American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-4, pp-204-210
www.ajer.org
Research Paper Open Access

# Comparative Analysis Of Heat Sink Performance Using Different Materials

Haydar Kepekci[1], Alpay Asma[2]
[1] Mechanical Engineering Department, Beykent University, Istanbul, Turkey.
e-mail:haydarkepekci@beykent.edu.tr
[2] Mechanical Engineering Department, Bogazici University, Istanbul, Turkey.
e-mail: alpayasma@boun.edu.tr

**Abstract:** *Due to the improvements in electronic devices, the cooling of electronic chips has become one of the most significant and challenging issues to be dealt with. With the developments in the material and CFD technologies, it would be possible to achieve the optimum cooling performance of the designed system in terms of cost and size. With this aim, various geometries and materials were studied to determine the effect of heat sink designs on the cooling performance. The primary purpose of this study is to determine the optimal heat sink geometry and material, which provides the best thermal performance by considering the cost factor. In the analysis, CFD software named COMSOL was used to determine heat sink design giving the optimal thermal performance and cost. In that sense, four different fin geometries, including straight, hexagonal, square, and airfoil, and 13 different materials were used. In the design, the temperature of the environment and CPU are assumed to be 25 ℃ and 80℃, respectively, and the airspeed providing by the CPU fan is accepted as 7.5 m/s. In the designed system, each fin has a length of 0.02 m and a thickness of 0.002 m. In the assessment of the cooling performance of each heat sink, cooling power and pressure loss are selected as performance indicators. According to results, the optimal fin geometry is determined as an airfoil. Further, a cost analysis was also made for predetermined materials, including various raw materials and Aluminum alloys. The results showed that the best cooling performance and cost were obtained as the silver airfoil fins were selected.*

**Keywords:** *Heat Sink, Cooling Power, Pressure Loss, Fin Geometry, Fin Material*

---

Date of Submission: 07-04-2020 Date of acceptance: 21-04-2020

---

## I. INTRODUCTION

Thanks to the advancements in the electronics industry, the removal of heat from electronic devices have become one of the essential issues recently. In the last two decades, a tremendous effort has been paid to develop cost-effective cooling systems providing optimum cooling performance [1]. Since the precursor work conducted by Tuckerman et al., heat sinks were used in many studies to improve heat transfer in electronic devices [2]. Improvements in materials and CFD technology have enabled researchers to more easily examine the impact of many factors on cooling performance, from novel geometries to thermal stability and cost. In many applications, the air was selected as a coolant to decrease the temperature of the electronic devices such as microchips, LEDs, and projectors.

One problem associated with the performance of heat sink is the high thermal resistance and maldistribution of the flow. This problem is tackled down by Peles et al. In their study, heat transfer and pressure drop have been examined for various microchannel heat sinks geometries, and results are verified by experimental work. According to their findings, forced convection of air over a fin pin surface is determined to be the most efficient way to decrease the thermal resistance and obtain a better cooling performance [3].

Due to the improvements in computer-based technologies, including image processing, big data analysis, and CFD simulations, there is a considerable need for powerful computers that can solve complex algorithms in acceptable time limits. In recent years, with the innovations in materials and manufacturing methods, micron and nano-scale electronic circuits have been produced so that it is necessary to examine the heat transfer of loops in this dimension. In that sense, heat sinks with varying geometries were used in the computer chassis as they offered a better thermal performance by providing better mixing. Notably, the aluminum and copper plate fins are standard materials in the market which are used in the cooling of microchips

[4]. Further, the morphology (i.e., rectangular, cylindrical, hexagonal) of the fins affect the heat transfer rate, and manufacturing cost of the heat sink significantly [5].

Another significant factor affecting cooling performance is the arrangement of the pin fins. In literature, both the in-line, staggered, and perforated pin fin configurations were used. Sparrow et al. showed that the staggered pin fins are superior to in-line arrangement both in terms of pressure drop and thermal performance at high Reynolds numbers [6]. Shaeri et al. conducted a comparative analysis between solid and perforated fins. According to results, solid fins are provided meager heat transfer rate than perforated arrangement. The study conducted by Ismail et al. was targeting to evaluate the thermal performance of perforated pin fin arrays for various hole geometries, including cube, round, triangular, and hexagonal shapes. The results revealed that circular perforations would give the best pin effectiveness, and all the perforated fins provided better performance under turbulent flow conditions [7]. Researchers also studied some novel geometries, such as splayed and wavy designs of plate and pin heat sinks. Junaidi et al. examined the heat transfer capability and fluid flow of splayed pin fin under low-velocity conditions. The results indicated that it would be possible to provide a 20-30% heat transfer enhancement by using splayed pin fin instead of standard pin fin [8]. The study conducted by Kai Zhu et al. was targeting to understand the effect of using heat sink with embedded heat pipe on CPU cooling performance. According to results, as the asymmetric U type heat pipe is mounted on the bottom plate of the Aluminum heat sink, the better cooling of the CPU can be obtained thanks to lower thermal resistance and improved heat dissipation efficiency [9].

In this study, the main aim is to determine the optimum heat sink geometry and material that can give an optimal cooling performance. In that sense, four different fin geometries, including straight, hexagonal, square and airfoil, and 13 different materials including ten raw elements and 3 Aluminum alloys, were analyzed in the COMSOL environment.

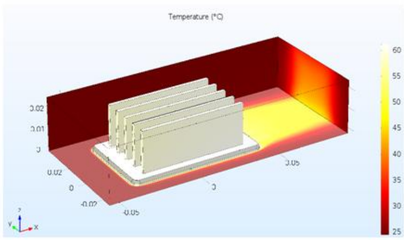
## II. MATERIAL AND METHODS

### 2.1. Mesh Independence

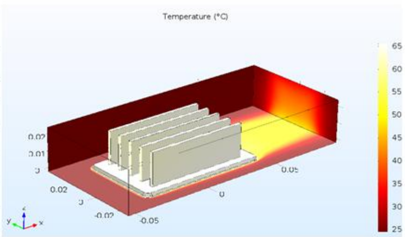
In order to calculate the cooling power and pressure loss of each specific heat sink geometry and material, firstly, the mesh independence of each geometry should be checked. For this purpose, mesh files containing hexagonal type meshes comprising of 1 Million, 2 Million, and 4 Million grids were prepared. All the analyses are conducted with CFD software named as COMSOL. In each specific case, inlet and boundary conditions such as air velocity, outlet temperature, and maximum permissible temperature limit of the heat sink are assumed to be the same and respectively selected as 7.5 m/s, 25 ℃ and 80 ℃ In the analysis, a PC with "Intel (R) Core (TM) i7-4710HQ CPU @ 2.50GHz, four cores" was used. The mesh independence test for the rectangular heat sink is provided in Table 1.

**Table 1.** Comparison of Mesh Types

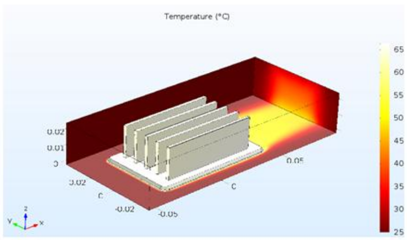
| Mesh Type | Grid Number | Cooling Power (W) | Average Pressure Loss (Pa) | Computational Time |
|---|---|---|---|---|
| Coarse | 1 million | 16.500 | 1.041 | 1 hour 30 min |
| Normal | 2 million | 17.307 | 1.013 | 2 hour 50 min |
| Fine | 4 million | 17.386 | 0.846 | 10 hour 30 min |




(a)




(b)




(c)

**Figure 1.** Temperature fields of the rectangular heat sink for the hexagonal type of mesh composed of a) 1 Million b) 2 Million c) 4 Million meshes.

As can be seen from Table 1 and Figure 1. there is almost no difference between standard and fine meshes in terms of cooling power, average pressure loss, and temperature fields. However, the computational time required for the analysis is incomparably high for the fine mesh case. Therefore, the standard mesh composed of 2 Million grids is selected.

### 2.2. Determination of Fin Geometry

To determine the fin geometry of the proposed heat sink model, various analysis is conducted in the COMSOL environment. In the analysis, five different fin configurations, including pin-square, rectangular, airfoil, pin-hexagonal, and pin-circular, were selected as candidates. During the analysis, the fin number of each case is determined in such a way that the total volume of the selected fins remains the same. The proposed fin geometries used in heat sink design are given in Figure 2.

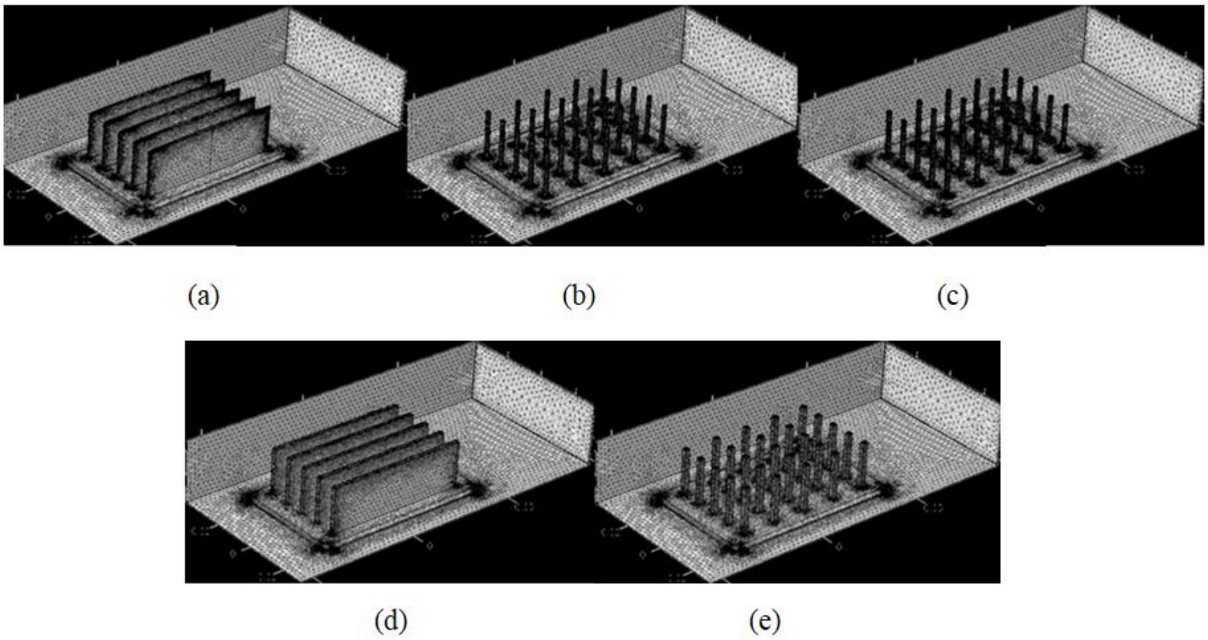



**Fig 2.** Heat sink configurations used in COMSOL software a) Airfoil b) Pin Hexagonal c) Pin Squared) Rectangular e) Pin Circular

**Table 2.** Cooling power (W) and average pressure loss (Pa) calculations for selected fin geometries.

| **Fin Geometry** | **Cooling Power (W)** | **Average Pressure Loss (Pa)** |
|---|---|---|
| Pin Square | 42.16 | 46.91 |
| Straight | 39.514 | 26.152 |
| Airfoil | 37.27 | 18.52 |
| Pin Hexagonal | 34.93 | 40.05 |
| Pin Circular | 31.01 | 35.42 |

According to results in Table 2., the maximum cooling power is obtained for pin square fin geometry with 42.16 W. However, for PC cooling applications maximum allowable limit for pressure loss is nearly 20 Pa. Therefore, the airfoil configuration meets this requirement is selected for the proposed heat sink.

### 2.3. Material Selection

In literature, aluminum and copper are commonly used as fin materials in heat sink applications for CPU cooling. However, there is still lesser effort paid on the comparative analysis for raw materials and alloys. In that context, 13 different materials, including ten raw materials, and three aluminum alloys, were used. In the selection of materials, conductivity, cost, and availability are considered. The materials selected during the analysis were aluminum, beryllium, copper, gold, lithium, magnesium, nickel, silver, titanium, tungsten, 356 alloys, 6061 alloys, and 7075 alloys. One of the primary motivation of this study is to determine the optimal heat sink design that could meet the performance and cost criteria at the same time. Therefore, a comparative analysis for predetermined materials is conducted for airfoil fin arrangement in such a way that the total mass of materials used in heat sink design does not change. The results for the selected materials are given in Table 3.

**Table 3.** Comparative analysis for various materials in terms of cost and performance using airfoil fin arrangement.

| Material | Dissipated Power (W) | Pressure Loss (Pa) | Price (USA Dollar) |
|---|---|---|---|
| Silver | 37.33 | 18.52 | 8.8593 |
| Copper | 37.27 | 18.52 | 6.46875 |
| Gold | 37.03 | 18.52 | 1396.875 |
| Aluminum | 36.68 | 18.52 | $2.3x10^{-3}$ |
| 7075 Alloy | 36.44 | 18.52 | 0.021 |
| Beryllium | 36.34 | 18.52 | 0.564 |
| 356 Alloy | 36.32 | 18.52 | $5.48x10^{-3}$ |
| Tungsten | 36.15 | 18.51 | 1.782 |
| 6061 Alloy | 36.02 | 18.51 | 0.0146 |
| Magnesium | 35.98 | 18.51 | 3.3711 |
| Nickel | 34.60 | 18.51 | 15.418 |
| Lithium | 34.46 | 18.51 | 0.166 |
| Titanium | 28.67 | 18.53 | 0.28 |

According to results in Table 3, it can be seen that the pressure loss values are approximately equal to each other, and all values are lesser than 20 Pa, which is given as limiting value for the PC cooling applications. The highest performance in terms of dissipated heat is obtained for silver. However, as the cost factor is taken into account, aluminum and 356 Alloys are preferable to others.

### 2.4. Numerical Simulation

In order to predict the heat transfer, fluid velocity, and pressure variation, we need a micro-channel heat sink model with solid and air interaction, In the prediction flow velocity and pattern Reynolds-Averaged Navier Stokes (RANS) formulation of Navier-Stokes equation were used. RANS equations can be given as follows,

$$\rho(u.\nabla)u = \nabla\left[-p.I + (\mu + \mu_T).(\Delta_u + (\Delta_u)^T - \frac{2}{3}(\mu + \mu_T)(\nabla.u)I\right] + F \qquad (1)$$

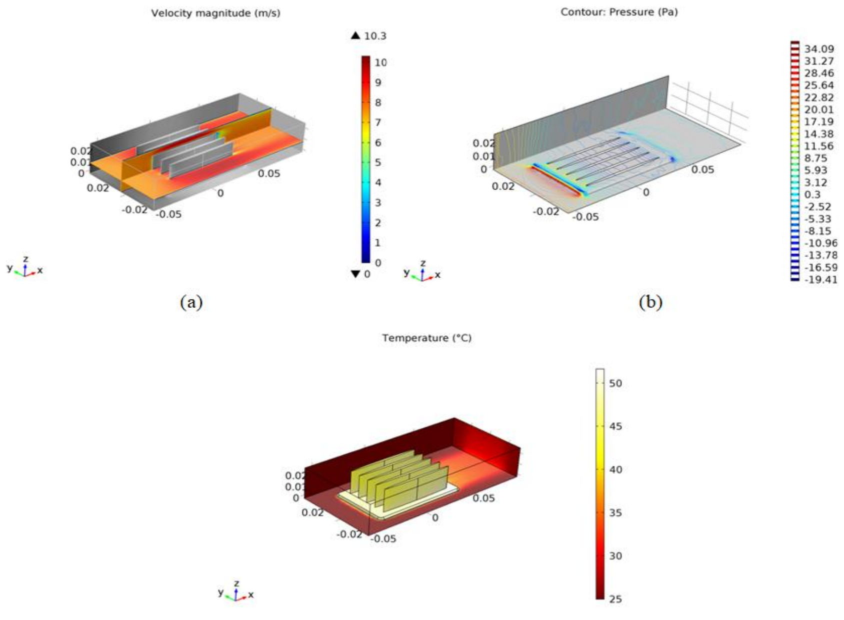
Coolant continuity equation can be given as follows,

$$\nabla(\rho.u) = 0 \qquad (2)$$

where $u$ and $p$ are time-averaged velocity and pressure, $\mu_T$ is turbulent viscosity determined by $k - \varepsilon$ turbulence model, and $F$ is the body force exerted on the fluid.

## III. RESULTS AND DISCUSSION

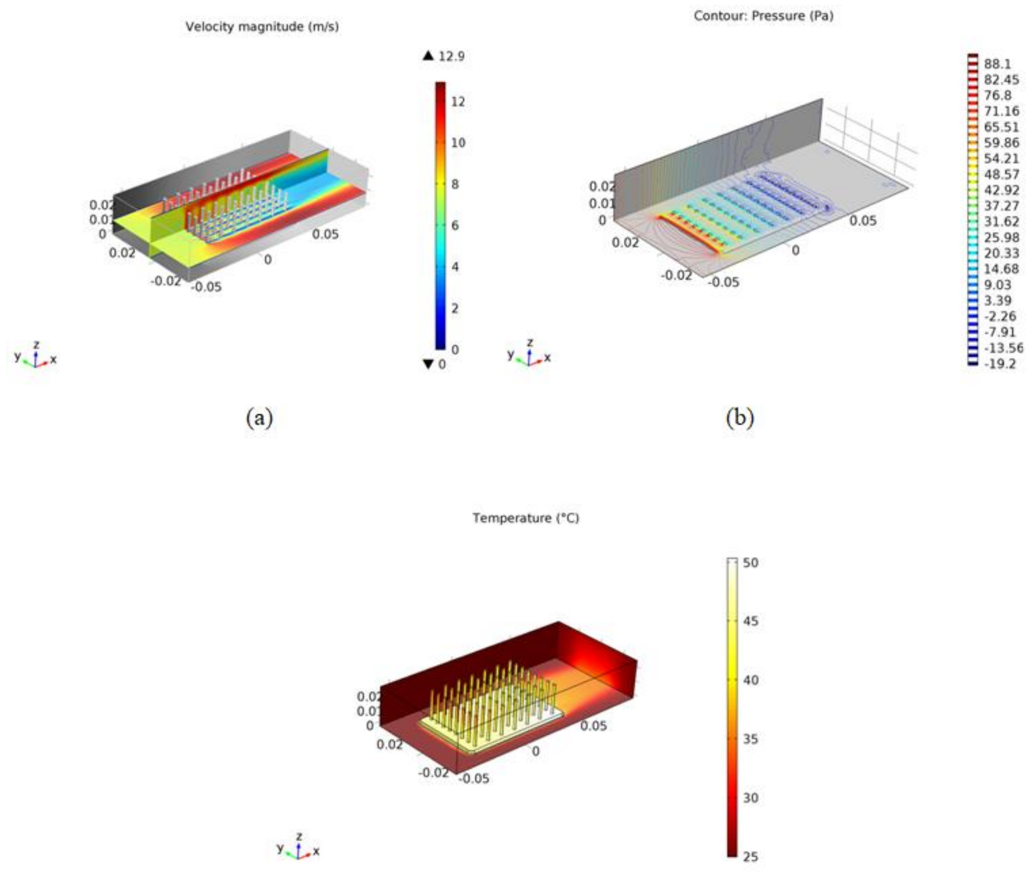
The main aim of this study is to determine the effect of pin fin geometry and arrangement on heat transfer characteristics of heat sink considering the material selection. Therefore, CFD analysis was conducted in the COMSOL environment for five different fin geometries and 13 different materials, including various raw materials and alloys. In the design process, three different variables, including change in the velocity field, pressure loss, and temperature variation along with the heat sink, were used to assess the cooling performance of each case.




(c)

**Fig 3.** Results from the airfoil-shaped aluminum heat sink a) Velocity b) Pressure c) Temperature

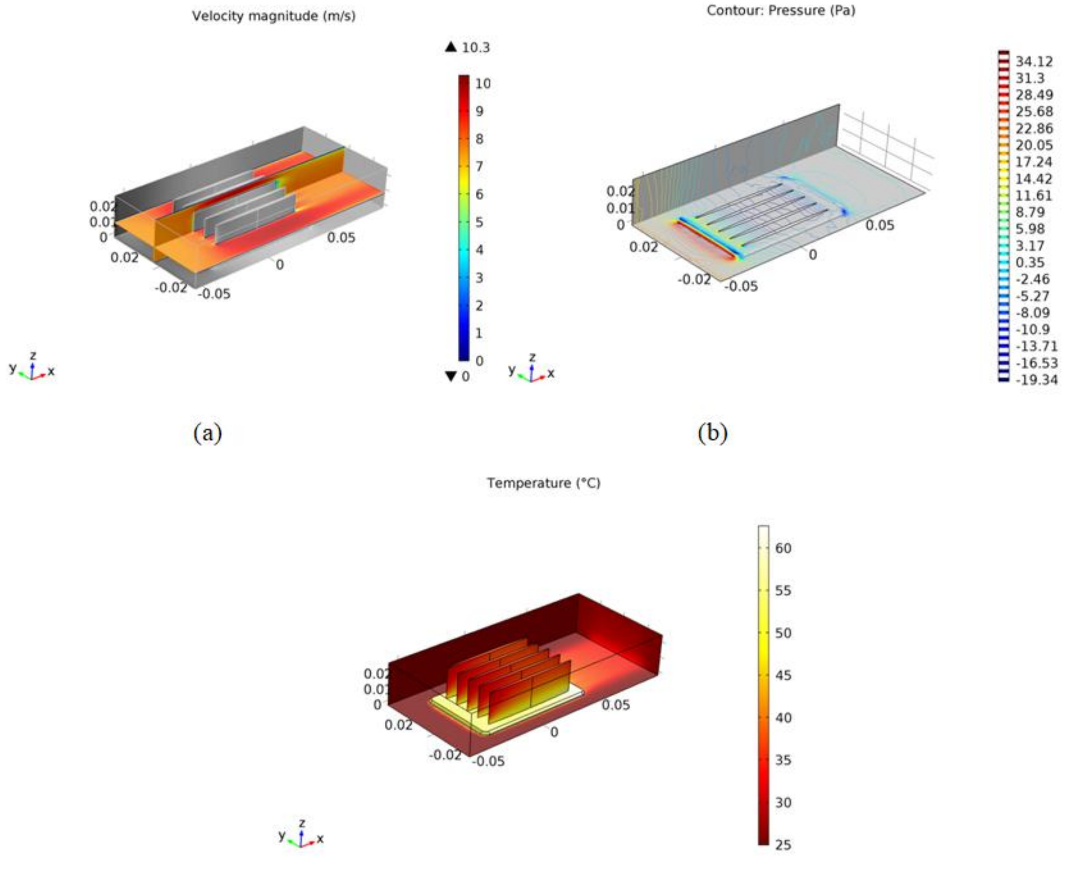
Figure 3. shows the change of velocity, pressure, and temperature along the heat sink combined with airfoil-shaped fin arrangement made from aluminum. According to results, it can be seen that temperature increases in the direction of flow due to the decreasing flow velocity as it is expected. Further, as the airfoil geometry is selected, a more uniform temperature distribution is obtained, and pressure loss along the pathlines is in the acceptable range (<20 Pa).




(c)

**Fig 4.** Results from the pin circular-shaped aluminum heat sink a) Velocity b) Pressure c) Temperature

Figure 4. shows the change of velocity, pressure, and temperature along the heat sink combined with pin circular-shaped fin arrangement made from aluminum. According to results, the higher pressure loss is observed compared to a previous case stemming from the creation of a wake region caused by the separation of flow. In that region, vortices are generated thanks to the existence of turbulent conditions. This effect can be seen in Figure 4.b. Acceleration of air on the right, and left side of the fin arrangement may provide better cooling performance for the designed heat sink. However, pressure loss values are unacceptably high (>20Pa) due to the creation of adverse pressure gradients behind the heat sink.




(c)

**Fig 5.** Results from the airfoil-shaped titanium heat sink a) Velocity b) Pressure c) Temperature

Figure 5. shows the change of velocity, pressure, and temperature along the heat sink combined with airfoil-shaped fin arrangement made from titanium. According to the results, depending on the decreasing flow rate, the temperature was expected to increase in the flow direction, but it did not. There was no significant change in temperature throughout the flow. This is due to the thermophysical properties of the titanium material. Additionally, as the airfoil geometry is selected, a more uniform velocity distribution is obtained, and pressure loss along the pathlines is in the acceptable range (<20 Pa).

## IV. CONCLUSIONS

In this study, fin geometry and material, the effect of heat sinks on their performance was investigated. Based on the results obtained, the main findings of this numerical study can be summarized as follows:

- It is found that fin geometry is the most significant factor leading to the pressure loss for heat sinks during operation. According to results, airfoil configuration is determined as the fin arrangement for heat sink geometry.

-Among the materials evaluated within the scope of the study, silver is determined as a most useful material in terms of cooling power with 37.33 W, and titanium is the worst performing material with 28.67 W. However, as the cost criteria are considered, aluminum and aluminum 356 alloys are superior to other materials.

- In future studies, instead of airfoil geometry, hybrid fin geometry one half is composed of rectangular and other half is an airfoil, or novel heat sink designs such as wavy fin arrangement can be used to achieve higher cooling performance.

## REFERENCES

[1]. A. Moradikazerouni, M. Afrand, J. Alsarraf, O. Mahiad, S. Wongwises, M.D. Tran, Comparison of the effect of five different entrance channel shapes of a micro-channel heat sink in forced convection with application to cooling a supercomputer circuit board, Applied Thermal Engineering, 150, (2019), 1078-1089

[2]. D.B. Tuckerman, R.F. Pease, IIIB-8 implications of high-performance heat sinking for electron devices, IEEE Trans. Electron Devices 28 (10) (1981) 1230–1231.

[3]. Y. Peles, A. Kosar, C. Mishra, C.-J. Kuo, B. Schneider, Forced convective heat transfer across a pin fin micro heat sink, Int. J. Heat Mass Transf. 48 (17) (2005) 3615–3627.

[4]. J. Choi, M. Jeong, J. Yoo, M. Seo, A new CPU cooler design based on an active cooling heatsink combined with heat pipes, 44 (2012) 50-56.

[5]. A. Al-Damook, F.S. Alkasmoul, Heat transfer and airflow characteristics enhancement of compact plate-pin fins heat sinks-A Review, Propulsion and Power Research, 7(2) (2018) 138-146.

[6]. E. Sparrow, J. Ramsey, C. Altemani, Experiments on in-line pin fin arrays and performance comparisons with staggered arrays, ASME J. Heat Transfer 102 (1) (1980) 44–50.

[7]. M.F. Ismail, M.N. Hasan, M. Ali, Numerical simulation of turbulent heat transfer from perforated plate-fin heat sinks, Heat Mass Transf. 50 (4) (2014) 509–519.

[8]. M.A.R. Junaidi, R. Rao, S.I. Sadaq, M.M. Ansari, Thermal analysis of splayed pin fin heat sink, Int. J. Modern Commun. Technol. Res. (IJMCTR) 2 (4) (2014).

[9]. K. Zhu, M. Zheng, B. Wang, B. Dai, Y. Wang, J. Wie, X. Cheng, Experimental study of energy saving performances in chip cooling by using heat sink with embedded heat pipe, Energy Procedia, The 8th International Conference on Applied Energy, 105 (2017) 5160-516

Haydar Kepekci, et al. "Comparative Analysis Of Heat Sink Performance Using Different Materials." *American Journal of Engineering Research (AJER),* vol. 9(04), 2020, pp. 204-210.