Development of Low Cost Lightweight Aluminum Foam for Railway Transportation

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Abstract. Metallic foams are commonly produced using hydride and carbonates foaming agents. However, carbonate foaming agents are safer to handle than hydrides and produce aluminum foam with a fine, homogeneous cell structure, low cost and easily available. The number of pores per inch (PPI) and relative density of the foam play an important role on their physical and mechanical properties. Hence it is very important to investigate effect of shell foaming agent on PPI and relative density. The present work deals with the effect of additive amount of the shell forming agent on the physical properties of an AlSi7Mg alloy closed cell foam. The foam was produced with different additive amount of shell (1, 3, 5 wt %) as a foaming agent. The PPI and density of the foam produced with different additive amount of shell as foaming agent are determined. Relative density is in the range of 0.21-0.29, PPI are in the range of 11-19 for the produced AlSi7Mg alloy closed cell foam. Therefore, the appropriate addition amount of shell is 3 % by weight for production of a uniform cell structure from the viewpoints of efficiency and economy.

1. Introduction
Metallic foams have lately attracted considerable attention as a lightweight structural components and energy absorption parts in automobile, railway transportation and aerospace industries. Metal can be foamed in many methods [1, 2].

Closed cell foams can be produced by (a) bubbling gas through molten Al-SiC or Al-Al2O3 alloys; (b) by stirring a foaming agent (typically TiH2) into a molten alloy; (c) consolidation of a metal powder with a particulate foaming agent (TiH2) followed by heating into the mushy state when the foaming agent releases hydrogen, expanding the material [3].

Aluminium foams synthesized with CaCO3 powder as a blowing agent can be prepared by both powder metallurgy and melt route. The properties of aluminium foam significantly depend on its porosity, so that a desired property can be tailored by controlling the foam density [4]. The foams can be produced by CaCO3 having appreciably finer cells and more uniform cell structures than currently available melt route foams. The decomposition characteristics of CaCO3 is well suited to foaming of aluminium melts [5]. An addition of CaCO3 into the molten metal alloy in an amount ranging from about 0.5 % to about 4.0 wt% is sufficient to provide sufficient metal oxide phases to stabilize liquid metal foam. The reactive gas producing particle is selected from the group consisting of CaCO3, magnesium carbonate, magnesium-shell (dolomite) as a foaming agent [6].
Dalian, as a coastal city, is rich in shellfish, however, most of the shells are discarded as garbage. In the present work AlSi7Mg closed cell foam has been produced using zero cost shell as a foaming agent by melt route. From an application point of view, the main concern is to control the size of the pore, porosity level and foam structure, which affect the physical and mechanical properties of the foam. Hence, in this work, effect of particle size of shell on porosity, pores per inch and relative density were studied.

2. Materials and Methods

2.1. Materials
AlSi7Mg cast aluminium alloy was used as a base material. The reinforcement phase consisted of MnO₂ particles with purity of 99.0 wt % and mean mass particle size of 45 μm. Heating MnO₂ particles for 1 h at 300 °C and then for 2 h at 150 °C in a conventional air furnace was carried out to improve the wettability between MnO₂ and AlSi7Mg melt by removing adsorbed gases from the surface of particles. Oyster-shell powders were used as a foaming agent, shown in figure 1 respectively. Shell powders were also heat treated at 200 °C for 2 h to remove humidity and adsorbed gases from the surface and improve wetting properties and dispersion of shell powders in molten metal. Scanning Electron Microscope (SEM) microphotographs of heat treated shell powders are respectively shown in figure 2.

![Figure 1.](image1.png)

**Figure 1.** The oyster-shell (a), (b) and its powders (c) were used as a foaming agent.

![Figure 2.](image2.png)

**Figure 2.** Microphotographs of oyster shell powders were used as a foaming agent.

(a) ≤ 150 μm; (b) ≥ 300 μm; (c) ≥ 850 μm.

2.2. Methods
Required quantity of AlSi7Mg alloy was weighed and melted in a graphite-clay crucible by using an electric resistance furnace. Molten alloy temperature is measured using thermocouple. When the temperature reaches around 670 °C, furnace was switched off and melt was stirred with stainless steel stirrer for about 60 s. Required particle size of shell of 1-3-5 % by weight was sieved, preheated and added into the molten metal while stirring. The stirring was continued till the foaming agent was distributed uniformly. The shell decomposes and releases the gas when it was directly in contact with molten AlSi7Mg alloy. The crucible was kept about 30 min in the furnace until it completes the foaming process. figure 3(a) and (b) shows the stirring and foaming process for the oyster-shell
powders. Then the crucible was taken out from the furnace, the foam was cooled in ambient air.

**Figure 3.** The stirring (a) and foaming process (b) for the oyster-shell powders.

### 3. Results and discussion

Figure 4 shows the influence of shell addition on the cell structure of foamed aluminum. A comparison of the cell structure shows that a shell addition of 1 wt% also creates a bubble-free zone at the bottom due to the presence of gravitational drainage effect [7]. In all cases, solid (unfoamed) portion was present in the bottom region of the foam ingot. Similar observations have been reported in the past and were attributed to liquid drainage [8]. The shell addition not only has an effect on the content of carbon dioxide gas release, but also has a relation with the melt viscosity. Two neighboring bubbles in the melt are separated by a liquid film in the liquid foam. The liquid in the film tends to flow due to surface tension [9]. If the melt with enough carbon dioxide content and a sufficient viscosity, minimizes the flow of the film the liquid drainage may be reduced [10]. This implies that the shell addition of 1 wt% is insufficient. So, the less structural stability consisting of a few irregular cells and solid aluminum phase were observed (figure 4(a)). On the contrary, a shell addition of 3.0 wt% induces a greater uniformity of spherical cell distribution (figure 4(b)). This results in the production of good foams with higher porosity. However, a shell addition of 5.0 wt% in figure 4(c) produced a partial combination of the cells. If the released gas was fully consumed to foam the specimen, the volume of the specimen will increase remarkably. However, experimental results have shown that the attainable volume is limited.

**Figure 4.** Macrostructures of foamed aluminum produced by different additions of shell at 670°C.

(a) 1%; (b) 3%; (c) 5%

The cut sections of the foams were examined for number of PPI. Pores per inch were measured along vertical (foaming direction) and horizontal direction of cut section. Then the average number of PPI was calculated and the density of aluminium foam, relative density and porosity was calculated. The variation of PPI and relative density with shell addition are depicted in figures 5 and 6 respectively.
Figure 5(left). Relationship between the PPI (Porosity) of foamed aluminum and shell addition.

Figure 6(right). Relationship between the relative density (density) of foamed aluminum and shell addition.

Pores per inch, density, relative density and porosity of the foam produced with different addition of shell are tabulated in table 1.

Table 1. Shell addition and other physical properties.

| Shell addition (mass %) | Pore per inch (PPI) | Density (g/cc) | Relative density | Porosity (%) |
|------------------------|---------------------|----------------|------------------|--------------|
| 1                      | 17                  | 0.57           | 0.21             | 78.73        |
| 3                      | 19                  | 0.78           | 0.29             | 70.89        |
| 5                      | 11                  | 0.61           | 0.23             | 77.24        |

A SEM micrograph of the fracture structure of foamed aluminum with 5% by weight of shell is shown in figure 7. The foam has remarkably thin cell walls (25 μm), which therefore leads to a film structure which is easily broken. Eventually, the cells will vanish. These thin cell walls are caused by the excessive foaming. These experimental results indicate that the higher the shell amount, the more gaseous carbon dioxide is released which can increase the foam porosity. However, excess released gas escaping through the melt results in low foaming efficiency. Therefore, the appropriate addition amount of shell is 3 % by weight for production of a uniform cell structure from the viewpoints of efficiency and economy [11, 12].

Figure 7. SEM image of fractured surface of foamed AlSi7Mg alloy.
(a) Cell image; (b) Cell image
4. Conclusions
The factors which affect the foaming in a foamed aluminum casting process were investigated. Properly controlling the shell content of the melt leads to the production of foamed aluminum which contains a uniform cell structure of high porosity. An optimum foamed aluminum with air bubbles of 1.3 to 3 mm diameter and a uniform distribution with 71% porosity is obtained by the addition of 3% shell at 670°C.

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