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A review on manufacturing and application of open-cell metal foam

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Abstract

The present paper introduces the manufacturing process and industrial applications of Alantum metal foams having a complete open-pore structure. Wide spectrum of foam products, based on several distinguished properties of metal foams is described. Examples of Alantum foam products, transited to the industrial applications are provided with the roles of foams during their performances.

Peer-review under responsibility of Scientific Committee of North Carolina State University

Keywords: Open-cell structure; Emission control; Energy storage system; Environmental catalyst

1. Introduction

Alantum is a global company located in Korea (HQ), China, Germany and the U.S., which produces 4M m^2 of pure foams (Ni, Fe, Cu, etc.) and 0.5M m^2 of alloy foams annually. Alantum has successfully developed its patented manufacturing process to enable the application-optimized, economical production of a variety of alloy foams in different material systems.

Alantum's high-quality metal foams (certified to TS 16949 and ISO 9002) possess completely open-pores (Figure 1) with tailored and uniform structural and material properties. The flow of fluid media (gas or liquid) through such a 3-D tortuous path is well-characterized in terms of pressure drop and mixing behavior as shown by Walther et al. (2010) and Oh et al. (2011). By adapting various cell sizes (450, 580, 800, 1200 and 3000 μm) and the alloy compositions (e.g. NiFeCrAl, NiCrAl, NiAl, NiCu, Inconel 625, FeCrAl, STS 316L), the Alantum metal foams meet clients' requirements such as corrosion resistance and high temperature stability.

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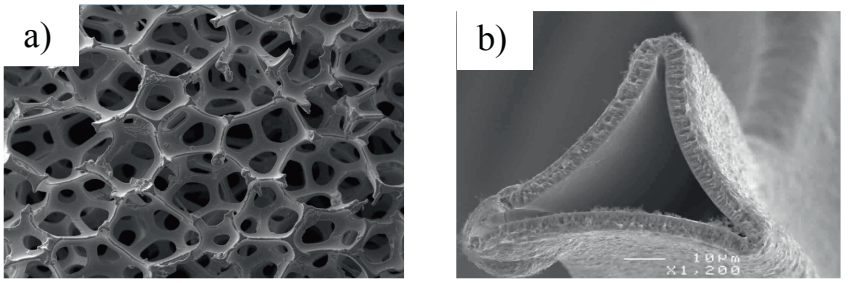

Fig. 1. SEM micrographs of a) open-pore structure of pure Ni foam and b) strut of Ni foam having unique hollow-structure inside.

Also, other properties including easy formability, light-weight and open-pore structure with design flexibility make the Alantum metal foams as a versatile material. These foams allow for an even temperature distribution in heated- or cooled-tools, optimum mixing of fluids or gases and effective filtering. Due to the above unique characteristics, the Alantum metal foams have been utilized in a wide range of applications such as catalyst supports, vehicle after-treatments, flame distributors, energy storage systems (ESS), etc.

2. Experimental

2.1. Manufacturing process of alloy foam

The manufacturing process of the Alantum alloy foams is schematically shown in Figure 2. The main features of the patented powder metallurgical process are the coating of the pure foam with an organic binder solution and afterwards with a high-alloyed powder using a spraying technique in a continuous process as demonstrated by Walther et al. (2010) and Oh et al. (2011). The amount of powder applied on the pure metal foam determines the powder-foam ratio (PFR), which is the percentage of powder with respect to the overall mass of the alloyed foam. Its optimum value depends on its respective applications and the pore size. The following heat-treatment includes de-bindering and sintering in a vacuum furnace, which allows the powder diffusion of transient liquid-phase ensures the homogeneity of the alloy composition throughout the alloy foam strut.

The SEM micrograph in Figure 3 reveals the bumpy surface of the Alantum alloy foam along the foam struts, resulting in much larger specific surface area. The combined characteristics of such high specific surface area and open-pore structure of the alloy foam manifest a variety of unique advantages such as outstanding mass transfer, high contact efficiency and good adhesion of catalytic coatings onto alloy foam in various industrial areas.

Also, for some specified applications demanding a thickness increase with mechanical strength, the foams can be stacked, compressed and sintered. This implies that the Alantum alloy foams can be effectively transformed into different shapes (Figure 4) which customers require due to their high flexibility and degree of freedom in designing products.

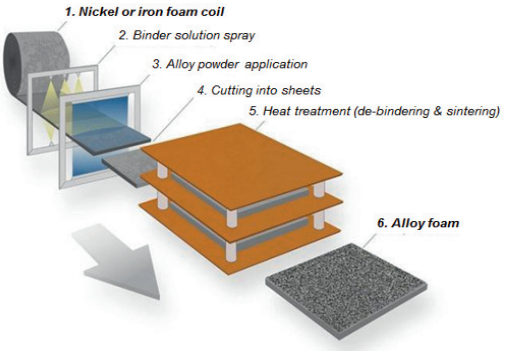

Fig. 2. Alantum's alloy foam production process

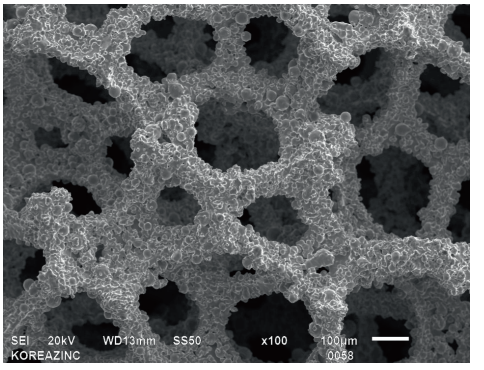

Fig. 3. SEM micrograph of Alantum alloy foam

Fig. 4. Alantum alloy foam products in different shapes

Fig. 5. The Alantum pDPF product consisting of radial candle assembly

3. Applications

The Alantum metal foams are currently applied to a number of industrial areas based on their unique structural and functional properties. Those industrial areas are categorized into three business segments, *i) Clean Air Technologies*, *ii) Chemical Process Technologies* and *iii) Special Products*. Several promising applications in each segment are described in the following.

3.1. Clean air technologies

The Alantum metal foams are the source material for many emission control applications, which include:

- Partial Diesel Particulate Filter (pDPF)
- Diesel Oxidation Catalyst (DOC)
- Four Way Catalyst
- Particulate Oxidation Catalyst (POC)
- Selective Catalytic Reduction (SCR)
- Water Gas Shift (WGS) catalyst support
- Exhaust Gas Recirculate (EGR) Filter

The Alantum metal foams are known as a good inherent filtering material. This is because large number of particulates can be entrapped within the tortuous structure under well-controlled pressure drop condition. Rough surface and large surface area ensure high contact efficiency and enhanced coatability of the washcoat as a catalyst substrate. Simultaneously, these foams can significantly reduce combustion noise from the exhaust system.

Representatively, Alantum pDPF products for light and heavy duty vehicles were officially certified by Korean and German Governments and over 15,000 vehicles equipped with the Alantum pDPFs are under operation currently. Standard design of pDPF and microstructure of DOC-washcoated metal foam are shown in Figure 5 and Figure 6, respectively.

3.2. Chemical process technologies

As a catalyst support, the Alantum metal foams can be applied to chemical processes such as:

- Steam Methane Reforming (SMR)
- Methanation
- Dehydrogenation
- Ethylene Oxide

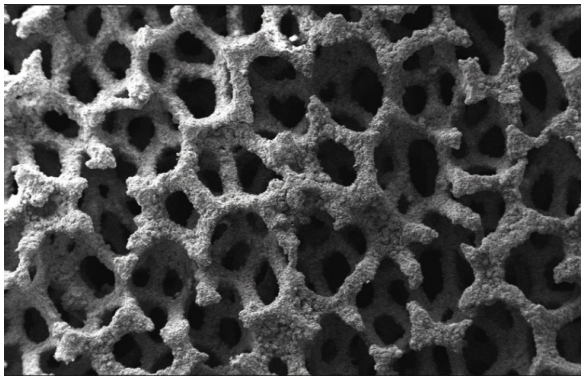

Fig. 6. SEM micrograph of washcoated Alantum foam used for DOC application.

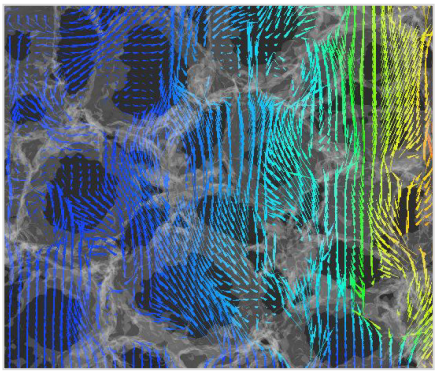

Fig. 7. Simulation of the flow inside the Alantum foams

The 3-D structure of the metal foam matrix allows them to continually disrupt and distort the flow path (Figure 7) producing exceptional mixing that enhances the accessibility of the reactants, products, and heat to and from the surface. This superiority of the metal foams in mass transfer and heat transfer improves process efficiency, reduces operational cost and enhances the catalytic reactivity.

In the applications to the chemical process, metal foams have to be formed into pellets in various shapes and dimensions as shown in Figure 8. Due to the excellent workability and reactivity of metal foams, Alantum foam pellet products can widely meet clients' needs including mechanical strength and chemical stabilities in a condition at high temperature and pressure.

3.3. Special products

Unique properties of the Alantum metal foams are highly employable for various applications such as:

- Industrial gas filters (SCR and VOC system)
- Gas and liquid mixers
- Pressure regulators
- Fuel cell components
- Battery components
- Gas burners

As a substrate for selective catalytic reduction (SCR) system and volatile organic compound (VOC) system, large surface area of the metal foams creates tortuous flow and plays an important role by significantly reducing the volume of platinum group metal (PGM) catalyst (Figure 9). In addition, good thermal and electrical conductivity allow for an effective operation in a wide range of temperature. Moreover, cell sizes over a wide range from 450 μm to 3000 μm and the uniformity in cell size distribution enable metal foam to perform as an optimized mixing promoter in industrial applications.

Fig. 8. The Alantum foam pellets used in applications to chemical processes

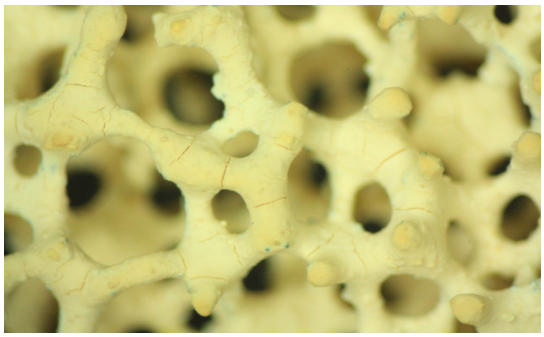

Fig. 9. SCR-washcoated metal foam

Here, high permeability and mechanical strength are the key factors for the use of fuel cell and rechargeable battery components. Conventionally, Ni foam has been used to Ni-metal hydride battery for many years and other alloy and composite metal foams are currently in the development to increase energy density and reliabilities. As a combustion enhancer, metal foams enable to deliver longer life cycle and effective performance compared to conventional materials.

Also, metal foams, especially in combination with cover plates, provide us with a high potential for applications as light weight and functional materials. Currently, a solution for aircraft turbines to reduce noise and to improve the performance is under development in cooperation with global partners.

4. Conclusions

The patented manufacturing process of the Alantum metal foams allows for homogeneous open-3D structure and alloy compositions that are distinguishable from other porous metal materials. Unique characteristics of the Alantum metal foams relying on these properties, offer a wide range of applications in the field of *i) Clean Air Technologies*, *ii) Chemical Process Technologies* and *iii) Special Products*. Due to the extendibility of applications, the latest metal foam is evolving to achieve specific characteristics such as thin-thickness, light-weight, excellent-temperature/chemical durability. In a few years of development, the Alantum metal foams will be able to be applied to advanced aerospace and bio-medical industries where ultra-light weight and high structure reliability are required.

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