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REGULAR ARTICLE

Thermal Performance Investigation of Functionally Graded Heat Sink Materials for Nano-Characteristics Electronic Devices: A Comprehensive Analysis

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The thermalperformance of a heat sink is evaluated in this study, which is then used for a thermal analysis. The heat sink's performance is verified by comparing the newly obtained experimental data to the numerical investigation conducted. The heat sink is made of composite material i.e. Functionally Graded Material (FGM) consisting of Al-SiC. Experiments were performed to observe the heat sink performance followed by numerical simulation. It has been observed that the performance can be enhanced by utilizing an FGM heat sink compared to a conventional (Al or Cu) heat sink. Forced convection is employed for both heat sinks, where an external source such as a fan is put on the top of the heat sink and is used to analyze the heat sink's performance. An average temperature differential of 1.2 °C was found between the two heat sinks. FGM has been shown to have a minimum temperature of 54.93 °C. At 58.15 °C, conventional heat sinks reach their maximum temperature. Both sinks show a maximum temperature of about 63 °C. Hence, FGM material can be used for manufacturing heat sinks in CPU cooling applications

Keywords: Heat transfer rate, Heat sink, Functionally Graded Material (FGM),Circular and rectangular profile.

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1. INTRODUCTION

In the realm of electronic devices, efficient heat transfer is paramount for optimal performance and reliability. Heat sinks play a crucial role in dissipating heat generated by electronic components, such as CPU processors, to prevent overheating and potential failure. Traditionally composed of materials like copper and aluminum alloys, heat sinks have evolved with the introduction of functionally graded materials (FGMs), offering improved heat dissipation efficiency. FGMs are advanced materials with properties that vary along their dimensions. They mitigate issues like unwanted reflections, poor adhesion, and stress singularities often encountered with conventional materials. Researchers have extensively explored FGMs, investigating their thermal conductivity, processing techniques, and potential applications. Studies have focused on enhancing the properties of materials like Al-Si alloys and CuCrZr/W-Cu composites for heat sink applications. Recent trends in electronic construction materials have seen a shift towards using metal-matrix composites like AlSi10Mg and CuSiC for their superior thermal properties. The design of heat sinks is influenced by material characteristics and spreading resistance, necessitating a systematic approach to heat dissemination modeling for various heat sink profiles. Considering the promising performance of FGMs for heat sinks, the authors have embarked on a study to develop AlSiC FGM-based heat sinks. They explore two different profiles-circular and rectangular – and analyze heat transfer under both natural and forced convection modes. Their research aims to further enhance heat sink performance, particularly in cooling CPU processors, by leveraging the advantages of AlSiC FGM materials.

2. PROCEDURE

For heat sinks for CPU processors, the proper selection of suitable FGM plays a crucial role. The type of FGM and the composition used makes the selected component perform with optimum efficiency. The processes involved the selection of the profile, modeling of the profile, simulation of the model, and experimentation. There are two types of heat sink profiles, carried out in the current work, which are distinct in their cross-sectional area and material which are shown in Fig. 1 and Fig. 2. The dimensions are shown in Table 1 and Table 2. To begin, the heat sink is subjected to a flux of 92 °C. After that, the solution is spread evenly throughout thewhole profile using a natural convection temperature of 10 °C.

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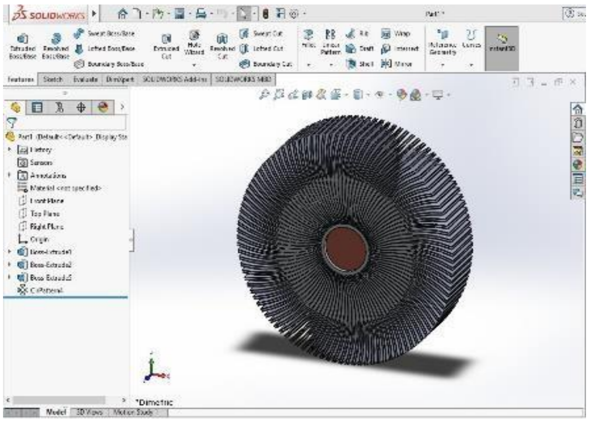

Fig. 1 – Circular heat sink profile

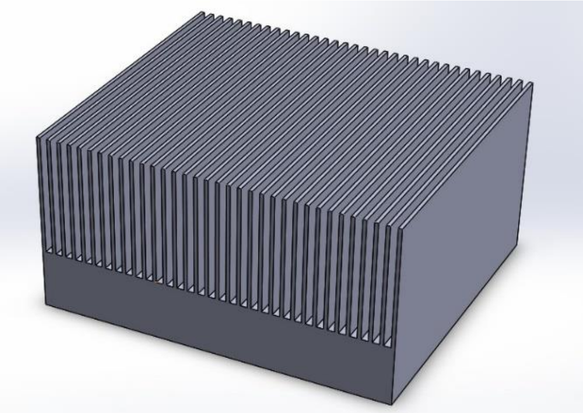

Fig. 2 – Rectangular heat sink profile

Table 1 – Details for the circular profile heat sink

S No	Specification	Measurement (mm)
1	Total Fins	103
2	Width at base	4
3	Width at inner	31
4	Thickness of the outer profile	87
5	Fin length	25
6	The inner diameter of the cylinder rim	36
7	The outer diameter of the cylinder rim	31

Table 2 – Details for the rectangular profile heat sink

S no	Specifications	Measurements (mm)
1	Limb height	27
2	Height of the profile	41
3	Limb width	0.7
4	The pitch of the limb	2.4
5	Material	Al
6	Widtthe h at based	15
7	Thickness of the heat sink	76

3. INVESTIGATION

To investigate thermal performance, as well as to assess the rate of heat transfer and heat indulgence, an experimental setup with thermocouples has been considered. Natural and induced convection are used to link the thermocouple to the heat sink, and the results are recorded every 30 seconds. The AMD FX TM-4100 CPU model numberand the gigabyte DX-10 motherboard employed in the experiment are shown in Fig. 3 and Fig. 4.

Fig. 3 – Thermocouple experimental setup

Fig. 4 – Attaching thermocouples to a profile

It is observed that the rectangular profile has heat dissipation in the vertical direction whereas in circular fins the heat dissipation is radial and thereby it takes less time to dissipate the heat. The contour plots also indicate that the FGM heat sink has better capability to dissipate the heat sink of the conventional materials. Thus, it is preferable to have a circular profile FGM heat sink for better heat dissipation in the CPU processor from the analysis study presented in the above figures.

4. MATHEMATICAL COMPARISION

Here we discuss governing equations, boundary conditions, geometry and meshing details required for the FVM investigation. ANSYS has been used with the following assumptions:

1. The heat sink operates under a 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 is used for the simulation.

The governing equations used for the investigation are conservation of mass, energy, and momentum [17, 18].

Figure 5 demonstrates the numerical model of the heat sink investigated. An element size of 1mm (optimal size) with 1847558 as the number of nodes was obtained, respectively. The highly skewed elements are replaced by the polyhedral type. 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 the no-slip condition was considered.

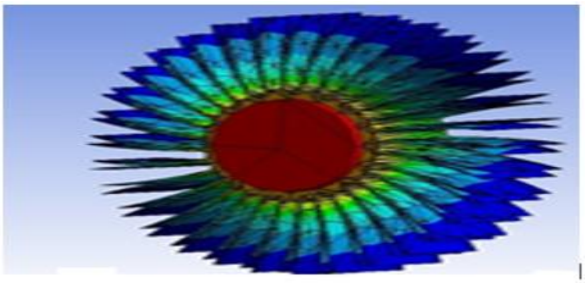

Fig. 5 – Circular profile numerical model of heat sink

Various solvers and models considered for the FVM analysis are the discrete approximation of the volume, steady state, surface integrals of the Navier-Stokes equations, energy equation.

5. RESULTS AND DISCUSSION

Testing is done on several circular heat sink models, including those with natural and forced convection. Compared to rectangular heat sinks, circular heat sinks have a betterheat dissipation rate. The results are tabulated in Table 3 and Table 4. Table 3 displays the minimum and maximum temperatures attained for different cases. It compares the experimental and numerical results for free and forced convection for circular profile heat sink. It can be observed that the deviation between experimental and numerical results, for studied cases, is around 1.4% (maximum). Whereas, table 4 displays the rate of heat transfer and time taken for free convection and forced convection modes. Their corresponding graphs are plotted in Figs. 6-9.

Table 3 – Comparing experimental and analytical results of circular heat sink performance

S.No.	Heat sink type	Min Temp. (°C)	Max Temp. (°C)	Min Temp. (°C)	Max Temp. (°C)
		(Exp)	(Exp)	(ANSYS)	(ANSYS)
1	(Al, Cu) Natural convection	87.21	92	88.35	92
2	(Al, Cu) Forced convection	57.35	63	58.15	63
3	FGM Natural convection	86.13	92	85.11	92

Table 4 – Heat transfer rates in circular heat sinks: Al, Cu, and FGM materials

S.No.	Heat Sink type	Rate of Heat Transfer (J/S)	Rate of Heat Transfer (J/S)	Time (sec)	Time (sec)
		(Exp)	(ANSYS)	(Exp)	(ANSYS)
1	(Al, Cu) Natural convection	0.0521	0.0397	30	30
2	(Al, Cu) Forced convection	0.0897	0.0770	30	30
3	FGM Natural convection	0.0638	0.0749	30	30
4	FGM Forced convection	0.1256	0.1281	30	30

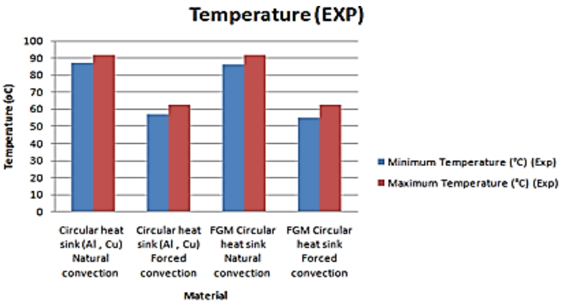

Fig. 6 – "Experimental Investigation: Temp in Nat. & Forced Conv. on Conventional vs. FGM Materials"

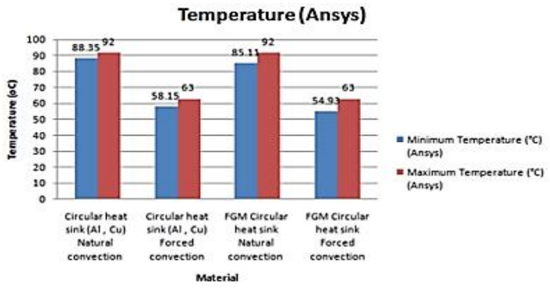

Fig. 7 – "Numerical Study: Temp in Nat. & Forced Conv. on Conventional vs. FGM Materials"

Figures 6 and 7 show the maximum and minimum temperatures obtained during

Experimental and numerical investigation for different materials at free and forced convection, respectively. It can be observed that the FGM material-based heat sink performs better in terms of the temperature attained. As FGM is a kind of composite materialo it shares the thermal properties of all the constituents and performs better which helps in cooling of CPU at a faster rate.

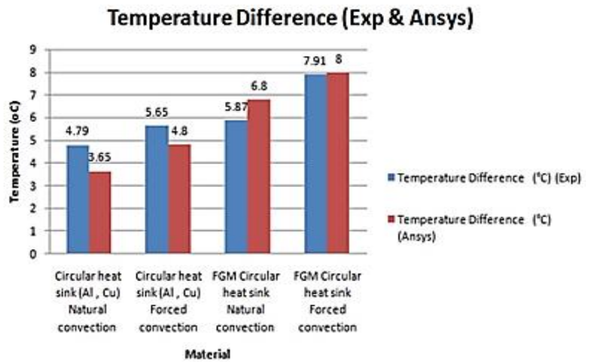

Fig. 8 – Temp Difference: Numerical Study in Conventional vs. FGM Materials under Nat. & Forced Conv.

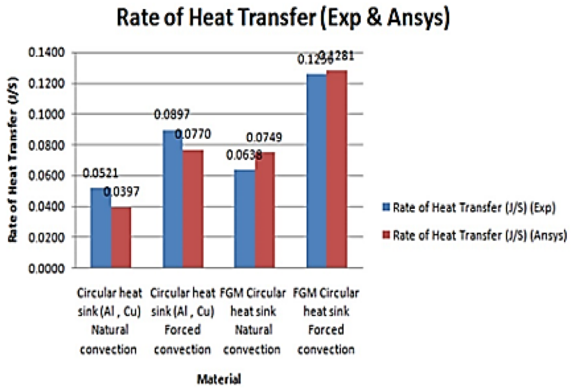

Fig. 9 – Heat Transfer in Conventional vs. FGM Materials: Numerical Study

Figure 8 displays the comparison between experimental and numerical results for temperature differences in free and forced convection for circular heat sinks made of conventional and FGM materials. It can be observed that the deviation between experimental and numerical results, for studied cases, is around 1.4 % (maximum). Therefore, it validates the present work and at the same time suggests that FGM material can replace conventional materials like Al and Cu for CPU cooling applications. Moreover, Figure 9 displays the comparison between experimental and numerical results for heat transfer rate in free and forced convection for circular heat sinks made of conventional and FGM material. It can be observed that the deviation between experimental and numerical results, for studied cases, is around 1.5 % (maximum).

6. CONCLUSIONS

An The following results were concluded based on the experimental and numerical investigation conducted for a circular heat sink used in CPU cooling applications:

1. The heat dissipation of a circular heat sink under free convection is found to vary by 1.5 °C.
2. Forced convection is employed, where an external source such as a fan is put on the top of the heat sink and is used to analyze the heat sink's performance. An average temperature differential of 1.2 °C was found in the heat sink.
3. FGM has been shown to have a minimum temperature of 54.93 °C. At 58.15 °C, conventional heat sink, made of copper or aluminum, reach their maximum temperature. The maximum temperature achieved is about 63 °C.
4. It has been shown that an FGM heat sink constructed of Al-Sic gives greater performance than traditional materials with less cost excellent performance and long-lasting durability.

Hence, FGM as a novel material can be used as a heat sink material for faster cooling of the CPU. In the future, the author will investigate different shapes and materials of heat sinks.

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Дослідження теплових характеристик матеріалів тепловідводу з функціональними градаціями для електронних пристроїв з нанохарактеристиками

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У цьому дослідженні оцінюється теплові характеристики радіатора, які потім використовуються для термічного аналізу. Ефективність радіатора перевіряється шляхом порівняння щойно отриманих експериментальних даних із проведеним чисельним дослідженням. Радіатор виготовлено з композитного матеріалу, тобто функціонально градуйованого матеріалу (FGM), що складається з Al-SiC. Були проведені експерименти для спостереження за ефективністю радіатора з наступним чисельним моделюванням. Було помічено, що продуктивність можна підвищити, використовуючи радіатор FGM порівняно зі звичайним (Al або Cu) радіатором. Примусова конвекція використовується для обох радіаторів, де зовнішнє джерело, наприклад вентилятор, розміщується на верхній частині радіатора та використовується для аналізу продуктивності радіатора. Середня різниця температур між двома радіаторами становить 1,2 °C. Показано, що мінімальна температура КЖМ становить 54,93 °C. При 58,15 °C звичайні радіатори досягають своєї максимальної температури. Обидві раковини демонструють максимальну температуру близько 63 °C. Отже, матеріал FGM можна використовувати для виготовлення радіаторів у системах охолодження ЦП

Ключові слова: Швидкість теплопередачі, Тепловідвід, Функціонально градуйований матеріал (FGM), Круглий і прямокутний профіль.