# Aluminum Foam,"ALPORAS ": The Production Process, Properties and Applications

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## Abstract

The production of foamed aluminum has long been considered difficult to realize because of such problems as the low foamability of molten metal, the varying size of cellular structures, solidification shrinkage and so on. These problems, however, have gradually been solved by researchers and some manufacturers are now producing foamed aluminum by their own methods. We have been manufacturing foamed aluminum under the trade name ALPORAS® since 1986 employing a batch casting process. This paper presents the manufacturing process, physical properties and some typical applications of ALPORAS.

## 1. Introduction

ALPORAS® is an ultra-light material with a closed cell structure. We have been working on such a material for many years and succeeded in its practical development. In particular, we have improved the sound absorption characteristics of ALPORAS and we could expand the market. We have installed a manufacturing plant that is capable of making large sized blocks of foamed aluminum with a better quality. The plant employs a batch casting process. With the new plant, we can control the cell size and density according to the applications.

## 2. Manufacturing process of aluminum foam

ALPORAS is manufactured by a batch casting process (Fig.1). To make aluminum foam from molten aluminum, it is necessary to stabilize bubbles in molten aluminum. The most important factor for stabilizing the bubbles in the molten aluminum is to increase its viscosity and prevent the bubbles from floating. We use 1.5 wt% Ca as a thickening agent. Ca is admixed with molten aluminum at 680°C and stirred for 6 minutes in an ambient atmosphere.

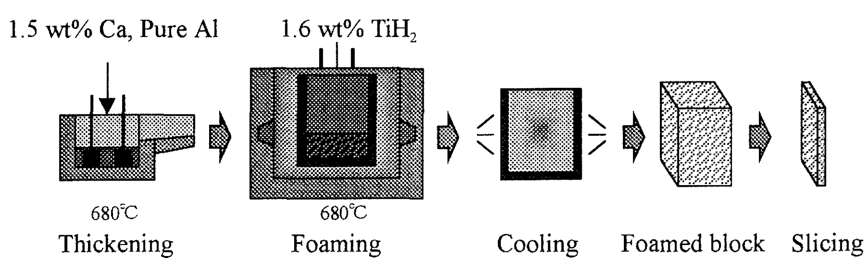



Fig.1. A manufacturing process of ALPORAS

Viscosity is represented by the shearing resistance or stirring resistance of a fluid, which is measured in torque. The thickened aluminum alloy is poured into a casting mold and stirred with a blowing agent of 1.6 wt% $TiH_2$ at 680°C. After stirring, the molten material is cured for about 15 minutes to expand and fill up the mold. Then, the foamed molten material is cooled with a powerful blower to harden in the casting mold. A cast ALPORAS block measures 450 x 2050 x 650 mm and weighs 160 kg. After the aluminum foam block is removed from the casting mold, it is sliced into flat plates of various thicknesses according to the purpose.

## 2.1 Thickening method

For adjusting the viscosity of a molten metal, there is a method to increase the apparent viscosity by suspending and dispersing fine solid-phase particles. Ceramic particles such as SiC, $Si_3N_4$ and $Al_2O_3$, and the solid-phase of an alloy system in the solid-liquid zone can be used for aluminum. In these cases, however, it is difficult to control the temperature for keeping the sold-phase ratio at a constant value. It is reportedly known that several hours of agitation are required for evenly wetting and suspending fine powders having a grain size less than 20 μm in the case of SiC. The solid phase of an oxide, in contrast, can be evenly dispersed by using an internal oxidation method such as agitation in an ambient atmosphere, blowing the air and so on. The addition and subsequent agitation of an element with a high oxygen affinity, such as Ca and Mg, facilitates an oxidation process on the surface of the molten metal. This process can generate an oxide (i.e. CaO, MgO, $Al_2O_3$, $CaAl_2O_4$ and so on) in such a volume as required for thickening the molten aluminum in a short time. This method utilizes a chemical reaction within a melt and is capable of evenly wetting and dispersing fine solid-phase particles in a liquid [1-2]. Fig. 2 shows the change in torque (stirring resistance) due to the addition of Ca to molten aluminum [1]. While the pure molten aluminum does not pick up torque so much by stirring, the addition of Ca increases the torque (viscosity) remarkably.

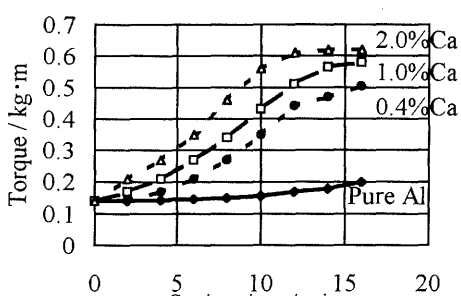



Fig. 2. A change in stirring resistance due to the addition of Ca to molten Al

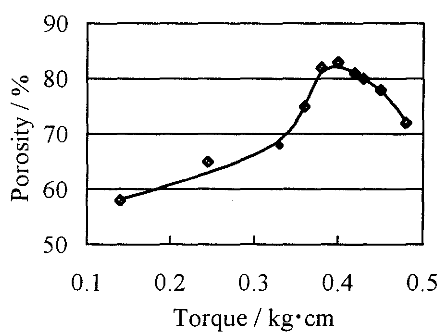



Fig. 3. Effect of stirring resistance on porosity of the resulting foam

Fig. 3 shows the effect of torque (stirring resistance) on porosity. When a stirring resistance is 0.25 kg·cm, for example, bubbles easily float through the molten material and gas is dissipated from the surface. So, the volume of each cell is small (Fig. 4). At 0.45kg·cm, bubbles hardly come to float in the foaming molten material and gas pressure rises so high in its center that the cell membranes collapse. Therefore, there is an appropriate stirring resistance for maximizing the foaming ratio [1].

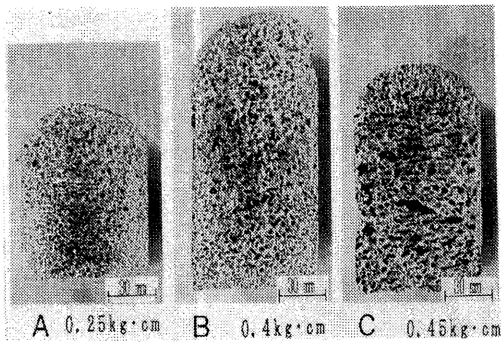



Fig. 4. Effects of stirring resistance on foam formation

## 2.2 Foaming

Fig.5 shows a mount of hydrogen gas produced by the thermal decomposition of 1g of blowing agent, $TiH_2$, in the molten aluminum. The volume was measured under atmospheric pressure. The volumetric yield of gaseous hydrogen from the decomposing $TiH_2$ depends on the temperature: The higher the temperature, the more and the faster the gaseous hydrogen is released from $TiH_2$. Most of the gaseous hydrogen bubbles that are released in the first 100 seconds of stirring float through the molten material and catch fire. Therefore, the effective blowing gas is only generated after 100 seconds of admixing $TiH_2$ and stirring.

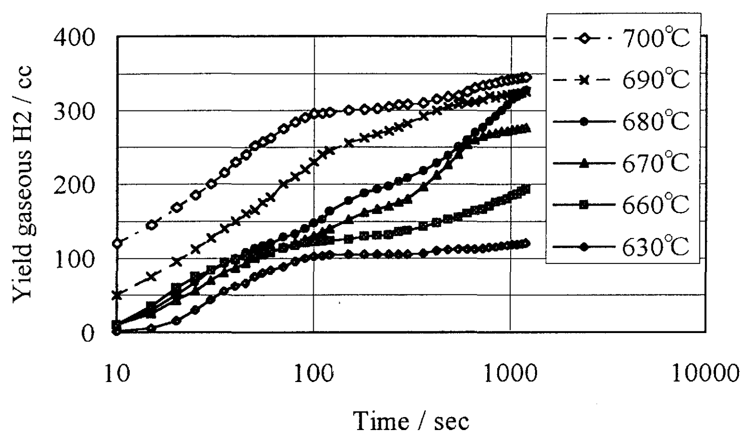
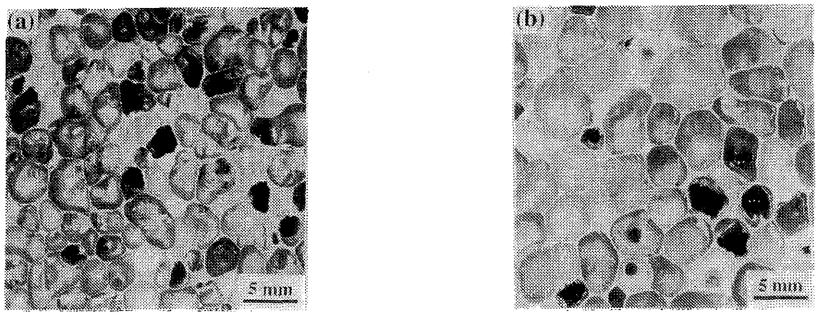



Fig. 5. Hydrogen gas produced by the thermal decomposition of $TiH_2$ in Al

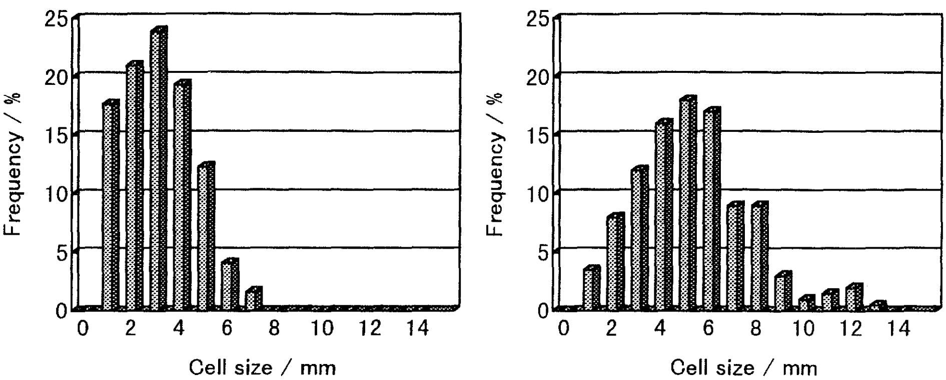
## 3. Characteristics

Typical cell structures of two different cell sizes of ALPORAS are shown in Fig. 6. Type (a) has smaller cell sizes than the type (b) that is a conventional ALPORAS for sound absorbent. The cell sizes of type (b) are distributed over a range of 1 to 13 mm (Fig. 7(b)) with a mean cell size of 4.5 mm, (Fig. 6 (b)). The mean cell size of type (a) is 3.0 mm, (Fig. 6(a)). The cell sizes of type (a) are distributed over a range of 1 to 7 mm (Fig. 7(a)).




(a) A smaller cell type (b) A conventional ALPORAS

Fig.6. Typical cell structures




(a) A smaller cell type (b) A conventional ALPORAS

Fig.7. Cell size distributions

Fig.8 shows examples of the distribution of the apparent density along the width of ALPORAS foamed blocks. The apparent density is high at either side of the block but gradually decreases toward the center. Because the foamed molten material keeps expanding until it hardens and the nearer center, the later it hardens.

The apparent density of the product is between 0.18 - 0.24 g/cm$^3$, which is approximately 13 times the volume of solid aluminum. We can control the cell size and the density to some degrees to meet the intended use.

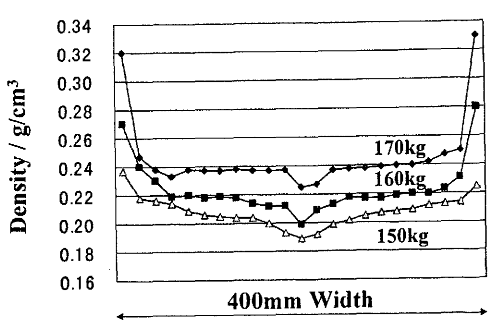



Fig. 8. The distribution of the apparent density along the width of foamed blocks

Typical stress-strain curves for type (a) and (b) at a quasi-static strain rate of $1x10^{-3}$ $S^{-1}$ are shown in Fig. 9. The diagram shows a quasi-elastic region at the initial stage, then, followed by a plateau region (with nearly constant flow stress). After the plateau region, the flow stress rapidly increases because the specimen densifies. The relative density of both samples is identical (0.105). It is clearly observed that the plateau stress in type (a), however, is higher than that in type (b). The average values of energy absorption per unit volume of ALPORAS at a strain of 0.5 for type (b) and type (a) are evaluated as 0.94 and 1.32 $MJ/m^3$, respectively. The energy absorption of type (a) is about 40% higher than that of type (b). It is noted that the enhancement of energy absorption can be achieved by modifying the structure [3].

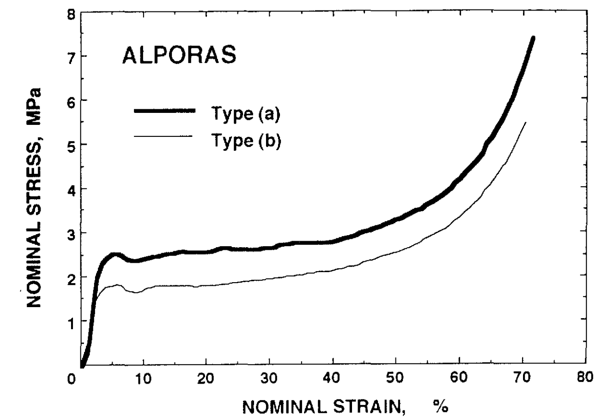



Fig. 9. Nominal stress-strain curves at a quasi-static strain rate of $1x10^{-3}$ $S^{-1}$

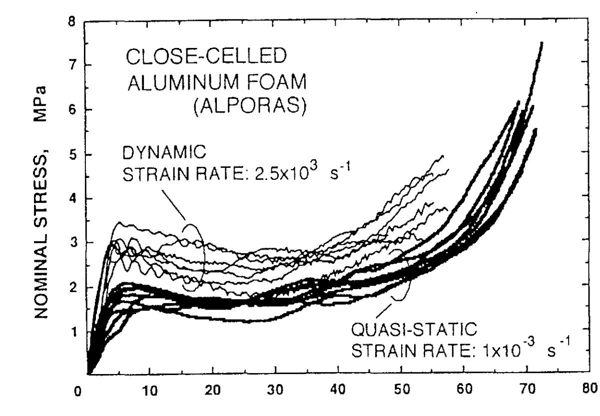



Fig. 10. Nominal stress-strain curves at a quasi-static strain rate of $1x10^{-3}$ $S^{-1}$ and at a dynamic strain rate of $2.5x10^3$ $S^{-1}$

Several stress-strain curves at a quasi-static strain rate of $1x10^{-3}$ $S^{-1}$ and at a dynamic strain rate of $2.5x10^3$ $S^{-1}$ are shown in Fig. 10. The average values of energy absorption per unit volume of ALPORAS at a strain of 0.55 for the quasi-static strain rate and the dynamic strain rate are calculated to be 1.00 and 1.51 $MJ/m^3$, respectively. The absorption energy at the dynamic strain rate is about 50% higher than that at the quasi-static strain rate [4].

Fig.11 shows tensile stress-strain curves in which the stress sharply decreases after yield and the breaking force becomes very low. After the peak stress, cracks start to propagate from the corners of relatively large cells, leading to an unstable fracture [5].

Fig.12 shows the relationship between compressive strength and the porosity of the aluminum foam [6]. With an increase in the porosity, the strength drops exponentially. The ratio of the drop further increases as the porosity exceeds 70%. This is because the spherical cells become polyhedron cells when the porosity exceeds 70% (Fig.13). This is one of the causes of stress concentration that occurs at the defects in the cell walls resulting from the growth and coalescence of bubbles. The tensile stress (Fig.14) and electrical resistance (Fig.15) also have a tendency similar to the compressive strength [6].

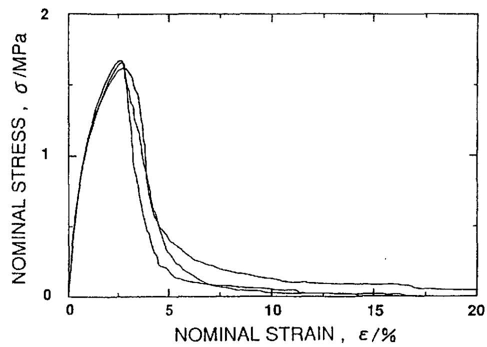



Fig. 11. Tensile stress-strain curves

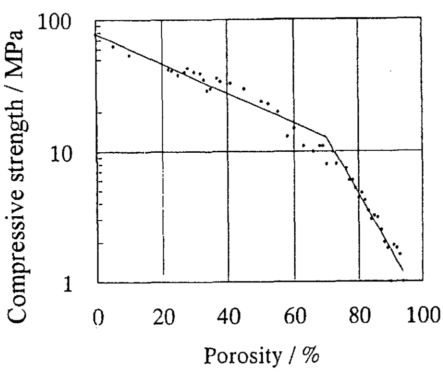
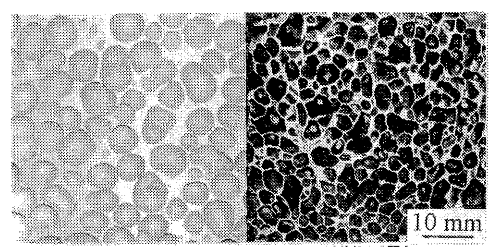



Fig. 12 Relationship between Compressive strength and the porosity




Porosity 60% Spheroid

Porosity 93% Polyhedron

Fig. 13 Structures of foamed aluminum

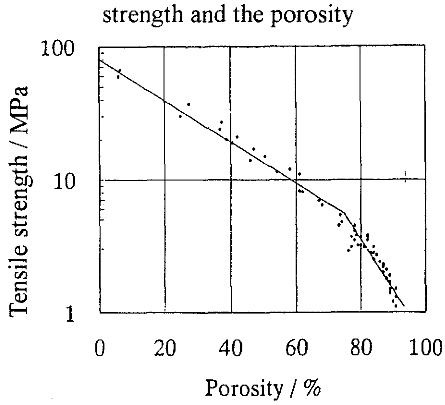



Fig. 14. Relationship between Tensile strength and the porosity

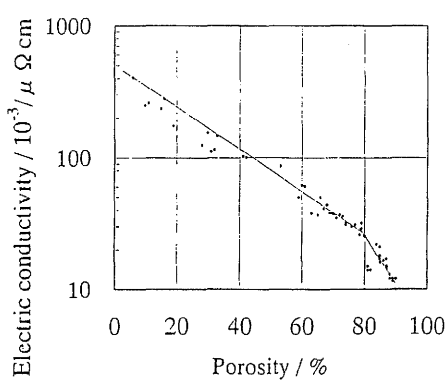



Fig. 15. Effect of porosity of the foamed aluminum on electric conductivity

## 4. Applications

Fig.16 shows the sound absorption coefficient of a rolled ALPORAS measured by the reverberation chamber method in comparison with an unrolled ALPORAS and a glass wool of 40 mm in thickness and 25 kg/m$^3$ in density [7]. The rolled ALPORAS has such a large sound absorbing coefficient that it is equivalent to the glass wool. Fig.17 shows an example of an application as a sound absorber: ALPORAS fixed to the under-side of an elevated expressway for noise absorption. A cylindrically bent sound absorbing structure is laid on the noise reflecting surface of an elevated viaduct to absorb the vehicle emissions, thus reducing the noise exposition to the neighborhood residents.

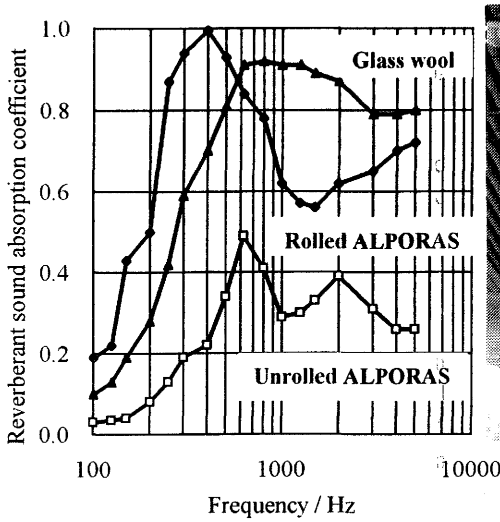



Fig. 16. The sound absorbing coefficient of rolled ALPORAS

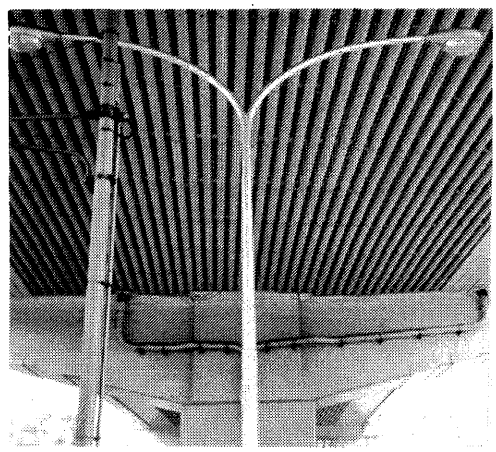


Fig. 17. Sound absorbing structure on the under-side of an elevated viaduct

ALPORAS has a high impact absorbing function owing to its substantial deformation capability under low stress (Figs. 9 and 10). It is used as an impact cushion for express rolling stocks and vehicles for saving drivers' lives in collisions.

Aluminum foam has many other applications, including the double layer floor of a room where electronic equipment is arranged for office automation, filter material and the microbiological incubation carrier.

## 5. Summary

ALPORAS is a closed cell type aluminum foam, which is manufactured by batch casting where Al is thickened by Ca and blown by $TiH_2$. The density of a general type is between 0.18-0.24 g/cc and its mean cell size is 4.5 mm in diameter. It has excellent sound absorption and shock absorption capabilities and its main application is as sound absorber.

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