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Numerical Study on Aluminium Metal Matrix Composite for Heat Exchanger Application

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Abstract - In order to keep electronic components at the ideal temperature, heatsinks are indispensable devices. Forced air cooling using a heatsink is appropriate and efficient for cooling low power applications. Specialised industries provide a variety of heatsinks to cool various types of electronic components. For most electronic or power electronic devices, managing the temporary heat generation from these devices requires the use of a proper heatsink. The heat transmission and evacuation processes are inextricably linked to the performance of the heatsink. This paper studied about the heat transfer characteristics of a heatsink applicable in an engineering application. In common, the aluminium heatsinks have utilized in electronic system. Here, the proposed heatsink to be studied by using Al6061 and Al6061+SiC. Also, the heatsink has suggested with cut-out cross section for fin alignment. Initially, the thermal analysis to be carried out for proposed heat sink design using FEA software ANSYS for both Al6061 and Al6061+SiC.

Index Terms- Heatsink, Cut-Out Fins, Al6061, Al6061+SiC, FEA.

I. INTRODUCTION

A heat sink is an element that displaces heat from a heated device by increasing the surface area of its working area and permitting low-temperature fluid to pass over it. Its functionality, design, and appearance change according on how the device is configured. The purpose of heat sinks is to divert heat away from a vital component, and the majority of them do this in four simple steps.

- The heat source produces heat.
- Heat is transferred out from the source.
- Heat is dispersed across the heat sink.
- Heat dissipates from the heat sink

Fig. 1 Heatsink

A heat sink is a type of heat reservoir that can take in heat without causing a large temperature change. For convection, radiation, and conduction to transfer heat in electronics, practical heat sinks need to be hotter than their surroundings. Since electronics' power supply are inefficient, excess heat may negatively impact a device's operation. Usually, the air passing through a duct has a lower temperature than the heat sink. The following equations may be obtained by applying Newton's law of cooling, steady-state conditions, and energy conservation.

$$Q = mc_p \, (T_{out} - T_{in}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

⇒ m, mass flow rate $\left(\frac{kg}{s}\right)$

⇒ c_p, specific heat capacity $\left(\frac{J}{kg\,°C}\right)$

⇒ T_{in}, temperature of inlet medium (°C)

⇒ T_{out}, temperature of outlet medium (°C)

The literature describes how surface heat transfer coefficient, material, and geometry affect heat sink performance and emphasises the benefits of these kinds of devices. Mohamed et al investigated the novel optimised form of an industrial heatsink [1]. The study focuses on optimizing industrial heatsinks for specific-cyclic heat release by adjusting channel height, adding an ellipsoidal channel, fin thickness, heatsink mass, pressure drop, and other parameters.

The results show noticeable improvements in cooling performance, with further analysis and optimization of fin thickness, heatsink mass, and pressure drop to meet desired cooling performance.

Prakash and Sabari Nathan looked at the forced convection cooling of CPU-mounted heat sinks [2]. The primary processing chip features fin attachments for heat dissipation as part of a design that prioritises overall chassis power dissipation. Different heat sink designs are used in order to maximise efficiency. Heat pump and air cooling are two types of cooling techniques. The updated fin shape that uses air cooling is more efficient and cost-effective. Direct conduction is increased by the cooler master with copper base plate, which raises the overall heat transfer rate by 17.8%.

A geometry-based optimisation tool for heat sink design has been developed by Imran and Syed, allowing component modifications to improve the cooling of electrical devices. This instrument tackles the problem of power production in electronic warfare equipment, which may have an adverse effect on effectiveness. High temperatures in hot environments can decrease component life span and cause permanent damage. The project aimed to design a heat sink for an 80mm x 60mm electronic chip in a 55°C environment. Design formulas were used to solve the problem.

Vennapusa et al. [4] used Sim Scale to analyse and design heat sinks with different fin sizes using a computer. Among all heat sinks, the best performer is decided based on the lowest temperature of heat sink under given conditions. The Slotted Rectangular design throughout the length has the least temperature at the base. In the simulation pin fin models of different cross sections were also created in the same virtual tool for evaluation. In this study it is clear that the rectangular slotted fin throughout the length performs better than the other heat sinks.

In order to dissipate heat on a circular LED light, Seung-Hwan Yu et al. investigated natural convection heat transfer around a radial heat sink [5]. They conducted parametric research on the effects of fin number, fin length, and heat flux on thermal resistance and heat transfer coefficient, and they corroborated numerical results with actual data by comparing three types of heat sinks (LM, LMS, and L). Multiple-objective optimisations taking into account mass and thermal performance were carried out, and Pareto front analysis was carried out using different weighting factors.

Pawar and Ghuge used a simulation road map to carry out an experimental investigation on the functionality of a heat sink within an acrylic cabinet. Applying the map to several heat sink shapes, they focused on a qualitative comparison on a computer chassis and contrasted the outcomes with experimental data. [6].

Jeon and Byon examined the phenomena of natural convection in double-height fin plate-fin heat sinks. As fin height fell, they discovered that thermal performance improved. Their conclusion was that performance started to decrease below a particular height of the conspicuous fin, and that's when the dual-height heat fin approach was only appropriate [7]. To enhance heat transfer performance, Feng et al. studied the use of double circular pin-fins. They discovered that the height and pin-fin separation considerably increased the rate of heat transfer and decreased pressure loss. When compared to smooth microchannels, the optimised parameters—0.88 mm in height, 12 mm in diameter, and 0.55 mm in spacing—improved heat transmission by 42% [8]. In a different study, Ozdilli and Sevik presented two models of trapezoidal, curved plate-fin heat sinks: one had a rectangular channel, while the other had a rectangular corner channel. When compared to the conventional plate-fin heat sinks, the models' convective heat transfer performance significantly improved. Furthermore, better heat resistance in spontaneous convection was also noted [9].

Heat sinks control thermal efficiency and performance by lowering the maximum temperature of mechanical and electronic equipment. They dissipate nonessential heat into the environment and are used in various applications. The shape and size of fins significantly impact heat transfer from sinks. Yadav et al. examine thermodynamic attributes like heat input and base to atmosphere temperature difference to develop correlations. Optimizing the geometry aspect ratio of heat sinks is crucial for enhancing overall heat transfer rate. The effect of a very low aspect ratio needs to be determined [10]. With an emphasis on the importance of interfacial bonding, Mirza et al. present a thorough review of research on enhancing the thermal performance of

Multi-Module Composites (MMCs) through the use of different reinforcements and their combinations [11]. Pillai et al explores the fabrication of aluminium-graphene composites using the stir casting method, focusing on heat management in electronic devices. The composites are made using pure aluminium and graphene powder, with varying stirring parameters and graphene content. In comparison to pure aluminium, the aluminium-graphene combination exhibits strong heat conduction and low wear rate. The investigation also looks at the manufactured samples' mechanical and thermal characteristics [12].

Asheesh et al. review advancements in technology to increase heat flow rates using heat sinks. It highlights the importance of fins in heat transfer, which are devices mounted on heat sinks to increase surface area for maximum heat transfer. The study reveals that the heat transferred by fins depends on their profile, length, angle, and surface area. It also discusses various fin geometries with copper and aluminium as heat sink materials, simulated in natural and forced convection conditions. The paper calls for further feasibility studies and optimisations for different fin types in heat sinks [13]. Ayman et al. studied the performance and heat transmission properties of aluminium heat sinks packed with aluminium foam for an Intel Core i7 CPU. They looked at three distinct configurations, using ERG aluminium foam to fill each channel gap. According to the findings, model C had the largest surface to volume ratio because of thermal boundary layers that prevented heat transmission, whereas model B had the highest average Nusselt number [14].

Hussain et al. examined the unique geometries and effects of heat sinks on heat dissipation while researching the thermal performance of heat sinks in industrial equipment. They went over topology-optimized heat sinks, pin fin, flat fin, and micro-channel hydrothermal design methods. In their investigation into the ideal weight and heat dissipation for heat sinks, Krishnamoorthy et al. discovered that, in comparison to 6061 and 7071 alloys, the highest heat dissipation was achieved by 6063 aluminium alloys with case II fin design. This occurred as a result of reduced mass, airflow, and temperature without adding weight to the heat sink [16].

II. OBJECTIVE OF FEA METHOD

Since radiation, natural convection, and pure conduction can only partially cool components in comparison to modern mechanisms, the lower temperature and slower temperature fluctuation over time are generally better for electrical equipment. The best way to decrease the hot spots is to use new heat sinks with greater expanded surfaces made of highly conductive materials and higher coolant flow. In this project, a slotted cut-out is introduced in flat finned heatsink to improve thermal performance. The focus of this project is to improve the heatsink performance by creating slotted cut-out in heatsink geometry. FEA analysis should be carried out for proposed heatsink model (Al6061 and Al6061+SiC) using ANSYS. The finned heatsink to be fabricated in Al 6061 + SiC material which results better from FEA. The temperature difference should be monitored manually and evaluate its performance.

III. MODELLING AND SIMULATION OF HEATSINK

The different shapes of heatsink geometries have been modelled in 3D by using SOLIDWORKS software for mechanical designers, SOLIDWORKS is a 3D CAD/CAM/CAE programme that provides solid modelling, assembly modelling, 2D orthographic views, finite element analysis, direct and parametric modelling, NC, and tooling features. It is a component of a group of cooperative programmes offering various functionalities for enhanced product development. Solid Works runs to the Microsoft applications & presents apps for 3-D model parametric feature 3D model, 2D orthographic view, FEA & simulation, graphic design, technological illustration, viewing & visualization. Figure 2 displays a 3D model of a Finned heat sink, which was designed through Solid Works and analysed using Ansys software for thermal analysis. The model consists of multiple fins attached to a base plate, optimised for efficient heat dissipation. Figure 3 displays a 3D model of a slotted cut-out heat sink, created using Solid Works and Ansys software for thermal analysis. The heat sink design features a series of slots to enhance airflow and improve heat dissipation.

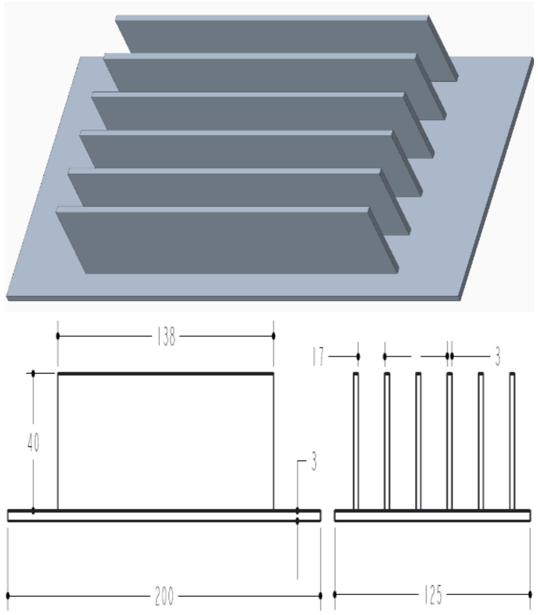

Fig. 2 Finned Heatsink Model

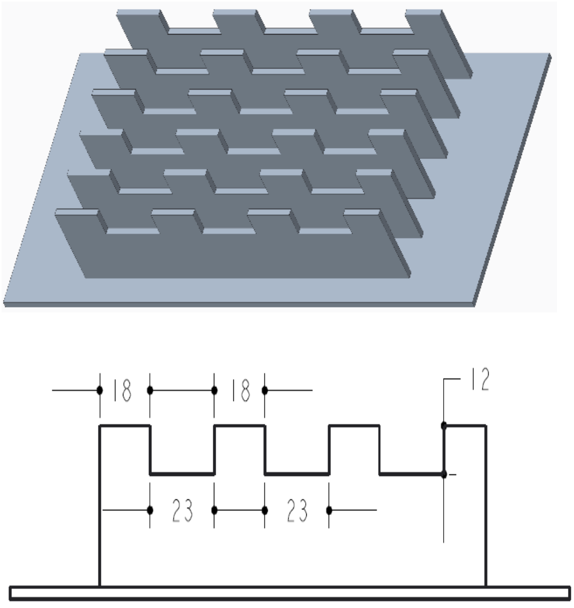

Fig. 3 Slotted Cut-Out Heatsink

A. Thermal Analysis (Pre-Processing)

The numerical study of heat energy-related processes and heat transmission is known as thermal analysis. It has an intricate collection of algorithms for modelling and simulating heat, electric currents, gases, and fluid flow. Pre-processing, processing, and post-processing are the three steps involved. Pre-processing refers to all of the operations that are performed before to the numerical solution process. These operations include problem formulation, meshing, and computational model creation. Processing is the process of solving mathematical fluid flow problems using a computer. The following figures 4 represents the model imported from SolidWorks software to ANSYS software.

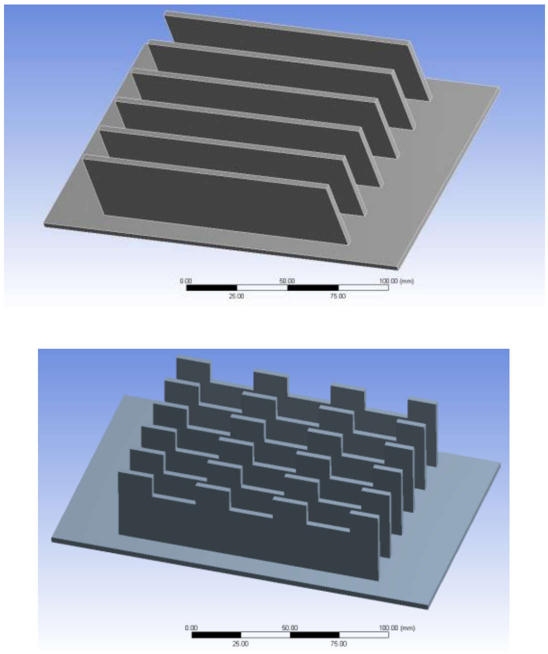

Fig. 4 Model Imported from Solidworks

In this study, the FEA conducted for the material of Aluminium 6061 alloy and composite of Al 6061 with Silicon carbide (SiC). The below table repersents the standatrd material properies of Al6061 and composite of Al6061+ SiC. in which the Al6061+ SiC have a better material propery.

Table. 1 Standard Material Properties

S. No	Material Property	Al 6061	Al6061+SiC
1	Material Density (gcm^{-3})	2.70	2.7069
2	Youngs Modulus (GPa)	68	73
3	Poisson Ratio	0.33	0.33
4	Thermal Conductivity (W/mK)	152	157.07
5	Specific Heat Capacity (J/kg K)	897	894.795

IV. RESULT AND DISCUSSION

A. ANSYS Results of Existing Model

The thermal analysis has conducted for both Al 6061 + SiC and Al 6061 material in the existing model (finned heatsink). The following figures 5 to 8 represents the results solved from ANSYS. Figure 5 shows the temperature distribution performed in heatsink without cut-out model for Al 6061 + SiC material whereas figure 6 heat flux respectively. Figure 7 and figure 8 indicates the temperature variance and heat flux for Al 6061 material of heatsink model. By observing the results of both the material, results to be almost equal i.e., the maximum temperature obtained about 80°C and heat flux 0.013 W/mm^2 for Al 6061 whereas 80°C and 0.0134 W/mm^2 for Al 6061 + SiC material respectively.

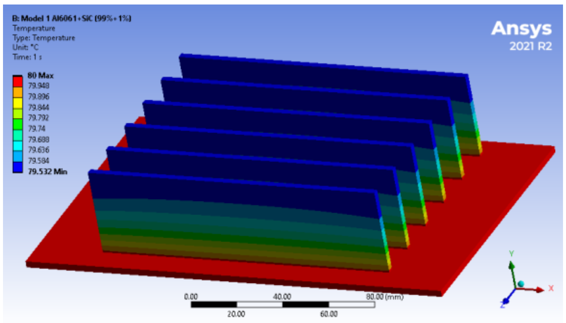

Fig. 5 Temperature Variance for Al 6061 + SiC Material

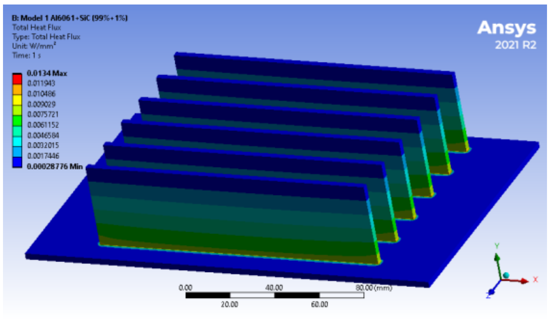

Fig. 6 Heat Flux for Al 6061 + SiC material

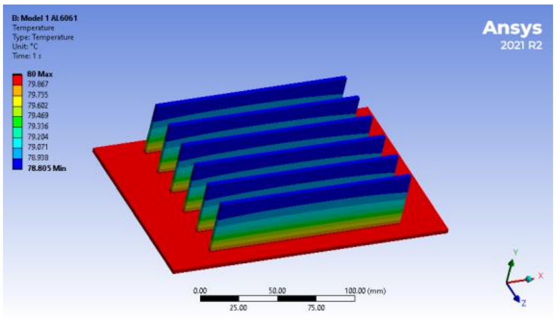

Fig. 7 Temperature Variance for Al 6061 Material

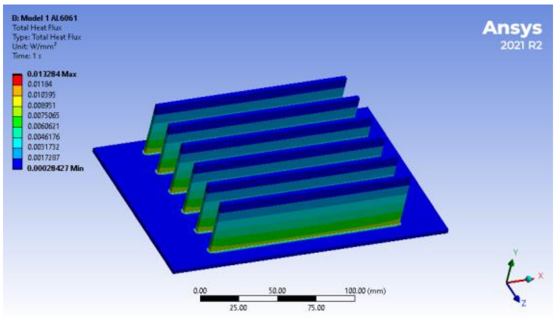

Fig. 8 Heat Flux for Al 6061 material

B. Results of Heatsink with Cut-Out Model

Similarly, the thermal analysis has conducted for proposed model finned heatsink with cut-out and results highlighted from the figure 9 to 12. Figure 9 shows the temperature distribution performed in heatsink with cut-out model for Al 6061 + SiC material whereas figure 10 heat flux respectively. Figure 11 and figure 12 indicates the temperature variance and heat flux for Al 6061 material of heatsink cut-out model. By observing the results of both the material, results to be almost equal i.e., the maximum temperature obtained about 80°C and heat flux 0.012034 W/mm^2 for Al 6061 whereas 80°C and 0.012342 W/mm^2 for Al 6061 + SiC material respectively.

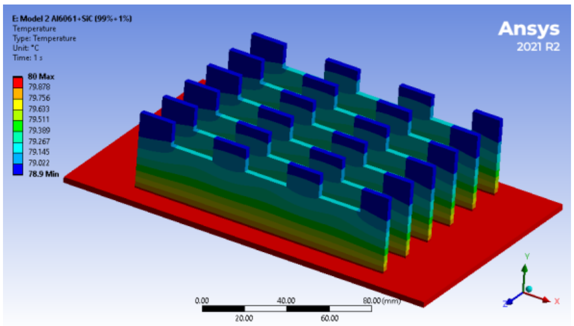

Fig. 9 Temperature of Cut-Out Model for Al 6061 + SiC Material

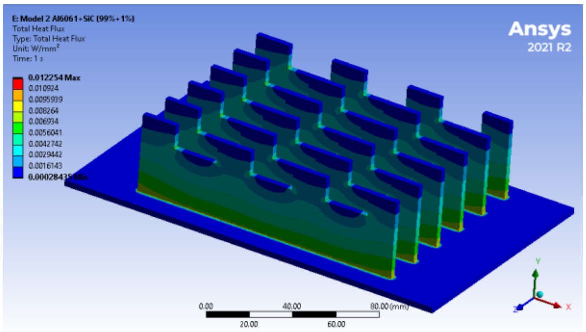

Fig. 10 Heat Flux of Cut-Out Model for Al 6061 + SiC Material

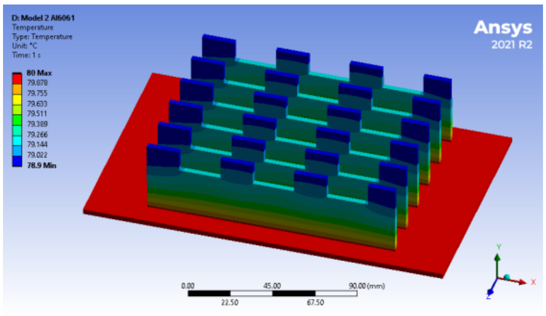

Fig. 11 Temperature of Cut-Out Model for Al 6061 Material

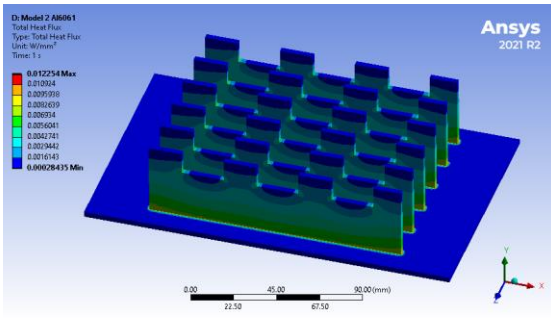

Fig. 12 Heat Flux of Cut-Out Model for Al 6061 Material

C. Summary of FEA

Table. 2 Validation of FEA Results

S. No	Parameters	Heat Sink without Cut-Out		Heat Sink with Cut-Out	
		Al 6061 + SiC	Al 6061	Al 6061 + SiC	Al 6061
1	Max. Temperature (°C)	80	80	80	80
2	Heat Flux (W/mm^2)	0.0134	0.013	0.012342	0.012034

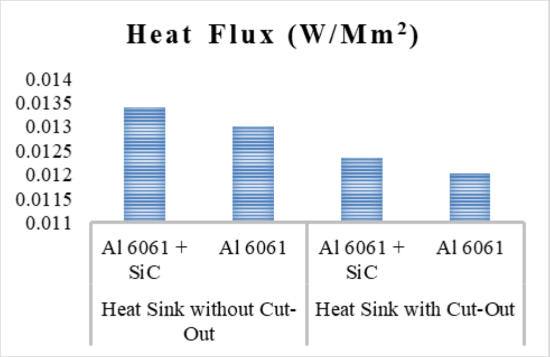

Fig. 13 Overall HeatFlux

The above graph (fig 13.) represents the over all Heat fluxuation for the Al 6061 and Al 6061+SiC material. Comparatively, the Al 6061 + SiC material results slightly better than Al 6061 material for both geometries of heatsink. The heatsink without cut-out model achieves 0.0134 W/mm^2 of obtained heat flux and heatsink with cut-out is 0.012342 W/mm^2 for Al 6061 + SiC material. The maximum temperature distribution obtained about 80°C for both material and both geometries. So, the Cut-Out heatsink of Al 6061 + SiC material could be better.

CONCLUSION

Improvement on heatsink was analysed in this study which applicable for industrial cooling systems. The heatsink fins have introduced with rectangular slotted cut-out to improve heat transfer rate. This proposed heatsink geometry has compared with Al 6061 and Al 6061 + SiC material by FEA method using ANSYS software. It results that the Al 6061 + SiC material heatsinks performed slightly better thermal characteristics than Al 6061 material. The slotted cut-out model was distributed more heat energy than Al 6061 i.e., 0.012342 W/mm^2 for Al 6061 + SiC material. Comparatively, the heatsink fins with rectangular slot was transfer more heat energy than normal fins.

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