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DESIGN AND FABRICATION OF ALUMINIUM FOAM TUBE FOR HEAT EXCHANGER APPLICATION

Ismail Lias, Mohammad Irsyadudden Nasir, Muhammad Hussain Ismail and Aman Mohd Ihsan Mamat
Center for Advanced Material Research, University Teknologi Mara, Faculty of Mechanical Engineering, Shah Alam, Selangor, Malaysia, Department of Polytechnic Education, Gelaria PjH, Presint 4, W.P. Putrajaya, Malaysia
E-Mail: ismailjmsk@gmail.com

ABSTRACT

Aluminium foam is a metal that consist of porous medium with special characteristics such as good energy absorption, high thermal conductivity and good heat transfer. The special characteristic make suitable to be used for a wide range of application include heat exchanger and energy absorption. The aim of this project is to design and fabricate aluminium foam tube for heat exchanger application. The infiltration method with vacuum-gas was used to fabricate aluminium foam tube. Stainless steel mould was designed with diameter size of 10 cm and core at the centre. The aluminium foam produced was scanned by using CT-Scan to observe the geometry and pores size after replication. In addition, the density and porosity of aluminium foam tube also determined in order to get correlation between the space holder used. Result show that aluminium foam tube with large size was fabricated successfully by using infiltration method with vacuum-gas. The aluminium foam tube with diameter of 10 cm and height of 4 cm to 13 cm was produced by this method. The pore size of the foam tube is in range of 2 mm to 6 mm .This aluminium foam manufacture method can be produced for variety of shape and size and can be applied for many applications.

Keywords: aluminium foam tube, infiltration method, heat exchanger.

INTRODUCTION

The heat exchanger is device to transfer heat between one fluid to another fluid with different temperature. There are widely used in many applications such as automotive, aerospace and many industrial applications [1]. Metal foam is a new type of material that has a special characteristic such as lightweight, high coefficient of heat transfer and high strength [2]. They can be divided into closed and open cell material. Open-cell metal foam is if the voids are connected each other via open pores while closed cell is if the voids are not connected via open channel and it is separated by the wall [3]. The characteristic of open cell metal foam such as large specific surface area is suitable for heat exchanger application [4].

There are many methods has been introduced in manufacturing metal foam or aluminium foam, namely melt-gas injection, melt-foaming, powder metallurgy, investment casting and melt infiltration [5]. The DUOCEL process is one of the casting processes that used open-cell polymer foam mold template to produce open-cell foam. Polymer foam is mixed with sand and then baked to harden the casting material and decompose polymer template. The metal alloy is filled into the mold and let it solidify. After that, the mold material is removed and open-cell foam was produced [6]. Another method in producing open-cell foam introduced by Shaik Dawood and Mohamed Nazirudeen [7] is using organic granule as space holder. This method known as casting metal around the granule by which a liquid material is poured into mold that contain a hollow cavity of the granule (e.g. sand ball), and then allowed to solidify. The example application of metal foam such as lightweight pressure tank is used DUOCEL aluminium foam as the structural core, heat exchanger and anti-slosh baffle [6].In producing open-cell aluminium foam, the common process that has been used is called infiltration casting process that used Sodium Chloride particle as a space holder [8][5]. This process use aluminium as main material because aluminium melting temperature is 660 ºC while melting temperature of Sodium Chloride is 801 ºC. Therefore, the aluminium will melt first and infiltrate through sodium chloride particle.

Although there have other report on the fabrication of aluminium foam, there is no specific method in producing aluminium foam tube. This paper is focus on the processing of aluminium foam tube using Sodium Chloride as space holder for heat exchanger application. It includes the density & porosity, and microstructure observation of the aluminium foam tube fabricated.

METHODOLOGY

Two method of fabrication aluminium foam tube had been done in this project. First is the conventional casting by using sand casting method and second is infiltration melting method.

Case study

Sand casting method

The aluminium foam tube was fabricated by using sand casting process. This method was implemented by past researcher and successfully produce open-cell aluminium foam [9]. The cylindrical cavity was made by using CO_2 casting process. The Figure-1 shows the schematic diagram of the process. Sodium Chloride (NaCl) particle was filling into the mould cavity and close by cope part. Then, aluminium molten was poured into the mould through the sprue and allowed for solidified.

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After removing the cast part from the mould, it was observed that the molten aluminium does not completely fill the cavity as shown in Figure-2. It is because aluminium molten was rapidly solidified before it is completely fill the cavity.

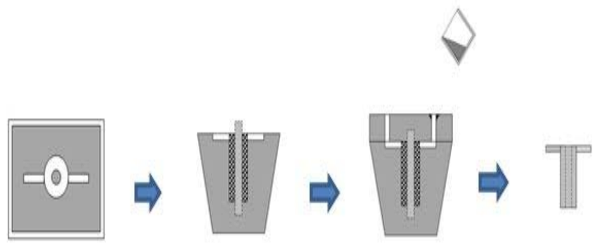

Figure-1. Schematic diagram of casting method.

Figure-2. Cast part.

Melting method

Aluminium foil was used to fabricate aluminium foam. The aluminium foil was mixed with NaCl particle in the mould. Then, the mould was placed in furnace and heat up. The idea is to melt the aluminium foil and it will flow through the NaCl particle evenly. After completely heat and cooled down, the sample was removed from the mould. From the observation, the aluminium foil was partially melted because the surface has been coated with aluminium oxide. The sample is shown in Figure-3.

Figure-3. Sample by using aluminium foil.

Infiltration method with vacuum-gas

Mold preparation

In the fabrication of aluminium foam tube, mould was designed according to the specified dimension. The schematic diagram of the mould is shown in Figure-4a and Figure-4b. It consists of a base plate, main cylinder, core, and mould cap. All parts are made from stainless steel. The core was placed on the centre of main cylinder to produce hollow on the foam sample. The assembly was tightened by using screw and nut.

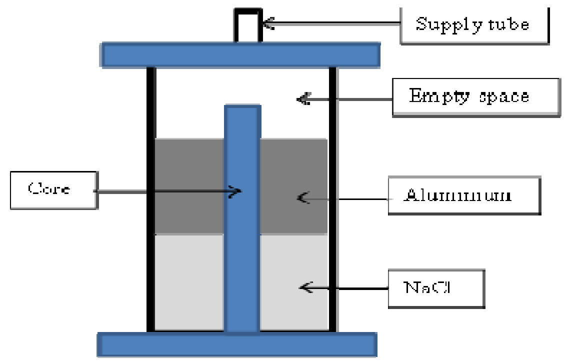

Figure-4a. Schematic diagram of mould.

Figure-4b. Picture of schematic diagram of mould.

Experimental procedure

The Infiltration method with vacuum-gas was using aluminium as main material and NaCl particle as space holder with the help of gas. This method was implemented by Barari [10] to manufacture the metal foam. The schematic diagram of apparatus for infiltration method is shown in Figure-5a and Figure-5b. The mould was prepared by coating with boron nitride. The NaCl particle was poured into the mould cavity followed by aluminium ingot on the top of NaCl. Then, the mould was tightly close by using nut and put in the furnace to heat up. After a few hours of heating, the vacuum pump valve was open to remove air in the mould. The argon gas valve was immediately open after vacuum pump valve is closed to purge gas into the mould cavity. The gas will push the aluminium molten to flow through the NaCl particle.

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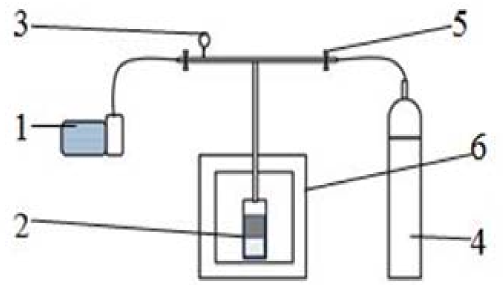

1-Vacuum pump, 2-Mould, 3-Pressure gauge,
4-Argon gas, 5-Valve, 6-Furnace

Figure-5a. Schematic diagram of apparatus.

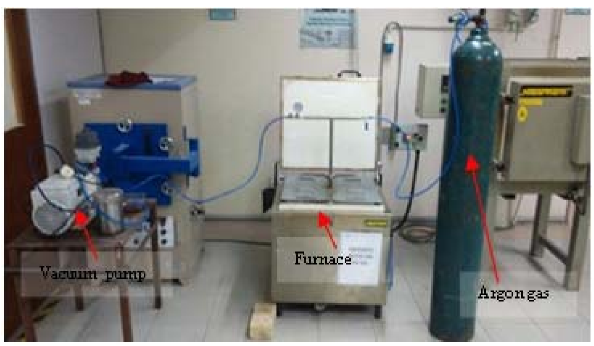

Figure-5b. Picture of schematic diagram of apparatus.

After solidification and cooling, the sample is removed from mould and then machined into required dimension by using lathe machine. Finally, the sample is cleaned by using ultrasonic cleaner. The water was set to temperature of 90 ^{o}C and the process was repeated a few times to ensure the NaCl was completely removed. The microstructure of aluminium foam tube fabricated was observed using stereomicroscope and CT-scanning to get the correlation between the space holder used.

RESULTS AND DISCUSSION

Infiltration process

In the infiltration method vacuum-gas method, the main parameter need to consider is design of mould, vacuum and gas pressure. These parameters are analysed and determined. The design of mould is important so that during the fabrication process it is no leaking. The leaking of mould can cause mould are not in vacuum condition and the gas cannot be compressed. In infiltration process, gas is necessary to push the molten metal to flow through the NaCl particle. Therefore, the pressure of gas must carefully control. The time taken to purge gas is depending on the height and size of the sample. Figure 6a-Figure 6d show the sample that had been produced in this process.

Figure-6a. Aluminium foam tube fabricated.

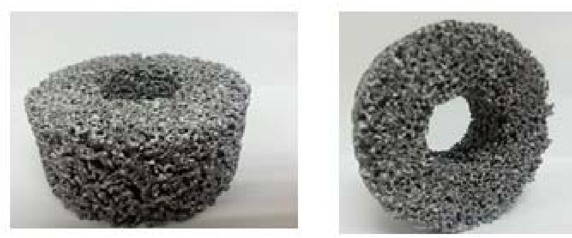

Figure-6b. Aluminium foam tube fabricated combination pore size (3 mm + 4 mm).

Figure-6c. Aluminium foam tube fabricated combination pore size (2 mm+3 mm + 4 mm).

Density and porosity

The quality of the foam produces in depend on its porosity and density [11]. Density is physical characteristic and is a measure of mass per unit volume of a material. The density of aluminium foam can be written as in the following equation.

$$\rho = m/v \quad (1)$$

where ρ = density, m = mass, v = volume

Porosity is percentage value of a material is made up of void space. It is also can be defined as the total open volume of interconnected and isolated porosity. Porosity

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percentage is calculated by rough measurement of the open volume equal to 100% minus the part density [7].

Figure-6d. Aluminium foam tube fabricated combination pore size (4 mm+5 mm + 6 mm).

$$\text{\% of porosity} = \frac{\rho_{Al} - \rho_f}{\rho_{Al}} x100 \quad (2)$$

Where:
ρ_{Al} = Density of aluminium, ρ_f = Density of the foam

Table-1. Density and porosity and aluminium foam tube.

Sample	Mass, g	Height, cm	Volume, cm^3	Density, g/cm^3	Porosity, %
1	198	2.6	184.70	1.072	60.29
2	139	4.0	221.46	0.628	76.77
3	454	7.1	407.52	1.114	58.74
4	798	8.2	544.07	1.467	45.67
5	675	10.5	696.68	0.969	64.11
6	634	14.0	729.86	0.867	67.89
7	553	10.0	577.25	0.958	64.52
8	596	10.0	570.61	1.044	61.33

Table-1 show the comparison between the aluminium foam tubes had been produced. By observing the data in the table, the density of sample is ranging between 0.6 to 1.5 g/cm^3. The sample 2 show the highest porosity and its produces density of 0.628 g/cm^3 which correspond to about 76.77% in porosity while the lowest porosity is produced by sample 4 which produces density of 1.467 g/cm^3 correspond to 45.67% in porosity. The different value of density is due to the size of NaCl used and also the compactness of the sample. By seeing the data it can be stated that the porosity of aluminium foam increase with decrease of the density.

Microstructure- stereomicroscope observation

As seen in Figure-7a and Figure-7b, the structure of the aluminium foam tube is different in term of pore size and shape. From the observation, pore size in Figure-7a (a) is slightly larger than pore size in Figure-7a (b). It is show that the percentage of porosity and density are depending on the pore size.

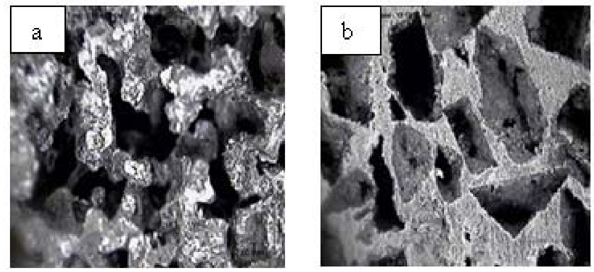

Figure-7a. Image of aluminium tube foam (a) Sample 2 (b) Sample 4.

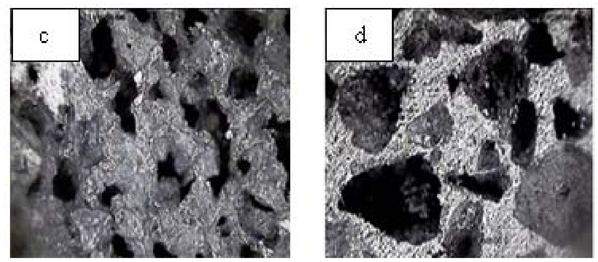

Figure-7b. Image of aluminium tube foam (c) Sample 3 (d) Sample 5.

CT-scan image

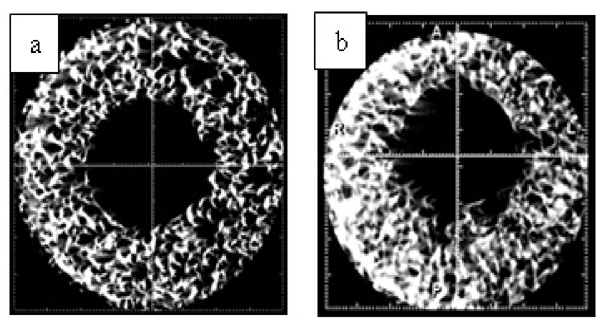

Figure-8a. Top view of CT-scan image (a) Sample 2 (b) Sample 4.

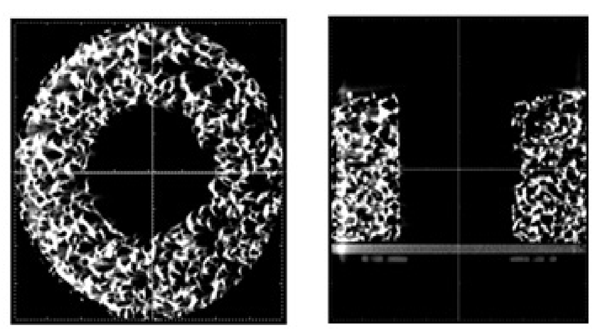

Figure-8b. Top and side view of CT-scan image for Sample 2.

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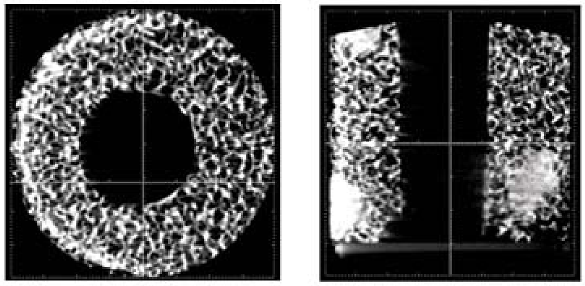

Figure-8c. Top and side view of CT-scan image for Sample 3.

The higher pore size will give higher porosity percentage and low density. In term of shape, Figure-7 (b) show that the fabrication of aluminium foam tube that replicate the shape and size of NaCl particle while in Figure-7(a) the replication of the NaCl particle shape cannot clearly seen.

Figure-8a – Figure-8c show the result from CT-Scanning. From the observation, can see the correlation between the space holder. The space holder from NaCl particle was creating the interconnection of metal to form open-cell aluminium foam. The dark region of the image represents the empty space and the light regions represent aluminium. More empty space can be seen in Figure8a (a) which mean it has high porosity compared to Figure-8a (b).

CONCLUSIONS

The method for producing aluminium foam tube was identified. Infiltration method with vacuum-gas with NaCl space holder is suitable to manufacture the aluminium foam tube. By this method, variety shape can be produce for many applications. The result on the density and porosity test show that the porosity is increase by decrease of density. The microstructure observation by using stereomicroscope show the pore size and the shape of NaCl particle was replicated by aluminium foam. In order to get uniform structure, the same size of NaCl particle is needed. The image from CT-Scanning gives the view of pore structure, pore distribution and the interconnected of the open-cell aluminium foam.

FUTURE WORK

The aluminium foam tube will be applied on the heat exchanger. The shell and tube heat exchanger will be used for analysing of heat transfer or heat absorbtion. Aluminium foam tube is fitted with the copper tube or stainless steel and insert in the shell. The hot gases will flow through the copper tube and liquid will flow in the shell.

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