Preparation of foamed aluminum and its application in China

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Abstract: As a new structural material combined with functional characteristics, aluminum foam possesses low density, high specific surface area and stiffness, good sound and energy absorption, as well as excellent electromagnetic shielding. Among the preparation ways which can be used to fabricate aluminum foam, the methods, such as direct foaming in aluminum melt, melt foaming by gas injection, powder metallurgy route and casting around space holder materials, may be the main ones. The R & D of the methods above in China is discussed in this paper. Aluminum foams have been exploited in road noise barrier, buildings, rail transit vehicles, aerospace and bridge protection in China nowadays. The applications of aluminum foams obtained by some methods are also emphatically described. It is speculated that the application fields and amount of the aluminum foams may be increased in the future along with the further development of Chinese economy.

1. Introduction
Near to the year of 2000, some literatures about manufacture and applications of aluminum foams have been published in succession. Among them, a method called batch casting process has been applied to prepare aluminum foams. The production of foamed aluminum, named ALPORAS, is not only produced in the plant but also used as a sound absorber under the elevated expressway in Japan[1]. At the same time, a way to produce aluminum foam by powder metallurgy route has been achieved in Germany. The design of this new metal foam is expected for transport industry to absorb energy instead of the traditional polymeric foams[2]. Meanwhile, aluminum foam sandwich (AFS) and complex-shaped foam parts have been also manufactured by using this powder compact foaming technique [3]. Besides, a sequential foaming technique, i.e. melt foaming by gas injection, has been paid attention and investigated carefully[4]. The product made by the process is generally called Cymat foam. The appearance of these literatures implies the maturity of each technique and good application prospects. As sound absorber, the ALPORAS product has been used as absorption facilities in various buildings, as absorption wall in tunnel or substation, and as absorption hood of motor or dynamotor, etc. As mentioned above, aluminum foam obtained by powder metallurgy route is mainly designed for transport industry. Typical example is that the body structure of Audi A8 has been filled with aluminum foam in numerous parts. The aluminum foam was also used as a core material in the lifting arm of engineering automobile and as an absorption material in the tramcar in Germany. In order to utilize its vibration resistance, special-shaped parts filled with aluminum foam, e.g. generator supporting bracket, were manufactured for BMW car by Austria LKR institute. The target market of Cymat aluminum foam relates to the architecture, military and automobile yields. Therefore, a large number of Cymat foams were used in the construction of conference centre which served the 2010 Winter Olympics in Vancouver, Canada. The aluminum foam R&D in China started from the eighth decade of twenty
century. The research work was confined to the laboratory in the first twenty years. The scale-up or engineering tests was undergone when entering the twenty-first century. Nowadays, the applications of aluminum foams have been carried out in many fields.

2. Manufacture of aluminum foams

Many approaches can be used to fabricate aluminum foams. The production methods may include liquid state, solid state processing procedure, as well as metal-deposition technique in general[5]. Although the metal aluminum may deposit on the surface of polyfoam through electro-deposition technique and the aluminum foam with open pore can be fabricated by thermal decomposition of the polyfoam, the successful utilization of this method is to prepare the nickel foam. The industrial technique was developed out in 1996 by Institute of Corrosion and Protection, Chinese Academy of Science. A company named Shenyang Golden Champower New Materials Corp., Ltd was registered to produce the nickel foam specifically for Ni-MH battery market. Therefore, it is limited in academic research to prepare aluminum foam through metal-deposition technique. Similarly, aluminum foam or porous aluminum fiber felt may be made out by solid state processing technique, such as sintering of aluminum powder or fibers. However, considering the reception of market, this preparation technique is preferred to produce nickel or its alloy foams and porous stainless steel fiber felt. Nickel or its alloy foam tubes were manufactured by powder sintering technique in the Key Lab of Porous Metal Materials of China. The size of the tube has reached $\phi 110\text{mm} \times 1000\text{mm}$ recently and the integrated formation between tube orifice and the flange, that is to say without welding seam, has been also achieved. Porous metal fiber felt (FeCrAl) was also produced through fiber sintering. The porous material holds stable sound absorption performance in the stage of high frequency. Besides, 3D printing technology has been applied to produce metal foams in this lab. The Ti-6Al-4V (TC4) alloy powder was superposed layer by layer through electron beam selective melting and an object with three dimensional structures could be obtained through accumulation of different graphics on each layer. Figure 1 is the samples made by the 3D printing technology. According to the current situation of Chinese research on aluminum foam, it is not difficult to conclude that aluminum doesn’t act as the main matrix to prepare metal foam usually when solid state processing procedure or metal-deposition technique is employed. The preparation of aluminum foam is mainly derived from liquid state foaming process, as can be found in practice.

![Figure 1. Photos of TC4 aluminum foams with different structures made by 3D printing](image)

As for the liquid state processing procedures, a lot of ways can make the aluminum melt expandable. Here, combining the practical applications, some methods are introduced emphatically, such as direct foaming in aluminum melt, powder metallurgy route, melt foaming by gas injection and casting around space holder materials. The method by direct foaming in aluminum melt, which is called batch casting process in Japan, is one of the majority ways in China. Northeastern University has been researching on this method for nearly twenty years. Two different ways were planned in the original testing programs. One way was called “melt direct foaming”, which means that the aluminum melt is foamed in a batch directly after thorough mixing. The other way was called “melt metastatic foaming”, which means that the aluminum melt after stirring is transferred to another batch for foaming. The sketching about the two ways is showed in figure 2. The two ways to fabricate aluminum foam were studied in detail in the lab.
and the second way was carried out through engineering-oriented experiment in 2004. The aluminum foam panel with dimensions of 800mm × 1800mm × 10mm was prepared successfully[6].

**Figure 2.** Sketch of two ways to prepare aluminum foam by direct foaming in aluminum melt

The powder metallurgy route to make aluminum foams has been also paid extensive attention. Many research institutions have done a lot of work in China and the samples prepared by the method include aluminum foam panels, special-shaped parts and sandwich structure materials. Some work has been done in Northeastern University to attain aluminum foam blocks or sandwich panels. Due to the adjustment of alloy composition, adding agent, heating rate and foaming agent treatment, the aluminum foams with uniform structure and nearly no bubble-free layer were fabricated. Figure 3 is the longitudinal section photos of aluminum foams made by powder metallurgy route.

**Figure 3.** Morphologies of aluminum foam samples split by wire cutting along longitudinal section

Although there are only several institutions concerning the research of melt foaming by gas injection, remarkable results were also obtained. The most significant progress was made by Dalian Jiaotong University. The preparation process of Dalian Jiaotong University differs from the “Cymat technics” evidently [7]. The main features of this process manifest in the distribution mode of compressed air. The hollow mixing propeller which can inject gas into the batch melt by strong rotation was replaced by an injection pipe which moves along the horizontal direction continuously. The laminar flow of aluminum melt generated by the pipe horizontal movement shears the gas injected through the pores on the pipe and makes bubble distribution homogeneous at the same depth in the aluminum batch. The industrial process can be currently achieved by the implement of this method. The route of casting around space holder materials may be divided into two methods further, i.e. infiltration casting and investment casting. As a traditional method, the infiltration casting method has matured and was applied in China commercially. However, corrosion and operational environment problems are the obstacle to restrict the development of the method because of the slather use of sodium chloride particles. One of the development directions of this technology is to find a new space holder material instead of sodium chloride. The investment casting method has been a proprietary technology of American Energy Research & Generation Inc. An open-cell aluminum alloy foam named “Duocel” has been produced since the sixth decade of twenty century. This method has been developed rapidly in China in recent years. The products made by Institute of Solid State Physics, Chinese Academy of Sciences have following characteristics: their porosity is between 85% and 95%, pore size between 8ppi and 20ppi, apparent density between 0.27 g/cm³ and 0.4 g/cm³. Figure 4 is the morphology photos of the products.
3. Applications of aluminum foams

The aluminum foams which have been used commercially are mainly manufactured by infiltration casting and direct foaming in aluminum melt methods in China. As sound absorption materials, the products made by infiltration casting are usually used in highway, bridge and rail transit, etc. The typical engineering examples are the sound barrier projects for “A5 Jiajin” highway, “Xupu” bridge (see figure 5 (a) and (b)), provided by Shanghai Zhonghui Aluminum Foam Co., Ltd.

The overall length of the sound barrier for “A5 Jiajin” highway is four kilometers. The sound barrier consists of three parts, i.e. top, absorber and pedestal. The top is a φ500mm cylinder with micropores, which is made of aluminum plate. The face panel of the absorber is the open-cell aluminum foam with pore size of 1.6mm and porosity ranging from 68% to 78%.

The rear panel of the absorber is aluminum alloy material. The pedestal is made of concrete. The combination of these parts can resist the uniform load of 108 kg/m² and its average absorption coefficient is greater than 0.6. As shown in Fig.5(b), the top and bottom of the sound barrier are all comprised of aluminum foam face panels. The intermediate part is glass fiber reinforced plastics. The structure together with the concrete pedestal can meet the design requirement of wind pressure of 31.3m/s.

The closed-cell aluminum foams, produced by the method of direct foaming in aluminum melt, need to be punched to increase their absorption efficiency if we want them to be as the face panel of the sound barrier. Similar to the open-cell aluminum foam, they also need to be combined with the rear panel to form a hollow composite structure. Figure 6 is the photos of a sound barrier project for latitudinal highway bridge in Shenyang, which is made of closed-cell aluminum foams treated by drilling and provided by Shenyang NEU Advanced Materials Development Co., Ltd. The whole structure of this sound barrier is similar to that of “Xupu” bridge.
Figure 6. Photos of a sound barrier project made of closed-cell aluminum foam (a) Front side of the sound barrier; (b) Back side of the sound barrier

The difference lies in that the former absorber is made of small pieces of open-cell aluminum foam while the latter is made of large scale of closed-cell aluminum foam. The noise reduction of two kinds of sound barriers is close to 10 decibel. In addition to the applications mentioned above, the closed-cell aluminum foams have been also used in buildings, vessels, railway, spacecraft and military protection engineering, etc. When the closed-cell aluminum foam panels are used in buildings, they are fixed on the interior wall of the buildings not only to act as a decoration but also to absorb the surrounding noises. In order to reduce the effect of noise on the surrounding environment, the panels are often fixed on all the walls of fen room or pump chamber. In terms of the application of aluminum foams in buildings, Shanghai SOHO Revival Square is a famous example. The building locates in the center of Shanghai inner ring road. A large quantity of aluminum foam panels were used in the lobby and other public areas to achieve the purpose of sound insulation, electromagnetic shielding and heat preservation, etc, shown in figure 7 (a) and (b).

Figure 7. Interior decoration of SOHO Revival Square, (a) Lobby; (b) Escalator room

It can be seen in figure 7 that aluminum foam not only holds multiple functions but also has a strong decorative effect. The aluminum foam used in the project was provided by Sicuan Yuantaida Nonferrous Metal Materials Co., Ltd. Similar to the application in buildings, the aluminum foams used in vessels include the following content: the separator of compartments, the lining of compartment door and the protective cover of engine cabin, etc. As a lightweight and shock resistance material, the aluminum foam can be widely used in railway. As for now, aluminum foams act mainly as the lining of the door of subway train and the crossbeam above the door. They are also made into shock resistance blocks and the blocks are inserted into the end of the train compartment to avoid the impact on each other. The supplier of this material is Hangzhou Longbang Alloy Science and Technology Co., Ltd. Figure 8 is the sketch of aluminum foam application in railway. The door of subway train filled with aluminum foam material has both flexibility and safety.
The application of aluminum foams in spacecraft suggests its energy absorption property. The aluminum foam used as buffer cushion of spacecraft re-entry capsule can absorb the impact energy from the capsule landing and protect astronauts. Likewise, the property can be also applied to the protection of military targets. Besides, an interesting example may reflect the application of this property further. The piers of Sichuan “Yingxiu” bridge are always destroyed by the flood and the rolling stones entrained during the rainy season (see Fig.9(a)). To prevent the piers repaired from damage again, the aluminum foams are bonded on the internal surface of a semi-circular steel plate to form a protective cover (see Fig.9(b)). In the process of installation, two semi-circular protective covers are slung to the bridge pier and closed together, then fixed by screw bolts (see Fig.9(c)). As shown in Fig.9(d), the bridge piers installed with protective covers can resist the flood, rolling stones and pass through the flood season safely.

4. Summary
Over the past thirty years, great progress has been made in the preparation and research of metal foams in China. Especially in the preparation of aluminum foams, they can be prepared by infiltration casting or direct foaming in aluminum melt method in commercial scale production. Meanwhile, the research on powder metallurgy route, melt foaming by gas injection and investment casting is successfully executed with great achievement. The aluminum foam production has been used in highway and railroad noise control, construction of building, vessels, subway train and spacecraft, as well as the protection of bridge. The manufacture and application of aluminum foams have become a prosperous trend in China.
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