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Experimental And Numerical Study Of Aluminium Microchannel Heatsink

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ARTICLE INFO **ABSTRACT**

Metallic micro channels are attractive option for electronics cooling applications. In this paper experimental and numerical study of aluminium based micro channel heat sink is studied**.** Rectangular micro channel of 400μm width and 800μm depth is machined on circular aluminium blank using micro milling technique. The thermal and fluid flow characteristics is found experimentally and validated with CFD software using FloEFD for three flow rates 5.26g/s, 7.7g/s, and 9.43g/s. The pressure drop is measured to vary from 1558Pa to 3432Pa. The maximum performance index of 45 is found 45. The simulated results have been validated with the experimental results. Variation of Nusselts number and heat transfer coefficient with respect to flow rate also discussed.

Keywords— metal based micro channels, Heat transfer characteristics, single phase cooling, micromilled heat sink,

I. INTRODUCTION

Predominantly the enclosures for military electronics are made out of aircraft grade aluminium based on strength and weight criteria. The power handling requirements of military electronics are increasing continuously. Many new competing technologies are being explored by the researchers, among which liquid-cooled microchannel heatsinks are highly attractive solutions.
The micro-channel heat sink cooling concept was first introduced by Tuckerman and Pease in the early 1980s [1]. They fabricated a rectangular micro-channel heat sink in a 1 x 1 cm2 silicon wafer. The channels had a width of 50 μm and a depth of 302 μm, and were separated by 50μm thick walls. Using water as cooling fluid, the micro-channel heat sink was capable of dissipating 790W/cm^2 with a maximum substrate temperature raise of 710˚C above the water inlet temperature and a pressure drop of 2.2 bar (31 psi). Due to their inherent advantages, micro-channel heat sinks have received considerable attention.
Various manufacturing process suitable for microchannel fabrication like LIGA, Chemical etching, Stereo lithography, Micromachining and diffusion bonding have been reported by Sean Asman et al [2].
Fabrication and testing of a microchannel cooling plate have been described by Pang et al., [3], Desmulliez et al [3] focusing microelectronic packaging cooling applications. The nickel based microchannel cooling plate is fabricated on a glass substrate using a two-layer electroforming process borrowed from the UV-LIGA (UV- Lithography, Electroforming, Replication) process. Forced convection of air or liquid is used for the micro channel plate. The cooling plate has been tested using a custom-made rig to measure the flow pressure head as a function of mass flow rate. Hydraulic performance of the cooling plate is presented.
Heat transfer in single-phase flow through a heat sink can be calculated using

$$q = N_u K T_f \frac{A}{D_h}$$

in which k is the coolant thermal conductivity, Tf is the mean temperature difference between the substrate and the coolant, A is the wetted area of the heat sink, Dh is the hydraulic diameter of an individual microchannel, and Nu the Nusselt number.
Eason et al 2004 [4] have investigated the manufacturing of a variety of micro channels, produced by wet and dry etching in silicon, as well as precision mechanical sawing in silicon and thermoset plastic. This paper describes the experimental equipment and methods used to measure the pressure flow characteristics of the manufactured channels. Since Tuckerman and Pease's pioneering study, several studies have since been published which can be grouped as analytical [5-9], numerical [10-13].
A novel integral micro-channel heat sink was developed, directly in the back-metallization layer of the direct bond copper or active metal braze ceramic substrate of the semiconductor junction was fabricated and tested[14]. The micro milled micro channels have been reported to perform better than laser ablated samples.
Both numerical and experimental methods were used to investigate the pressure drop and performance index of an aluminum microchannel heat sink using CFD-ACE+ Microchannel heat sink including ten channels with each channel having a rectangular cross-section, a width of 500 μm, a depth of 210 gym, and a corresponding hydraulic diameter of 296 μm has been made using micromachining techniques. The heat sink was tested for the mass flow rates varying from 0.2 to 0.4 *g/s* and the pressure drop was found to vary from 1761 to 4184 Pa.
Thermal and hydraulic performances have been. In this paper the thermal and hydraulic performances of aluminum based plate fin type micro channel heat sink have been analyzed using CFD. Aluminium based micro channels with Dh of 0.533mm have been manufactured by micro milling technique and tested. The results of manufacturing, simulation and experimental testing of aluminium micro channel are described.

II. EXPERIMENTATION

Experimental setup consists of reservoir, micro pump, power supplies, heater, pressure gages , thermocouples, data acquisition, micro channel heat sink etc Micro channel heat sink has been machined on aluminium material [Fig:1] for preliminary studies and to rig up experimental set up. Plate fin types of micro channels have been machined using micro milling technique. The micro channel heat sink dimensions are 400 microns width and 800microns depth. This heat sink can accommodate nichrom heater on one side and the channels on the other side. The heater of 80W capacity has been potted to the Microchannel heat sink. Perspex enclosure [Fig:2] has been made with provisions to house the heat sink and the small pump. The Perspex enclosure acts as a insulator for heat loss from the heater so that maximum heat flows in to the microchannel. Access holes have been drilled on the Perspex for thermocouple and pressure gages. The experiment has to be carried out in a controlled atmosphere and a 100microns filter is to be used to avoid, clogging issues while testing.

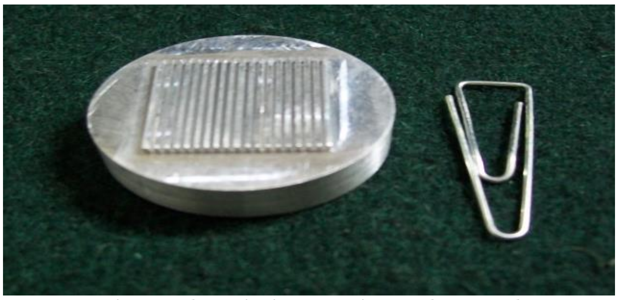

Fig:1 Aluminium Microchannel

Fig: 2 Perspex Parts and Micro channel

The microchannel was assembled inside the Perspex enclosure and the experiments were conducted for three different flow rate of 5.26g/s, 7.7g/s, and 9.43g/s for the heat load ranging from 8.8W to 63.8 W. The pressure drop across the micro channel heat sink has been monitored using Differential pressure gage. There are five J Type thermocouples are used in the experiment two of them are used to measure the Microchannel heat sink temperature, two of them are used to measure temperature of inlet, outlet water temperature and the remaining one is used to measure ambient temperature.

III. SIMULATION

Computational fluid dynamic (CFD) analysis has been used to analyze the heat transfer characteristics of the Aluminium plate fin micro channels. CFD analyses have been carried out using FloEFD software from M/s Mentor Graphics inc., USA. The pressure drop and Thermal profile have been analyzed using the CFD analysis for various loads. Here the flow is modeled as laminar as the Reynolds number ranges from 727 to 1595. Typical pressure drop and temperature profiles for the flow rate of 5.26g/s are as shown in Fig:3 and Fig:4. The coolant fluid enters at the circular hole and flows through the heat sink. The outlet is open to atmosphere.

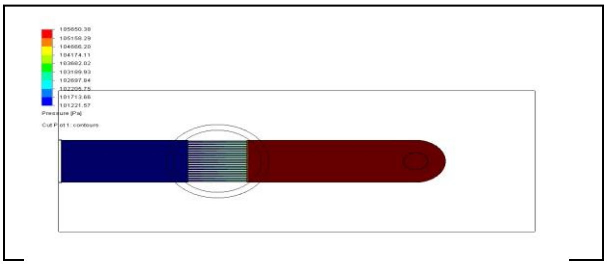

Fig: 3 Pressure drop acr ... he pressure drop is 4435 Pascal

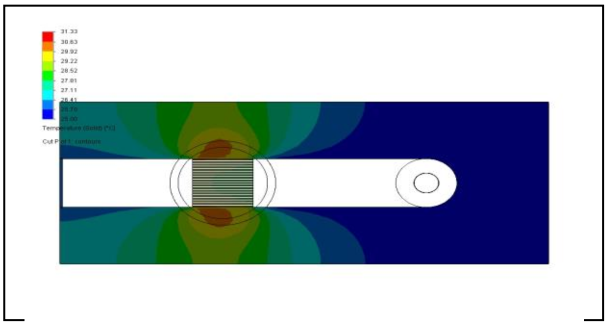

Fig: 4 Temp profile or ... The Max temp is 31° C

To ensure the accuracy and reliability of simulation results it is necessary to carry out the mesh independency of the results. Mesh independency is carried out by varying the cell density on a model for the same set of boundary conditions. The structured hexahedral cells have been used for the model. The mesh densities have been varied from 20574 cells to 1027286 cells. The minimum required mesh density can be selected if the consecutive results are repeatable. Fig: 5 and Fig: 6 show the mesh dependency effects of temperature difference and pressure difference on the mesh cell count at 5.26g/s mass flow rate. Based on the mesh dependency, it was found that the mesh of 10349 cells will be adequate to get stable results. The graph red color indicates the temperature difference on the micro channel heat sink. And the Blue graph indicates the temperature difference in the coolant liquid.

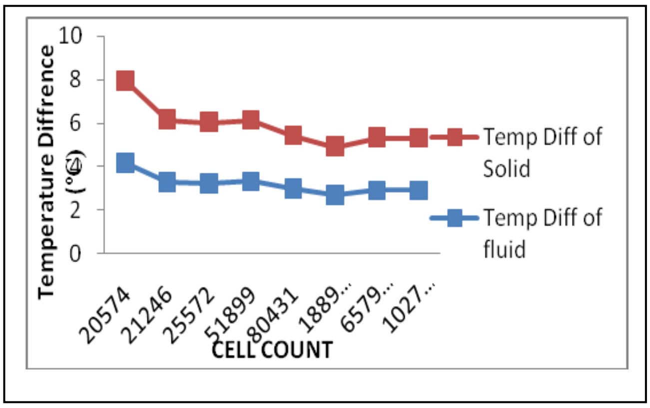

Fig: 6 The Temperature Difference Vs Cell count for the Mass flow rate of 5.26 g/s

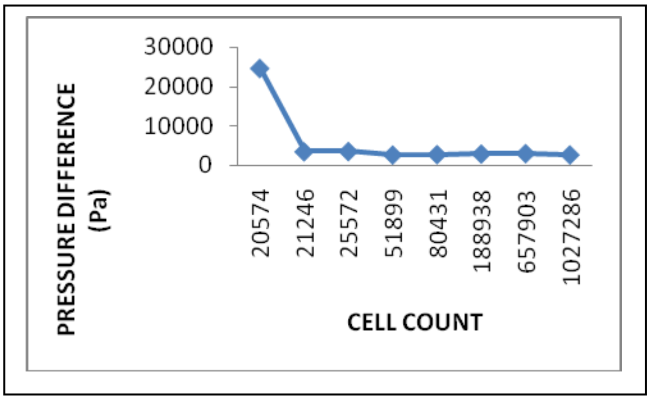

Fig: 5 The pressure difference Vs Cell count is plotted for the Mass flow rate of 5.26 g/s

IV. DATA REDUCTION

From the experiment and numerical simulation parameters such mass flow rate, Microchannel heat sink temperature, inlet and out let temperature of water, Pressure drop are considered in calculation. All of the correlations available assume both fully laminar flow and a uniform inlet condition. The actual size of the channels are relatively short in comparison with the hydrodynamic length. In the analysis the assumption that the flow enter in the tubes as uniform and laminar, leads to overestimate for the experimental cases due to the effects of the hydro dynamically developing region.

In the present study the Reynolds Number is calculated using the expression shown below.

$Re = \rho * v * DH / \mu$

Where

Re = Reynolds Number

ρ= Density of fluid in kg/m3

v= Velocity of fluid in m/s

DH= Hydraulic Diameter in m

μ= Dynamic Viscosity in kg/ms

For flow through noncircular tubes, the Reynolds number as well as the Nusselt number and the friction factor are based on the hydraulic diameter Dh which is defined as

$DH = (4 * Ac)/P$

Where

DH = Hydrodynamic Diameter in meters

Ac = Area of cross section in square meters

P = Fluid Wetted Perimeter in meters

Heat supplied to the Microchannel is obtained by multiplying voltage and current supplied to the heater

$QSupplied = VxI$

Where

V= Voltage applied across heater in volts

I= Current drawn by the heater in Ampheres

The convective heat transfer coefficient is calculated from the following

$h = Q/(As\ (Ts - Tm))$

Where

h = heat transfer coefficient

Q = heat carried away by the fluid

Ts = Temperature of heatsink surface

Tm = mean fluid tempearture

The conservation of energy equation for the steady flow of a fluid in a tube can be expressed as

The Nusselt number is a dimensionless number that measures the enhancement of heat transfer from a surface that occurs in a situation compared to the heat transferred if just conduction occurred. The nusselt number is calculated using

$Nu = (h*DH)/k$

Where

Nu = nusselts number

K = conductivity of the fluid

V. Results and Discussion

The experimental testing and numerical simulation has been carried out for the aluminium based micro channel heatsink. The experiments have been carried out for three different flow rates such as 5.26g/s, 7.7g/s and 9.43 g/s. The experimental results were compared with simulated results for all the three different flow rates.

The effect of heat load on the convective heat transfer for the heat loads from 9.77W to 70.38W has been shown in Fig:6. Nusselt number is found to vary linearly for the Reynolds number from 727 to 1595 as shown in fig:7. Thermal resistance is found to decrease from 0.6 oC/W to 0.4 oC/W as the mass flow rate increases. As the flow rate increases, the pressure drop and Convective heat transfer coefficient increases proportionally. It can be inferred from the fig:7 that, it is possible to achieve the convective heat transfer coefficient of 7000 to 9000 W/m2Ko with the present geometry of the micro channel heat sink.

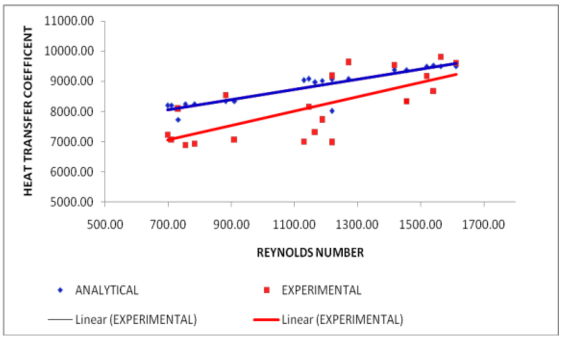

Fig:6 Reynolds Number Vs Heat Transfer Coefficient

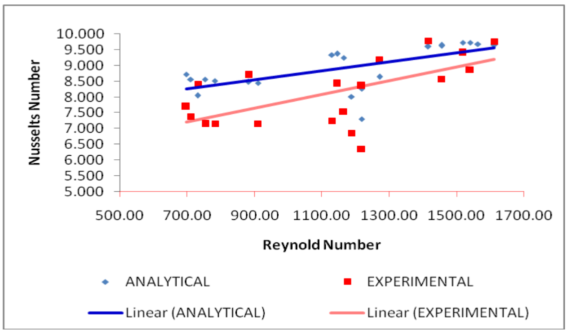

Fig:7 Reynolns number Vs Nusselts Number

The CFD simulation has predicted the value close to experimental results. Pressure drop plot of CFD with respect to experimental values is found to be linear as shown in Fig;8

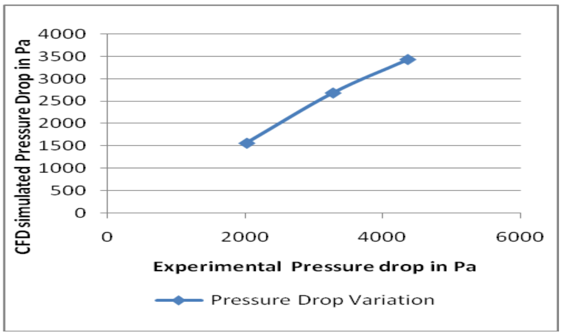

Fig: 8 CFD simualted results Vs Experimental results

The friction factor have been plotted with respect to Reynolds number as shown in fig:9. Friction factor decreases as the Reynolds number increases. The average f/Re value is found to be 176. Though it is laminar flow the f/Re value for rectangular channel is higher than the pipe flow

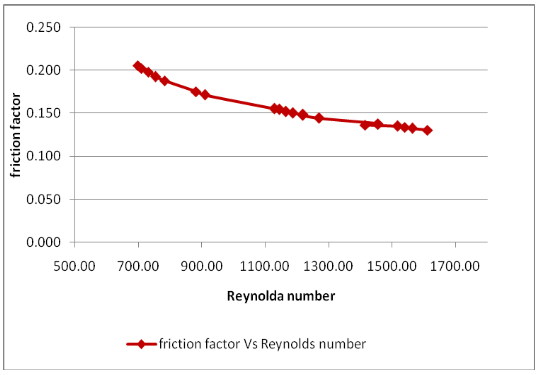

Fig:9 Reynolds number Vs Friction factor

The pressure drop is found to increase with respect to velocity as shown in Fig :10.

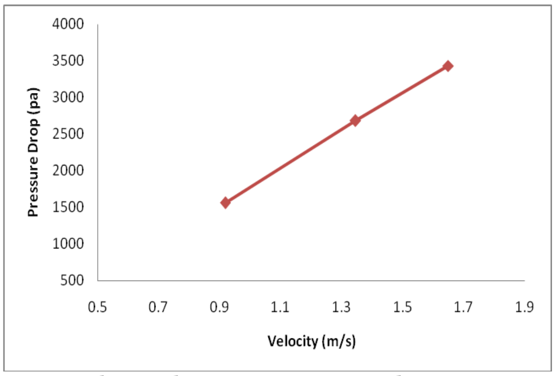

Fig:10 Flow velocity Vs Pressure drop

The total thermal resistance is the sum of conduction resiatnce heatsink to fluid, covective resistance from heatsink surface to fluid and the resitance offered for heat obsorbtion of the fluid [1]. The thermal resistance decreases as the flow velocity increases as shown in fig:11. The total average thermla resistance was found to be 0.1425 °C/W.

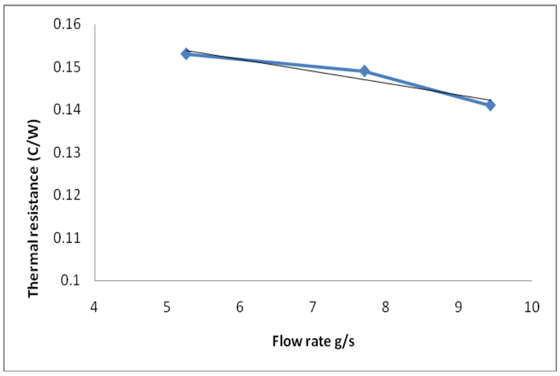

Fig:11 Flow rate Vs Thermal resistance

The average temperature of the heat sink from simulation is found to match closely with the experimentally measured values as shown in Fig:12.

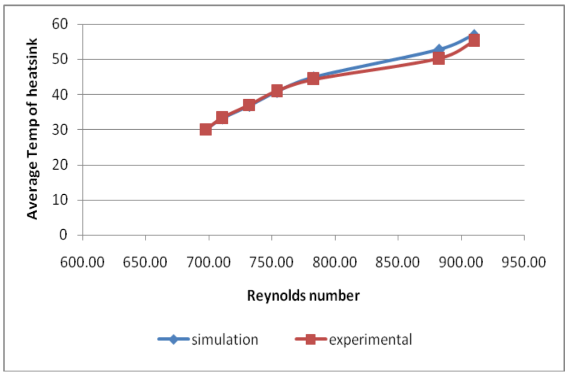

Fig:12 Reynolds number Vs Average temp of heatsink

The performance index is defined as the ratio of heat pumped out by the pressure drop in *Kilopascals* [16]. The performance index increases with Reynolds number. Fig :13 shows that the performance index of simulation matches closely with the experimental results.

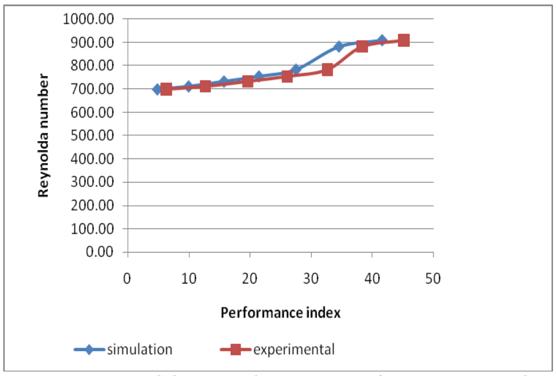

Fig:13 Reynolda number Vs performnace index

VI. Conclusion

Metallic microchannel of 400 micron width and 800 micron depth, to a length of 15mm has been machined out on aluminum using micro-milling technique. The aluminium micro-channel has been tested for three flow rates and seven heat loads. A maximum heat transfer coefficient of 9610W/m²K has been achieved which is comparable to that has been reported in literature. The friction factor is found to be from 0.131 to 0.2 A performance index of 45 has been achieved for 5.26 g/s flow rate. The micro channel thermal and hydraulic performance has been simulated using floEFD 11 package. The results points that the alunimium micro channels have potential application in electronics cooling.

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