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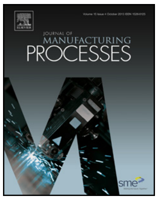

Role of fine size zircon sand ceramic particle on controlling the cell morphology of aluminum composite foams

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ABSTRACT

Composite foams exhibit unique properties such as light weight, blast palliation, sound absorption, high energy absorption, and flame resistance. In the present investigation, role of fine size zircon sand ceramic particle on controlling the cell morphology of LM13 alloy composite foams has been studied. For this purpose LM13 piston alloy of near eutectic composition is used as foaming matrix material and zircon sand ceramic particles as reinforcement. Composite foam was developed by stir casting route at different temperatures. Variation in microstructures of the composite foam is observed with the addition of zircon sand ceramic particles and also with varying foaming temperatures. The results show that the cell morphology parameters such as cell size, node and ligament length increases with increasing foaming temperature. However, the addition of zircon sand ceramic particles leads to decrement in the ligament length with increasing foaming temperature.

1. Introduction

Metallic foams, as a new class of engineering materials, offer a unique combination of properties such as low density, energy absorption capability, high stiffness and strength. These improved properties of the metallic foams make them highly desirable materials for different engineering applications [1–4]. Recent improvements in the production methods for metallic foams have offered a variety of applications in different fields such as the automobile, railway and aerospace industries [5]. In these applications, the composite foam is subjected to high-velocity deformations. Miyoshi et al. [3] have shown the application of aluminum composite foam as a functional material for sound and impact energy absorption. Metallic foams are excellent impact energy absorber, and they can convert impact energy into deformation energy and absorb more energy than bulk metals at low stresses [4,6]. Main application of particle reinforced metallic composite foams is in defence and is used as passive safety systems due to energy absorption and dissipation properties of the foams. Both physical and mechanical properties of aluminum composite foams are not only controlled by composition of matrix and reinforcement but are also significantly affected by cell structure of foam [6]. Ma and Song [5] found that the Cell structure of aluminum foams can be controlled by the foaming process where viscosity of the aluminum melt has be controlled by addition of Ca and continuous stirring of the melt. The average cell diameter of aluminum foams decreases with increasing viscosity of the melt. Many studies have been carried out to optimize the microstructural properties of aluminum foams as it influences the above said properties which are of at most importance. This includes the cell wall thickness, node size, ligament length and interdependent relationship of foam density with cell size [4–6]. Since all these microstructural properties are believed to originate from manufacturing condition of metallic foams [3,7], it is of interest to modify the processing conditions in order to achieve more uniform cell size distribution with reduced morphological defects for better performance. The blowing agent used for foaming decomposes in molten aluminum and generates gas bubbles therein. However, to have a uniformity in structure, it should generate the desired amount of gas bubbles of desired sizes during the foaming process. Apart from this the molten aluminum must possess a certain viscosity which is affected by the addition of ceramics particles so that the generated gas bubbles are retained in the aluminum matrix during solidification [8]. In this entire process, temperature plays an important role.

Role of reinforcement of SiC on foam stability has been studied by Prakash et al. [1] and also by Deqing and Ziyuan [9]. They have controlled the stability of aluminum foam with the distribution of SiC particles and the addition of higher content of SiC, increase the brittleness nature of foam [9]. Mukherjee et al. [10] have studied the affect of SiC on the microstructure, density, and strength of closed

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Table 1
Composition of the LM13 alloy in wt.%.

LM13 alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Pb	Sn	Al
wt.%	11.8	0.3	1.2	0.4	0.9	0.2	0.02	0.9	0.02	0.005	Balance

cell foams using $CaCO_3$ as foaming agent. The stability of foam generally depends on the wettability of ceramic particles along the cell walls and nodes. The position of particles depends on the gas pressure inside the bubble and viscosity of melt alloy which vary with foaming temperature. For a liquid foam to become stable, the liquid–gas interface must be altered either by introducing a surfactant that reduces surface tension or by increasing the viscosity of the surface layer [5].

Few literatures are available on the effect of foaming temperature on the microstructure of the alloy foam [8,9]. It is reported that in case of alloy foam, the porosity increases with increases in foaming temperature [11,12]. However, in case of composite foam, the microstructure is hardly affected due to addition of ceramic particles in the melt alloy [13–15]. The fracture resistance and damage tolerance of foamed parts can be significantly improved with non-metallic reinforcement onto the foam surface. Moreover, a comparative study on the microstructure of the alloy foam and the corresponding composite foam which is affected by increase in the foaming temperature is not available. The microstructure is controlled by the process variables such as foaming temperature, foaming agent, impeller design, impeller speed, size and volume fraction of the solid particles during the foam making process. To the best of our knowledge, till date no work is reported describing the role of reinforcement of fine size ceramic particles on controlling the cell morphology of aluminum composite foams at different foaming temperatures. The present study is aimed to investigate the influence of fine size zircon sand ceramic particles on the cell morphology of LM13 alloy composite foam at different foaming temperatures using different size of $CaCO_3$ powders as blowing agent. In this present study, the porosity and foam quality has been optimized to minimize the imperfections. The role of zircon sand particles as reinforcing agent on stabilizing the foam has been studied and compared with the obtained structure.

2. Experimental details

In the present work, Al–Si alloy (LM13 piston alloy) of near eutectic composition is used as matrix material for the development of foam. Fine grade blowing agent ($CaCO_3$) was obtained from S D Fine-Chem Limited, Mumbai (India). Zircon sand was obtained from Indian Rare Earths Ltd Mumbai. The procured sand was sieved with AS 200 RETSCH analytical vibratory sieve shaker. Particles below 25 μm were used in the present work. The distribution of particles within the selected size range for blowing agent ($CaCO_3$) and zircon sand was further analyzed with the help of CAMSIZER XT. 2 wt.% $CaCO_3$ of particle size range 1–25 μm and 50–100 μm of sample-1 and sample-2, respectively, were used as blowing agent. 5 wt.% zircon sand ($ZrSiO_4$) of particle size range (1–25 μm) is used as reinforcement. LM13 alloy was obtained in the form of ingots. The chemical compositions of LM13 alloy and zircon sand were done by wet chemical method, which is given in Tables 1 and 2, respectively. Addition of zircon sand (1–25 μm) was done to improve the mechanical properties of the LM13 alloy composite foams. Before charging, the blowing agent ($CaCO_3$) and zircon sand particles were preheated at 300 °C to remove moisture and other volatile substances. The composite foam was made by stir casting route. For preparing the foam, the required quantity of LM13 alloy was taken in a graphite crucible and melted in an electric furnace. The temperature of melt was raised to 750 °C. This molten mass was stirred using a graphite impeller at a speed of 630 rpm to create the vortex. After the formation of vortex in the melt, blowing agent $CaCO_3$ was added. However, for composite foam the zircon sand particles were charged inside the vortex first at the rate of 15–20 g/min. After the addition of the ceramic particles, the blowing agent was added into the molten metal. To get uniform dispersion of blowing agent particles, the molten metal was stirred quickly by increasing the speed of impeller up to 650 rpm. The furnace temperature was also increased and maintained at the desired temperature for 5 min to allow $CaCO_3$ to decompose. The released gas forms bubbles. The foamed melt was removed from the furnace and cooled in air. Table 3 shows the list of processing parameters for the development of foam. Specimens from different parts of the alloy foam as well as composite foam of $12 \times 12 \times 50\,mm^3$ were cut by diamond cutter. These specimens were further ground on 400 up to 800 grit papers and then polished with 0.5 μm diamond polishing paste and etched by Keller's reagent for microstructure analysis. The density of the prepared composite foams was measured using Archimedes principle. The density of a foam material is measured as mass per unit volume, which excludes all voids or pores. A common way to measure the density of a closed cell foam material is based on Archimedes principle, which states that a body submerged in a fluid will be buoyed up by a force equal to the weight of the fluid it displaces. Density (ρ) measurement of the foam was carried out on the LM13 alloy foam and reinforced LM13 composite foam samples using the Archimedes principle as given below.

Table 2
Composition of the zircon sand ($ZrSiO_4$).

Elements	ZrO_2	SiO_2	TiO_2	Fe_2O_3
% in Bulk	65.30	32.80	0.27	0.12

Table 3
List of parameters of the developed metal foams.

List of parameters of the development of metal foams	
Temperature at the time of addition of zircon sand	750 °C
Temperature at the time of addition of blowing agent	800 °C
Foaming temperature	850 °C, 875 °C and 900 °C
Particle size of zircon sand	1–25 μm
Particle size of blowing agent	1–25 μm and 50–100 μm
No. of blades in stirrer	3
Blade angles of stirrer	45°
RPM of stirrer	630
Height of the stirrer in the melt	2/3 Inside the melt

$$\rho = \frac{m}{m - m_w}\rho_w \tag{1}$$

where m is the mass of the foam sample in air, m_w is the mass of the same foam sample in distilled water and ρ_w is the density of the distilled water.

3. Results and discussion

3.1. Role of particle size and shape on the decomposition rate of blowing agent

The particle size distribution of the blowing agent ($CaCO_3$) and reinforced zircon sand particles was measured with the help of