposition of metal on polymer foam precursor[16]: Foaming take place by galvanically deposing polymer in ionic state of metal. Ions of metal and vapours are deposited on polymer and then polymer is removed to obtain the foam. Metal powders, fibres or even metallic micro-spheres can be used to make porous metals without space holders by simple loose sintering. Alternatively, one can compact metal powder and allow gas to be entrapped which is then expanded in a second step by a thermal treatment which leads to a creep expansion of the compact and the formation of fairly uniform porosity

Sintering of metal powder with a leachable foam powder[17]: In manufacturing of metal foams using sintering thermal treatment is used to entrap gas in first step and it is expanded in second step. It forms uniform porous metal due to creep expansion.

Hydrogen Gas dissolution in hot liquid metal under pressure[18]. A pore free melt having completely solved hydrogen is prepared at high pressure and pressure. Now two phase region having solid and gas is formed by reducing temperature and pressure. The gas gets accumulated in the form of fine bubbles and forms foam if cooling rate and pressure profile are selected correctly. A centrifugally cast powder metallurgy precursor in a stationery furnace is a new approach applied to develop Al-Si Alloy Foam.

EXPERIMENTAL SETUP AND METHODOLOGY

LM2 (Al-Si alloy system) having composition as (Mn 0.16, Si 9.64, Cu1.34, Fe 0.8, Zn 0.89, Ni 0.07, Pb 0.3, Al Balance) is selected as material for foam manufacturing. Titanium hydride and Lithium aluminium hydride are used as forming agents Lithium Aluminium Hydride is a powder which is metastable at room temperature.[19] It get decomposed to Li3AlH6 and LiH which is time dependent process. The process can be accelerated by using catalytic elements, such as Titanium, Iron or Vanadium.

Heating of Lithium Aluminium Hydride gives

$3\ LiAlH_4 \rightarrow Li_3AlH_6 + 2\ Al + 3\ H_2$. .. ……. (Reaction 1)
$2\ Li_3AlH_6 \rightarrow 6\ LiH + 2\ Al + 3\ H_2$................ (Reaction 2)
$2\ LiH + 2\ Al \rightarrow 2\ LiAl + H_2$. .... (Reaction 3)

Reaction 1 is usually initiated by the melting of Lithium Aluminium Hydride in the temperature range 150–170 °C, immediately followed by decomposition into solid Li_3AlH_6, although R1 is known to proceed below the melting point of $LiAlH_4$ as well. At about 200 °C, Li_3AlH_6 decomposes into LiH (Reaction 2) and Al which subsequently convert into LiAl above 400 °C (Reaction 3). Reaction 1 is effectively irreversible. Reaction 3 is reversible with an equilibrium pressure of about 0.25 bar at 500 °C. Reaction1 and Reaction 2 can occur at room temperature with suitable catalysts. The above decomposition is used to create Aluminium alloy foam where Hydrogen is responsible for foaming.

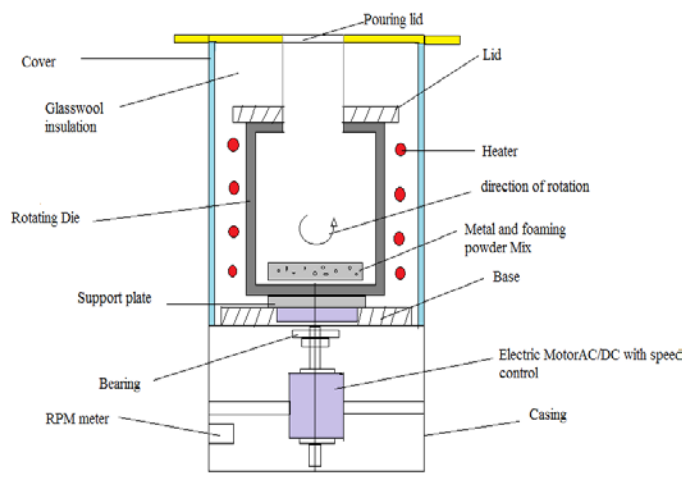


Figure 1. Experimental Setup

A centrifugal casting setup consisting of metallic die is rotated at 60 rpm at 580 °C and 600°C. Figure 1 shows experimental set up. Foaming agents are added to 2%, 5%, 10% and 15% by weight in molten alloy while rotating in furnace.[20] This process can be repeated for higher temperatures 600°C, 640°C and 680°C. After solidification, these samples are cut, polished, etched and observed visually and under optical Metallurgical microscope.[3] The effect of concentration of foaming agent is related with microstructure observed. A machine is fabricated, consisting of a rotating vertical mechanism for metallic die of Mild steel mounted on a disc. This set up is fitted in an electrical resistance furnace having maximum temperature 800°C having heating rate 9°C /min. to 25.5°C /min. Figure 2 shows photograph of actual foam formation process and Figure 3 shows flowchart of the process. The die is rotated by D.C. electric motor at 60 rpm..

Figure 2. Photograph of foam formation process

The total cycle time for 50gm batch is 50-60 min. The variables like rotational speed, weight of foaming agent, temperature of melting can be studied on this setup

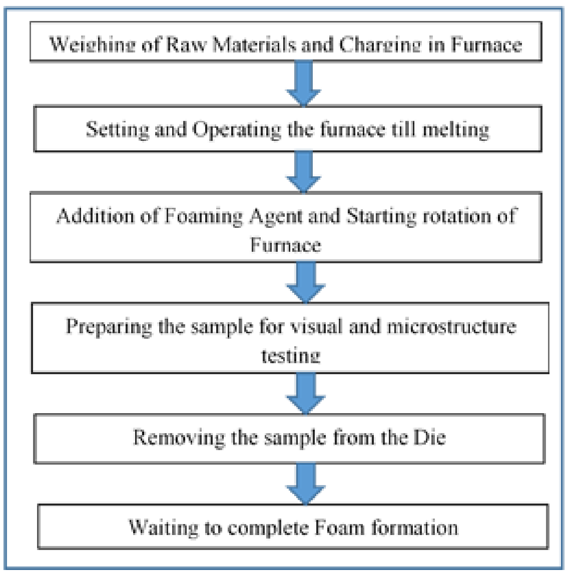


Figure 3. Flowchart of the process

Four different samples are prepared by using methods as shown in table 1.

Table 1. Sample preparation method

Sample Number	Methods
Sample 1	LM2 alloy without Foaming Agent and without Rotation
Sample 2	LM2 alloy with 10%TiAlH4 Foaming Agent and with Rotation of Die at 60 rpm
Sample 3	LM2 alloy with 10%TiAlH4 Foaming Agent and with Rotation of Die at 60 rpm
Sample 4	LM2 alloy with 10%TiH2 Foaming Agent and with Rotation of Die at 60rpm

Samples are prepared at three different heats. Its Log chart is given in table 2.

Heating rate is computed by using equation 1.

$$Heating\ Rate = \frac{Set\ Temp.-Start\ Temp.}{Time\ required\ to\ reach\ Set\ Temperture} \quad (1)$$

Table 2. Furnace log sheets for three heats

Parameters	**Sample**			
	1	**2**	**3**	**4**
Crucible Wt. (gm)	180	180	180	180
Crucible + charge (gm)	230	230	230	230
Start reading Units	3425	3717	3717	3701
Start time	11:40 am	09.35 am	09.35 am	09.15 am
Start temp	29°C	29°C	29°C	29°C
Set temp	600°C	580°C	580°C	580°C
Temp. Reached at	12:40 pm	10:00 am	10:00 am	10:10 am
End reading units	3430	3720	3720	3707
Units consumed	5	3	3	6
Heating Rate (°C/min)	9.51	22.04	22.04	10.01

OBSERVATIONS

A) Macro Examination and Visual Observations

Macro Examination and Visual Observations are shown in Table 3.

(1) Samples are cleaned, polished and observed by naked eyes for porosity on surface from all the sides.
(2) A magnifying lenses 50X magnification can give a clear view of porosity.
(3) Longitudinal and transverse sections at different locations can give the depth of foaming in centrifugal machine.
(4) Samples are machined on lathe with a light depth of cut to see the occurrence of pores.

B) Microstructure Examination

After solidification of sample, preparation for microscopic observation is done. Standard Metallurgical sample preparation involves

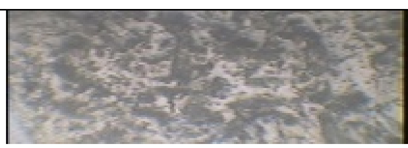
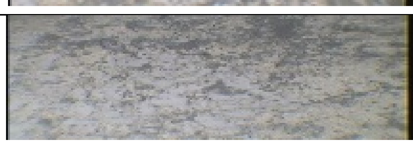
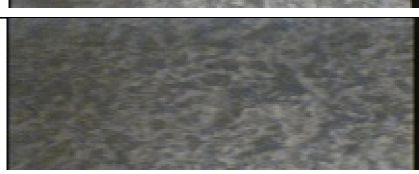
a. Rough Cutting and polishing.
b. Dry polishing with Silicon Carbide emery papers having mesh size 200, 400, 600, 800, and 1000 is done.
c. Wet polishing with $Al_2\ O_3$ powder on wet polishing machine.
d. Etching with NH_4 OH.
e. Optical Microscope observation at 250X and 400X magnification.

Table 3. Macro Examination and Visual Observations

No. Of Sample	Macro Examination and Visual Observations	Machined View
Sample 1		
Sample 2		
Sample 3		
Sample 4		
Sample 4 A (Side View)		

The microstructure of four samples are shown in Table 4.

Table 4. Microstructure of samples

Samples No.	Microstructure
Sample 1	
Sample 2	
Sample 3	
Sample 4	

The microstructure observations are summarized in Table 5.

Table 5. Microstructure Observations

Parameter	Sample			
	1	**2**	**3**	**4**
Temperature	600°C	580°C	580°C	580°C
Foaming agent %	Nil	10% $TiAlH_4$	10% $TiAlH_4$	10% TiH_2
Speed of rotation	No Rotation	60 rpm	60 rpm	60 rpm
% Porosity observed	Nil	25%	35%	55%
Pore shape	Not applicable	Irregular	Irregular	Angular

From microstructure examination following are the observations:

(1) The samples are observed under Vertical metallurgical microscope at 400X magnification to confirm porosity at microscopic level in between phases.

(2) The pore size, shape and distribution can be measured under microscope.

(3) At 100X magnification and by using X-Y table of microscope measurement of pore size is done.

(4) A standard reference pore size data can be used to compare the observed pores and data.

(5) This method can guide for process improvement.

Conclusions

A foam formation can be assured by visual examination by naked eyes to 20%, Use of 50X magnifying glass can assure to 40%. The optical microscopy can confirm porosity to 100% assurance looking at phases, grain and grain boundries. Following are the conclusions from above work.

(1) Visual examination of non-machined surface showing pores can confirm suitability of process of foaming.

(2) In visual examinations size, shape, location of pores at different cross sections can confirm process suitability.

(3) Occurrence of pores after machining at subsurface level can give depth of pores. This can be confirmed by removing material layers and measuring the diameter or thickness of samples.

(4) A specimen mounting table of metallurgical microscope having micrometer attachment can determine size of pores up to 0.01mm accuracy of sample on a prepared sample.

(5) Microstructure observation at 400X can give morphology of pores in detail,

(6) The equipments are basic, low cost and simple to operate.

(7) The manual skill is minimum and operator can be trained easily.

(8) Foaming agent TiH_2 is showing better results than $TiAlH_4$

(9) Lower foaming temperature is suitable for TiH_2 and $TiAlH_4$.

Conflict of Interest

Authors declare that there is no conflict of interest for publication of this work.

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