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Exploring Thermal Characteristics of Functionally Graded Nanomaterials for Enhanced Heat Dissipation in Electronic Devices

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With the advancements in electronic systems, efficient cooling has become an exciting task in thermal grounds. For optimum working conditions of electronic systems energy-efficient a heat sink is used. In the present paper, thermal simulation is carried out on two different profiles of existing heat sinks used in the processor. Six different cases were studied and compared namely natural and forced convection on circular and rectangular heat sinks with and without FGM (Functionally Graded Materials.) Conventional material aluminium alloy 6061 and functionally graded material AlSi10Mg are used to understand the variation of temperature of the heat sink by applying the necessary boundary conditions for the heat sink profile. The energy model and finite volume method have been used for investigation using ANSYS software. In comparison between the two heat sink profiles, it is witnessed that the circular heat sink dissipates more heat. From the thermal analysis, it is found that using FGM will improve the heat transfer rate, and the temperature variation is found to be 3°C in comparison with conventional material because FGM is inhomogeneous materials consisting of two or more materials.

Keywords: Electronic systems, Functionally Graded Materials, Heat Sink, Thermal performance, CPU.

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1. INTRODUCTION

In Heat sinks made from functionally graded materials (FGM) were developed [1] as a means of increasing the heat dissipation efficiency of electrical mechanisms. The general view of FGMs has been explained by Rasheedat M. Mahmood et al. [2]. The term "functionally graded material" refers to one of the sophisticated materials whose qualities vary with changes along its dimensions. El-Wazery et al [3] carried out an extensive study on functionally graded ceramic-metal composites. Unwanted reflections at the interface, poor adhesion, and stress singularities caused by mismatched elastic or thermal properties may all be avoided with FGMs. FGM materials have been researched [4] to establish a suitable mathematical model for thermal conductivity. Based on the precise evaluation study for the various manufacturing processes, and then an appropriate FGM combination was identified for each specific application. Metal-ceramic FGM was studied [5]. Metal-ceramic composites were studied as to how they can be utilized as functionally graded materials for specific purposes. FGM's processing approaches and processing techniques were studied by different researchers [6-7]. Accomplished extensive exploration of FGM, and the findings of their investigation were compiled into a book [8]. A study [9] brought into being with the intention of the modulus of elasticity Al-Si alloy was increased by using co-continuous structures in the matrix. Material matrix thermal expansion and conductivity and heat sink application investigated the thermo-mechanical properties of permeated CuCrZr/W-Cu complex materials and also copper matrix composite heat sink was a research study by various investigators [9-11]. The use of CuSiC and AlSi10Mg metal-matrix composites as electronic construction materials is in demand. Al and Cu have traditionally been employed as heat sinks; however, they are currently being replaced by AlSi101Mg and CuSiC which are more suited to thermal applications [12]. Material characteristics and spreading resistance have an impact on the design of heat sinks [13]. A methodical heat dissemination model for a variety of heat sink cross-sections was presented.

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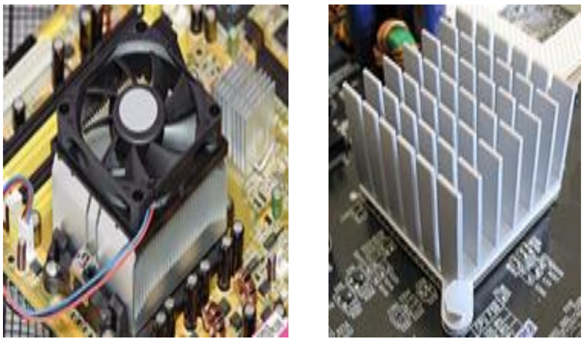
2. PROCEDURE

A heat sink is a thermally conductive device designed to absorb and dissipate heat from hot components such as a CPU. Usually, a heat sink is installed inside the fan to keep the CPM and heat at the desired level. Heat sinks are made of mono metal or a mixture of different materials such as FGM. It can be fabricated by different techniques like Powder metallurgy, Dry processing, Wet processing, Vapour deposition technique, Sintering process, Centrifugal method, etc. These are located at the top of the processor. Most of the heat sinks have fins, which help to dissipate heat faster. It can be of different types such as active and passive heat sinks (Figure 1). Active heat sink utilizes the power supply and is fan incorporated or Peltier cooling devices. Whereas passive heat sinks don't have mechanical components and are made of aluminium. They dissipate heat by the thermal convection process.



Active Heat Sink Passive Heat Sink

Fig. 1 – Heat Sink Modelling Techniques [14]

2.1 Modelling

To increase the heat dissipation process, the heat transfer per unit time needs to be increased. It can be augmented either by enhanced heat transfer coefficient (h) or by providing more surface area (A_s). The heat transfer coefficient can be increased by incorporating a pump or a fan. This method is less feasible as compared to increasing the A_s by attaching fins. A heat sink can be chosen based on:

1. Thermal resistance θ_{SA}
2. Airflow
3. Volumetric resistance
4. Fin density
5. Fin spacing
6. Width
7. Length

2.2 Selection of Heat Sink Profiles

In our present work, we have considered two heat sink profiles of different cross-sectional and different combinations of materials. These two profiles of heat sinks are currently used in our computers for cooling the processor. Aluminium and copper are used as a material in these heat sink profiles. These heat sink profiles were experimented on a running computer by attaching a thermocouple to the bottom and surface areas of the heat sink and the temperature of these were noted at 10 sec time intervals. We have designed these two models of the heat sink and analysed them with respective material properties.

3. MATHEMATICAL PROCEDURE

Here we discuss governing equations, geometry, meshing details, and boundary conditions required for the FVM investigation.

3.1 Governing Equations

ANSYS has been used with the following assumptions:
1. The heat sink operates under steady-state.
2. No fouling and mal-distribution during flow and heat transfer.
3. The fluids do not change the phase during the process.
4. The heat sink walls are insulated.
6. $\kappa - \varepsilon$ model has been used in the CFD simulation.

The governing equations used for the investigation are conservation of mass, energy and momentum [15].

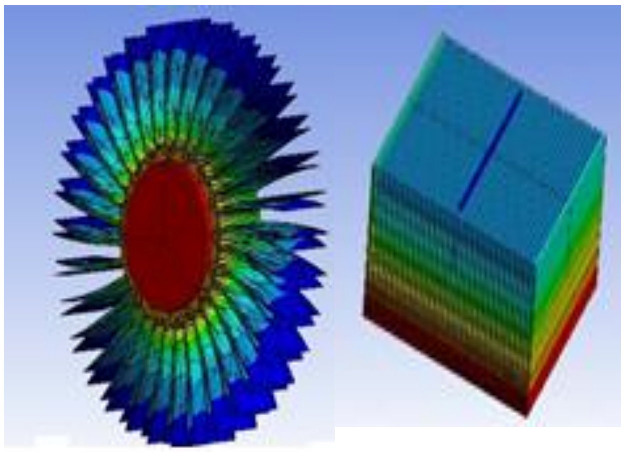
$$\nabla\left(\rho\vec{V}\right)=0$$

$$\nabla\left(\rho\vec{V}H\right)=-\nabla q-\tau\nabla\vec{V}+S_e$$

$$\nabla\left(\rho\vec{V}\vec{V}\right)=-\nabla p+\nabla\left(\mu\nabla\vec{V}\right)+S_m$$

3.2 Geometry and Mesh Topology

Figure 2 demonstrates the geometry/ shape of the heat sink investigated. An element size of 1mm (optimal size) with 1847558 and 1051143 as the number of nodes was obtained, respectively. The highly skewed elements in the domain were changed to polyhedral type.



Circular Profile Rectangular Profile

Fig. 2 – Heat Sink Geometry Overview

3.3 Boundary Conditions

The following boundary conditions were considered to obtain the numerical solution:
1. Inlet condition: The velocity and temperature specification method was used with normal direction velocity to the boundary.
2. Outlet condition: Outlet pressure condition of zero Pascal gauge pressure was taken.

3. Wall condition: The convective heat transfer through the stationary wall with no-slip condition was considered.

3.4 Solving and Post-Processing

Various solvers and models considered for the FVM analysis are the discrete approximation of the volume, surface integrals of the Navier-Stokes equations, steady state, pressure-based solver, energy equation, and k-epsilon model with standard wall functions have been used with default settings.

4. RESULTS AND DISCUSSION

In the present work, conventional materials used in manufacturing the heat sink such as aluminium and copper are replaced with FGM materials such as Al-SiC and other FGM materials and are analysed with different profiles and orientations to determine the difference between thermal stresses with different materials. Two different oriented profiles of the same volume are considered. The applied thermal heat on the base of the heat sink is 92 °C which has been obtained during experimental results. In addition, free convection of 10 °C is added to the analysis process. Two profiles are being used in this process Circular heat sink profile and rectangular heat sink profile. The numerical investigation has been conducted and results are reported with proper justification. Specific properties of aluminium matrix with silicon carbide (al-sic):

- Chemical Symbol: Al-Sic
- Atomic Number: Tailor-made
- Atomic Weight: 63.54
- Density: 2.89/cm^3
- Thermal Conductivity: 200-210 W·m^{-1}·K^{-1}
- Electrical Resistivity: (20 °C) 30 nΩ·m
- Crystal Structure: Face Cantered Cubic

4.1 CFD Simulation of Circular Heat Sink under Natural Convection

Simulation of a circular heat sink is performed in the Ansys software. An original temperature of 23 °C is considered and the bottom surface of the heat sink is given a heat flux of 92 °C. The remaining surfaces are provided with natural convection of 10° C temperature. Figure 3 displays the thermal profile for natural convection through the circular-shaped heat sink. A minimum temperature of 88.34 °C and a maximum temperature of 92 °C can be observed in the temperature profile.

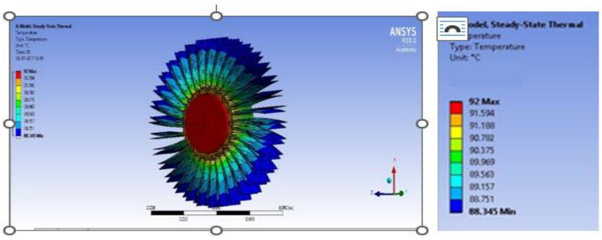


Fig. 3 – Temperature Profile in Circular Heat Sink: Natural Convection

4.2 CFD Simulation of Circular Heat Sink under Forced Convection

A starting temperature of 23 °C is provided to the heat sink circular profile and the bottom surface of the heat sink is provided with a heat flux of 63 °C. The remaining body surfaces are provided with the forced convection temperature.

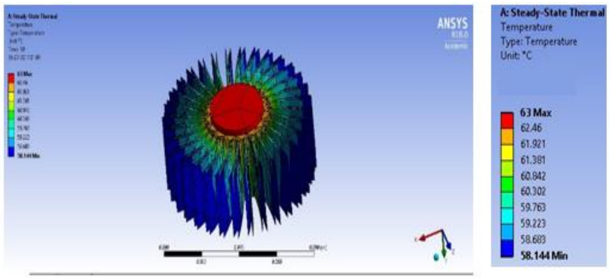


Fig. 4 – Temperature profile of circular heat sink under forced convection

Figure 4 displays the thermal profile for forced convection through the circular-shaped heat sink. The minimum temperature attained is 58.14 °C and the maximum temperature attained is 63 °C.

4.3 CFD Simulation of Rectangular Heat Sink under Natural Convection

An original temperature of 23 °C is considered and the bottom surface of the rectangular profile heat sink is given a heat flux of 92 °C. The remaining surfaces of the rectangular heat sink are provided with natural convection of 10° C temperature. Figure 5 displays the thermal profile for natural convection through rectangular-shaped heat sink.

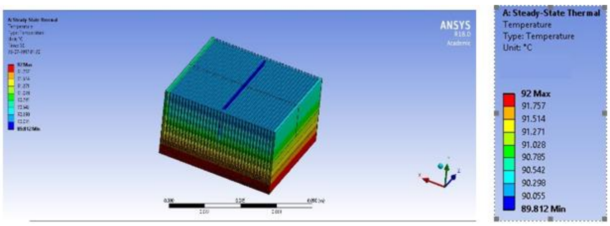


Fig 5 – Rectangular Heat Sink: Natural Convection Temperature Profile

4.4 CFD Simulation of Rectangular Heat Sink under Forced Convection

A starting temperature of 23 °C is provided to the heat sink rectangular profile and the bottom surface of the heat sink is provided with a heat flux of 63 °C. The remaining body surfaces are provided with the forced convection temperature. Figure 6 displays the thermal profile for forced convection through the rectangular-shaped heat sink. The minimum temperature attained is 59.19 °C and the maximum temperature attained is 63 °C.

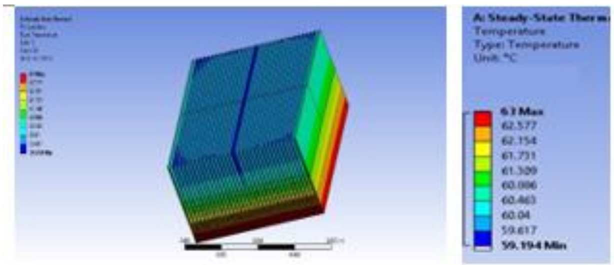


Fig. 6 – Temperature Profile of Rectangular Heat Sink under Forced Convection

4.5 CFD Simulation on FGM Circular Heat Sink under Natural Convection

A numerical study is conducted on a circular heat sink made up of Al-SiC (FGM). Properties of Al-SiC are measured and added manually in Ansys with the same parameters as previous cases (without FGM).

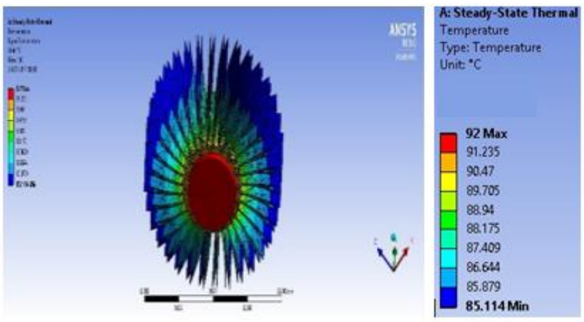


Fig. 7 – Natural Convection Results for FGM Circular Profile

Figure 7 displays FGM circular profile natural convection in the heat sink. A minimum temperature of 85.11 °C and a maximum temperature of 92 °C can be observed in the temperature profile.

4.6 CFD Simulation on FGM Circular Heat Sink under Forced Convection

A circular heat sink is chosen over a rectangular profile due to comparatively high heat dissipation. Finite volume simulation is conducted on a heat sink made from FGM material Al-SiC. Figure 8 displays FGM circular profile forced convection in the heat sink. A minimum temperature of 54.9 °C and a maximum temperature of 63 °C can be observed in the temperature profile. Analysis of Heat sink of circular, rectangular and FGM material heat sink is done using ANSYS and the results are discussed below:

1. In the circular heat sink (Al) with Free convection, the temperature difference found is 3.65 °C.
2. In the circular heat sink (Al) with Forced convection, the temperate difference is 4.8 °C.

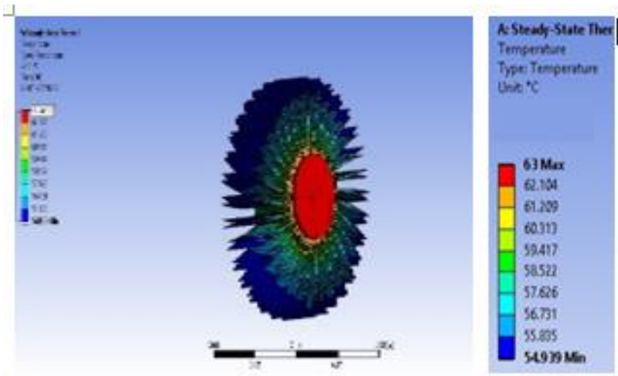


Fig 8. Forced Convection Results for FGM Circular Profile.

3. In the rectangular heat sink (Al) with Free convection, the temperate difference is 2.2 °C.
4. In the rectangular heat sink (Al) with Forced convection, the temperate difference is 3.8 °C.
5. In the FGM Circular Hear sink (AlSi10Mg) with Natural convection, the temperature difference is 6.8 °C.
6. In the FGM Circular Hear sink (AlSi10Mg) with Forced convection, the temperature difference is 8 °C.

5. CONCLUSIONS

An FGM heat sink consisting of AlSi10Mg composition has been considered in comparison to conventional heat sink materials such as Aluminium, copper. Two different heat sink profiles of different geometry are selected and designed. In comparison between two heat sinks it has been observed that circular heatsink dissipate more heat. Circular heat sink made of FGM material have given the optimum heat distribution having a variation of 3 °C in comparison with conventional materials.

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Дослідження теплових характеристик наноматеріалів із функціональною градацією для покращеного розсіювання тепла в електронних пристроях

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З удосконаленням електронних систем ефективне охолодження стало захоплюючим завданням на теплових майданчиках. Для оптимальних умов роботи електронних систем використовується енергоефективний радіатор. У роботі теплове моделювання виконується на двох різних профілях існуючих радіаторів, які використовуються в процесорі. Було вивчено та порівняно шість різних випадків, а саме природну та примусову конвекцію на круглих і прямокутних радіаторах з FGM (функціонально градуйованими матеріалами) і без них. Звичайний алюмінієвий сплав 6061 і функціонально сортований матеріал AlSi10Mg використовуються для розуміння зміни температури радіатора. шляхом застосування необхідних граничних умов для профілю радіатора. Енергетична модель і метод кінцевого об'єму були використані для дослідження за допомогою програмного забезпечення ANSYS. Порівняно між двома профілями радіатора, видно, що круглий радіатор розсіює більше тепла. З термічного аналізу виявлено, що використання FGM покращить швидкість теплопередачі, а коливання температури становлять 3 °C порівняно зі звичайним матеріалом, оскільки FGM є неоднорідним матеріалом, що складається з двох або більше компонент.

Ключові слова: Електронні системи, Функціонально градуйовані матеріали, Радіатор, Теплові характеристики, Центральний процесор.