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EXPERIMENTAL ANALYSIS OF AIR FLOW AND HEAT TRANSFER THROUGH ALUMINIUM METAL FOAMS

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ABSTRACT

The aim of the research works was to investigate the effect of pore size of the Aluminium metallic foam on air flow and heat transfer through three different pore sizes. Al foams were produced through infiltration process by open metal die casting using soil granules of different diameter as space holder particles (SHP). The fluid flow tests were conducted as per Darcian principle by using custom-made air duct. Developed Al foam density varies from 0.93g/cc to 1.22g/cc, the minimum density of 0.93g/cc for Al foam with SHP ball size of 8mm. Heat transfer test was conducted on Al foam to compare with commercial heat sink using custom made heat transfer setup. Results shows the pressure drop was directly proportional to the SHP ball size in Al foam, it was varied from 2616 Pa/m to 16023Pa/m for Al foam with SHP ball size 10mm. Heat transfer result showed that around 50% reduction in weight of the heat sink used for 2N3055 transistor by replacing commercial TO3 heat sink with Al foam heat sink.

KEYWORDS: *Al Foam, Air Flow, SHP, Pressure Drop, Heat Sink*

INTRODUCTION

Enhancement of heat transfer for electronic device applications is one of the highly interesting topics for research and industries. Many research showed that improvement of the heat transfer increases the heat transfer area. In this direction, the metallic foam is one of the best techniques to enhance the effective thermal conductivity for fluid flow. Because of the complex and nonlinear geometry of foam, it enhances disturbance of the fluid flow through them. In other hand due to the higher heat transfer surface area of the foam, it improves both fluid flow as well as greater heat transfer through them. Few researchers investigated both heat transfer and flow performance of metallic foam in air flow condition [1-3].

Open cell Al foam provide highly effective thermal conductivity due to their larger exposure area hence they find significant applications in both refrigeration and heat exchanger applications. The metallic foams heat exchanger provides double the heat transfer capacity than that of solid fin heat exchangers [4-5]. For designing metal foam heat exchangers both pressure drop and heat-transfer should be characterized before using it in real applications. Higher porosity foams provide relatively larger thermal conductivity heat transfer along with thermal radiation [6].

Although many works investigated on the effect of percentage of porosity foam on heat transfer of metal foams successfully but few or no research work focused on the effect of pore size pressure drop, permeability and heat transfer of the metallic foams. Pressure drop and heat transfer depend on each other hence this research work is very much essential.

The objective of the work was to develop and characterize Al foam for both pressure drop and heat transfer for different velocity and temperature respectively [7-8].

EXPERIMENTAL STUDY

Al6065 alloy was selected as a material for foams, Al is known for its low density, ductility, and thermal conductivity. Due to these interesting properties, they have been using a wide variety of applications. Chemical Composition of Al6065 alloy has given in Table 1 and a conductivity of 218 W/m K.

Table 1: Chemical Composition of Al6061 Alloy

Mg	Si	Fe	Cu	Ti
0.92	0.76	0.28	0.22	0.10
Cr	Zn	Mn	Be	Al
0.07	0.06	0.04	0.003	Bal

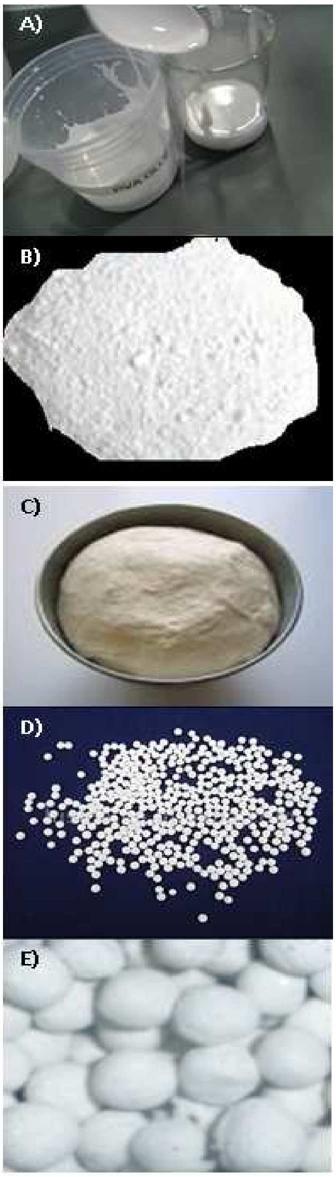

Figure 1: Steps for Preparation of Alumina Balls

The pore density can be found in several options, the most common are 8, 10 and 12 pores per linear inch (PPI) and can be adjusted independently of the variation of the relative density. Poly vinyl alcohol "Figure 1(a)" powder of 4 grams is mixed in 50 ml of water and then heated untill the PVA powder get completely dissolved in water. 100 gram of Alumina (Al_2O_3) (1 to 5 µm) is mixed with 22 ml of PVA solution "Figure 1(b&c)". This dough is extruded and cut into equal parts; these are rolled in an empty ball mill which results in solid spheres. Preparing the solid spheres was using a ball mill apparatus shown in "Figure 1(d)". The spherical shape was desirable to the regular packing of these ceramic balls in the mould "Figure 1(e)". These ceramic balls were then stored in a sealed bag to prevent any loss of moisture content. Preparing green sand mold of a dimension of 100 X 95 X 30mm include drying "Figure 2(a)" the mold sand at room temperature for 24 hours, pre-heating the mould box up to 500ºC and placing the solid spheres in the hot mould cavity and allowing it for 5 minutes as shown in "Figure 2(b)".

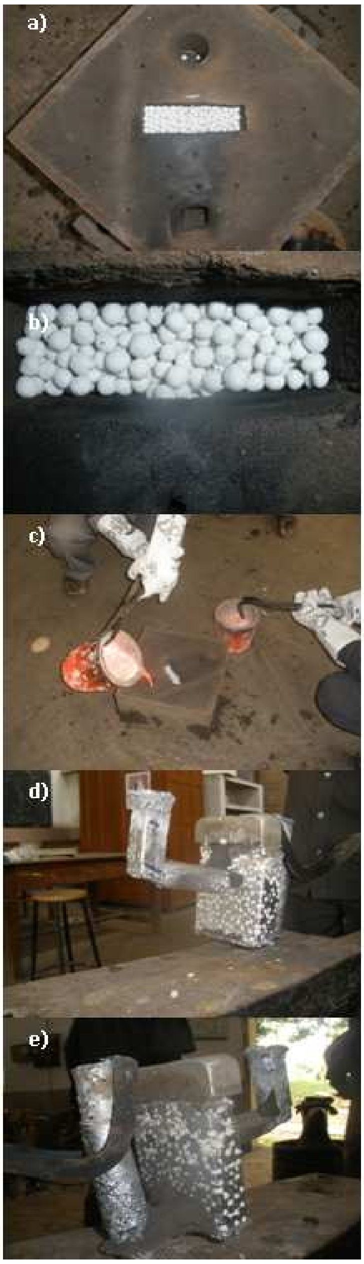

Figure 2: Steps for Preparation of Aluminium Foams

Melting of Al 6061 alloy using muffle furnace up to 800 °C, adding degas agent into the liquid aluminum and pouring the molten aluminum (>800 ºC) in the mold cavity filled with solid spheres and cooling it as shown in "Figure 2 (c-e)". Finally removing the solidified casting and cleaning it. After removing the cast from the mold, it was then put in a water bath. The ceramic balls were removed with the aid of ultrasonic vibration. Open-cell aluminum foam was therefore obtained.

After development of varying density aluminum foams, next work was to characterize them for its porosity and density, that is calculating the theoretical density and percentage porosity valves and compare it with experimental values.

Three different pore sizes of Al-foam specimen's size (40×40×30) mm were used for conduction fluid flow and pressure drop tests using Darcy's law. Pressure drop while fluid is flowing through the Al-foams is very a important factor to consider because the exact value of pressure drop should be used for different heat transfer applications. Al-foam specimen which covered by thermocol were inserted in the air duct. Gap between the foam and air duct was filled with thermocol to make sure that fluid was only passed through the porous structure of Al-foam. A reciprocating compressor was used to compress the ambient air and pressure gauge was used to measure the pressure of outlet air to control the fluid velocity through the pipe. The pressure was varied from 0.3 bar to 4.9 bar for different Al foam specimens in varying steps. After repeating the experiment for different Al foams at different conditions readings were tabulated and graphs were drawn which is explained in the results and discussion section.

The permeability of the different foam structure was calculated using basic Darcy's equation which is shown as Eq.1.

$$K = \frac{\mu\, v}{(dP/dx)} \quad \text{.......(1)}$$

In this work, for heat transfer, a specific type of transistor (2N3055) was taken and it was compared with developed TO3 heat sink commercially using to heat dissipation in the 2N3055 transistor. The thermal conductivity of the Al foam was determined on the basis of thermal diffusivity using Micro Flash equipment. The sample was tested from 50°C to 160^{o}C. The temperature at the top of the Al-foam at the different location was noted down. In the same way, the commercially available heat sink was tested.

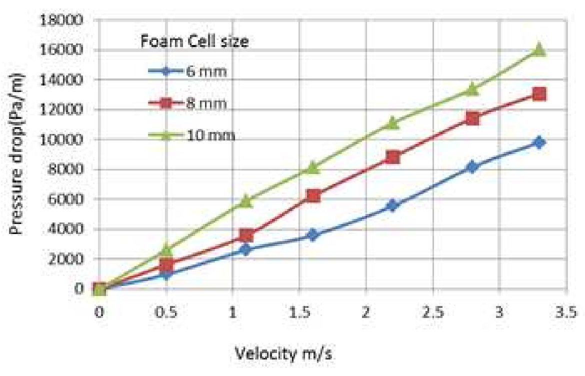

Figure 3: Effective Average Pressure Drop of the Air of Al Metal Foam as a Function of Velocity of Air

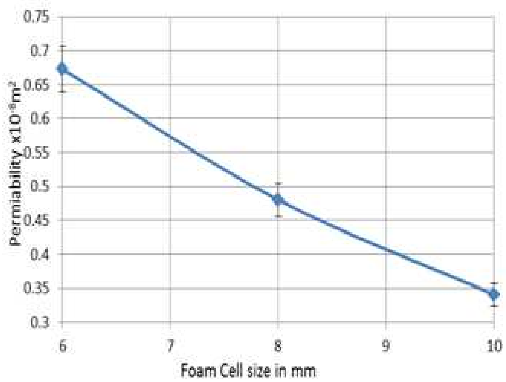

Figure 4: Effective Average Permeability of Al Metal Foam as a Function of Pore Diameter

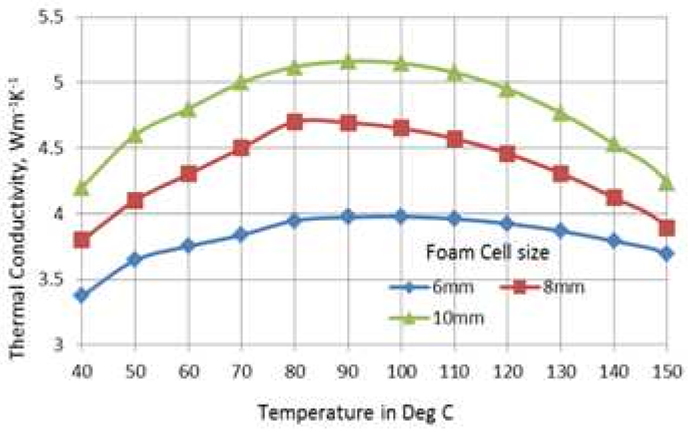

Figure 5: Effective Average Thermal Conductivity of Al Metal Foam as a Function of Temperature

RESULTS AND DISCUSSIONS

The fluid pressure drop of air in Al metal foam under different experimental velocity is shown in "Figure 3". It illustrates pressure drop in Al foam increases with increasing velocity of the blower and higher the foam size higher the pressure drop due to cell connectivity.

For 6 mm SHP ball size (density 0.85 g/cc and porosity 71%), the range of the air velocities and pressure changes were from range 0.5 to 3.3 m/s and 981 to 9810 Pa/m. Normalised pressure drop against Darcian velocity is shown in the "Figure 3". The nature of the curve is linear which proves Darcy's law. The average permeability for the foam sample 1 is 0.66×10^{-8} m^2 as shown in "Figure 4". For 8 mm SHP ball size (density 0.93 g/cc and porosity 65%), the range of the air velocities and pressure changes were from the range of 0.5 to 3.1 m/s and 1635 - 13080 Pa/m. The average permeability for the foam sample 2 is 0.48×10^{-8} m^2. For 10 mm SHP ball size (density 1.06 g/cc and porosity 60%), the range of the air velocities and pressure changes were from range 0.6 to 2.9 m/s and 2616 - 16023 Pa/m. The average permeability for the foam sample 3 is 0.34×10^{-8} m^2. During fluid flow through foam i.e., turbulent flow, the pressure drop is highly significant due to viscous forces of the air.

Thermal conductivity is not only affected by different pore sizes but also the temperature has the influence on magnitude of the thermal conductivity as shown in "Figure 5". The variation of thermal conductivity with increasing temperature is parabolic in nature. The foam materials with the increase in temperature and the internal particles velocity, the thermal conductivity increases at the initial temperature. In other hand, the thermal resistance also increases with increasing temperature and so does thermal conductivity. Initially less thermal resistance is a small barrier for heat transfer but the velocity of particles promotes higher heat transfer.

The "Figure 5" showed that non-linear (parabolic in nature) thermal conductivity as a function of temperature. The peak conductivity reached all type of materials from 80°C to 90 °C and then it is decreased due to high thermal resistance than that of vibration of particles in the materials. The weight comparison between the Al foam sample (22 g) and heat sink (55 g) tested for a measure of the thermal conductivity and the values are 5.3 W/mK and 3.12 W/mK respectively. With Al foam exhibiting higher pressure drop due to drainage performance between the foam cell, it leads to higher pressure drop with higher heat transfer rate, hence it increases theopportunity to use it in heat exchangers.

CONCLUSIONS

Different density Al foams were developed and tested for fluid flow and heat transfer. Al foams showed that pressure drop was directly proportional to SHP ball size due to deterioration of drainage between the foam cell. The pressure drop of 10 mm pore size Al foam is 25-35% higher than that of 6 mm and 8 mm Al foam materials. The thermal conductivity of 10 mm pore size Al foam 20-30% larger than that of 6 mm and 8 mm Al foam. Although at the lower temperature the thermal conductive directly proportional to temperature but at a higher temperature, it is reversed. The weight comparison between the Al foam sample and heat sink revealed that aluminum foam weighs less.

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