Preparation of big size open-cell aluminum foam board using infiltration casting

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Abstract: This paper presents an infiltration casting technique for manufacturing big size open-cell aluminum foam boards. The principle and key technologies of infiltration casting are also analyzed. Based on the previous practice of the small size aluminum foam production, the die for preparing big size aluminum foam boards is designed and manufactured. The experiments on aluminum boards of 300 mm × 300 mm × (20–75) mm, with the pore size ranging from 1.0 to 3.2 mm and average porosity of 60%, have been performed. The experimental results show that a reliable infiltration process depends critically on the pouring temperature of the molten Al-alloy, the preheated temperature of the mould and salt particles and vacuum. Current research explores the possibility of large-scale manufacturing and application of the aluminum foams.

Key words: infiltration casting; aluminum foam; board

Metallic foam is a newly developed structural and functional material with combination of unique properties, such as low density, high stiffness, sound absorption and impact resistance. It has attracted considerable research efforts over the past decade. As a result, sufficient knowledge with respect to processing technology, materials properties, structure control etc., has been established. Metallic foams can be divided into closed and open cell structures (i.e. spongers). Due to their high porosity, super permeability and high surface to volume ratio, open-cell metallic foams find wide applications in heat exchangers, filter elements, acoustic absorbers, stiffening elements, crash absorbers and metal matrix composites [1-3].

Metallic foams based on aluminum are commercially available. A common process for producing open-cell aluminum foams is called infiltration casting process, which utilizes a dissolvable mold (e.g. made of NaCl particles). Currently, the majority of researches in the field of aluminum foams, especially open-cell aluminum foams, are focusing on small-scale parts [5-7]. This largely limits their challenging applications that require large board and blocky structure. In this paper, we propose a new mould assembly containing heating component to produce large-scale open-cell aluminum foams; some up-to-date experimental results with regard to the quality control of this particular infiltration process are reported.

1 Experimental procedure

1.1 Infiltration process

A schematic diagram of the infiltration casting process is shown in Fig.1. The porous mould is made of pre-compressed soluble particles. Liquid metal is poured into the mould and pressed into voids among particles. After solidification and cooling, the metal-filled composite is then machined into required shape and dimension. Finally, filling particles are rapidly eliminated by soaking in solvent (e.g. water) and then a porous metal is formed.

![Fig.1 Schematic illustration of infiltration casting processing](image)

1-Pressing solid, 2-Mould, 3-Molten Al, 4-Filling particles, 5-Base plate

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casting for manufacturing aluminum foams include:

(1) Choice of granular filler with considering the following properties: refractoriness, strength, elimination capability, chemical stability, shape and size, prolific resource, price and environmental impact. Granular sodium chloride was selected as filler for this study.

(2) Molding process should be strictly controlled to achieve a uniform compaction of salt granules with homogenous and high porosity. Layer jolting method was adopted in this study. Higher pressure is favorable for a better compactness. However, too high pressure should be avoided to prevent salt particles from being crushed.

(3) Major technical parameters which affect infiltrating process include the preheating temperature of mold and salt granules, the pouring temperature of molten aluminum and the penetrating pressure.

Materials in natural format are hard to satisfy the above requirements. Salt particles are dried at low temperature and baked at high temperature. After infiltrating, complex of Al/particle is rapidly removed from the die and machined in time, then the die needs to be washed and cleaned to avoid further corrosion.

1.2 The die for preparing aluminum foam board

It is well known that the structure and material of the die play key roles in producing big aluminum foam boards \([8,9]\). Based on the previous experience of producing aluminum foams \([8]\), we propose that the die for preparing big aluminum board must meet the following criteria:

(1) The die must be tightly sealed to avoid leak of molten aluminum during infiltrating casting, by either exerting external pressure or applying vacuum suction;

(2) The die should have heating capability;

(3) The die should have a simple structure and easy to remove the casting from the mould.

A schematic diagram of die structure in accordance with the above-mentioned principles is shown in Fig. 2. It consists of a basement, base plate with vent-hole, middle mould, heating plate and cover plate, etc. The middle mould is dispersed into two symmetrical halves and is vertically set on the base plate. Four heating plates are installed surrounding the sidewalls of the middle mould, two of them are fixed, and the others are detachable. Seven throughthickness holes were machined in each heating plate for accommodating tubular electric heating elements. Insulating material is wrapped around the heating plate to minimize heat dissipation. Exhausting system is installed to the basement, on top of which the base plate with evenly distributed air-vents is placed. The middle mould and the heating plate can be compressed and fixed by a horizontal apparatus to keep the mould being sealed. After casting, two detachable heating plates can be removed, and the middle mould can then be taken out conveniently.

The determination of hydraulic pressure or vacuum suction is highly depending on the requirements of designated pore structure of metallic foams and experimental conditions, such as gas pressure and temperature. In this study, vacuum infiltration process is employed. After pouring, air was exhausted through the vacuum system and molten metal was drawn through voids among particles.

1.3 Materials and Equipment

Casting alloy ZL102 was used for producing large scale aluminum foam. NaCl with grain sizes of 1.6–3.2 mm, 0.8–1.6 mm, 0.063–0.8 mm were chosen as filling particle material. Other equipment involved in current research included a homemade die, melting and pouring devices, and a vacuum pump.

2 Results and discussion

Further experiments were designed based on previous exercise on preparing for small size foam specimens \([3]\). The experimental details and results are presented in Table 1. It is
clearly seen from Table 1 that the designed die meets the needs described above, and it can be used successfully to produce the big size aluminum foam boards. A typical sample obtained from this work is presented in Fig.3. The big size aluminum foam board can then be directly machined into different shapes and sizes accordingly, some examples are shown in Figure 4.

**Fig.3 Typical sample of aluminum foam board obtained in this work**

**Fig.4 Aluminum foam samples with different shapes and sizes, which are machined directly from big size aluminum foam boards.**

The experimental results presented in Table 1 also reveal that a reliable infiltration process depends critically on the pouring temperature of the molten Al-alloy, the preheating temperature of the mould, salt particles and vacuum. It can be seen that the penetrating length, \( L \), is comparable to the height of the salt bed, \( H \), in the samples Nos.1 and 3 with the particle sizes of 1.6–3.2 mm, even though the pouring temperature, \( T_1 \), in the sample No.1 was as low as 700\(^\circ\)C, lower than that in the sample No.3. However, a small amount of the molten aluminum was observed to leak out from the vent-hole to the base plate. This is possibly because the void among the salt particles with the large size is so large that the molten aluminum can easily leak out under the pressure. When the size of the salt particles decreased to 0.8–1.6 mm and 0.63–0.8 mm, the salt bed can be observed indicating insufficient infiltration (compared with the samples Nos.1 and 3). Thus, vacuum infiltration process is required for the small size salt particles when using the same designated die.

Comparing sample No.1 with 3, it can be found that the penetrating length, \( L \), increases with a rising of the pouring temperature, \( T_1 \). This is due to the phenomenon that fluidity of molten metal increases with temperature. However, it should be noted that if the pouring temperature, \( T_1 \), is too high, the molten metal can easily leak out from the bottom. On the contrary, the lower pouring temperature, \( T_1 \), will reduce the fluidity of the molten metal and finally result in the decrease in the penetrating length, \( L \). More severely, the lower pouring temperature, \( T_1 \), also can cause the uneven distribution of the penetrating length, \( L \), in the different parts of the bed. Our investigation showed that the suitable pouring temperature \( T_1 \) for producing the big size aluminum foam boards should be at the range from 720 to 760\(^\circ\)C.

Further, it can be seen by comparing sample Nos.4, 5 and 6 that the preheating temperature \( T_2 \) can significantly affect the penetrating length \( L \). The higher the preheating temperature \( T_2 \) is, the longer the penetrating length \( L \) is. However, too high preheating temperature \( T_2 \) should be avoided to prevent the molten metal from leaking out from the bottom. Inversely, lower temperature decreases the infiltrating length and also the filling speed of the molten metal into the mould. We found the optimized preheating temperature is in the range of 450 – 500\(^\circ\)C.

The vacuum also influences the infiltrating length \( L \), which can be seen from the comparison of Nos.3 and 4. In the infiltrating process, the pressure is used to overcome two types of resistance: flow resistance of the molten aluminum and surface tension of capillaries between the molten aluminum and the salt particles. It is anticipated that the resistance caused by capillarity is greater, and therefore the infiltrating length is longer. In our study, the suitable vacuum ranged from – 0.04 to – 0.06 MPa depending on the particle size.

A 3-D profile analysis of the foam metal after infiltration casting reveals that the infiltrating length \( L \) varies in the different areas of the die. This is completely different from the small size aluminum foams. Such infiltration length distribution is comparable to the experimentally tested temperature distribution of the die during casting. It can therefore be concluded that uneven temperature distribution caused the variation in infiltration length in large size foam aluminum manufacturing. The temperature distribution in the different parts of the die and the salt bed during heating is shown in Fig. 5. It can be seen from Fig.5 that the temperature at the bottom of the inside wall of the middle mould increases slowly with time. This usually results in the lowest infiltrating length in the part. But the temperature distribution can be controlled by regulating the power distribution of the electric heating elements and minimizing the heat dissipation of these parts using the insulating materials with the lower thermal conductivity. Figure 5 also indicates that there exists a temperature gradient along

**Fig.5 Temperature distribution in the die and the salt bed**
the vertical direction of the salt bed, which also changes with time. This provides a foundation for determining the board height by controlling the pouring time. A numerical simulation of optimizing such infiltration casting including both fluid and thermal fields is necessary. A detailed discussion can be found in Ref. [8].

3 Conclusions

(1) The die designed with heating component is valid for producing the big-size aluminum foam boards. The aluminum foam boards with the dimension of 300 mm × 300 mm × 28 mm are successfully produced with such a mould, with the porosity of 60% and the pore sizes ranging from 1.6 to 3.2 mm.

(2) A reliable infiltration process depends critically on the pouring temperature of the molten Al-alloy, preheating temperature of the mould, and salt particles, and vacuum. The optimized infiltration parameters obtained from current investigation are the pouring temperature of 720-760 °C, preheating temperature of 450-500 °C and vacuum of −0.04 to −0.06 Mpa.

(3) The experimental results reveal that uneven temperature distribution and insufficient pressure can result in insufficient infiltration for the particle size of 0.8–1.6 mm and 0.63–0.8 mm. It is critical to modify the mould and change the technical parameters, based on the pore size, for producing the aluminum foam boards.

References


