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Investigation of Heat Transfer Performance of Metallic and Composite Pin Fins with Geometrical Variations - A Review

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***Abstract*- Efficient thermal management is essential in designing compact electronic devices and integrated circuits. As device sizes shrink, removing excess heat becomes more challenging. An *extended surface* is a solid structure that improves heat dissipation. It conducts heat through the material, then transfers it to the surrounding fluid by convection at its surfaces. This approach aids cooling and maintains safe operating temperatures. Additionally, there are some situations were heat transfers predominantly by radiation. Many problems involve both conduction within solids and convection in a fluid, but the most common example is the fin. A fin is added to improve heat removal when increasing the convection coefficient is not feasible. By extending into the fluid, fins provide a larger heat exchange area, transferring more heat from the surface. This review presents research on how different materials and geometries affect pin fin performance. Studies conclude that material properties and pin fin geometry influence heat transfer rates. Most research covers circular pin fins; other geometries remain unexplored. Aluminium and copper pin fins are better for high accuracy and fast response, while circular fins transmit heat more effectively.**

Keywords- Thermal performance, Heat transfer, Fin materials, Fin Geometries

I. INTRODUCTION

A. Introduction:

A pin fin is a type of extended surface designed to enhance heat dissipation. Heat travels through the fin by conduction within the solid material and is then released to the surrounding fluid through convection. With the rapid growth of power electronics, effective cooling methods have become increasingly important for controlling heat transfer. Electronic components are highly sensitive to temperature, and maintaining an appropriate operating temperature is essential to ensure their reliability and long service life. [1] To achieve long-term durability and reliable operation, it is essential to keep temperatures within safe operating limits.

Heat transfer refers to the movement of thermal energy that occurs because of a temperature difference. In modern engineering systems, a significant amount of residual heat is generated during operation and must be effectively released to the surrounding environment. If this excess heat is not removed, equipment can overheat, leading to reduced performance or even failure. Therefore, efficient heat transfer is a critical factor in ensuring the proper and reliable functioning of both mechanical and electronic components, such as engines, transformers, and condensers. Therefore, Extended surfaces of fins are used to increase heat transfer [2]. A fin is an extended surface that projects outward from the main heat-transfer surface. As heat flows along the fin, the temperature gradually decreases from the base toward the tip due to heat loss to the surrounding environment. Fins are widely used in thermal systems and are manufactured in many different shapes to suit specific applications. Common examples include circular fins attached to motorcycle engine cylinders and pin-type fins used on refrigerator condenser tubes. Heat transfer describes how thermal energy flows from a warmer area to a cooler one. This movement of heat happens in three main ways: through direct contact between materials (conduction), by the motion of fluids like air or liquids (convection), and through electromagnetic waves that can travel even through empty space (radiation). [2].

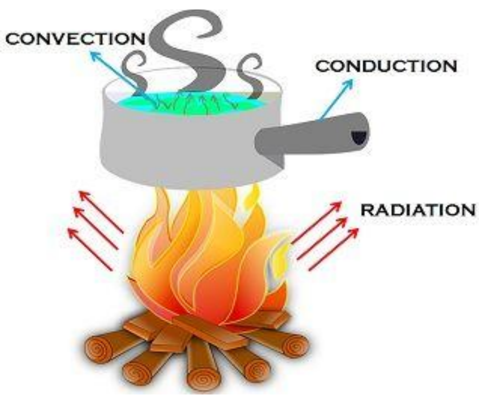

Fig- 1. Conduction, convection & radiation [3]

B. Fin shape:

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The effectiveness of fins depends on several parameters, such as their length, orientation, surface area, and overall shape. Changes in fin geometry can significantly influence how effectively heat is dissipated. For example, increasing the fin height or decreasing the spacing between adjacent fins generally improves heat dissipation. These changes increase the total surface area available for heat exchange, which helps reduces the operating temperature of the system [4].

Pin fins are manufactured in a wide range of shapes, including conical, circular, square, rectangular, and I-shaped designs. Their arrangement on a surface also varies depending on the application, with configurations such as inline (plain), perforated, and herringbone patterns commonly used to improve heat-transfer performance. In addition to these, many new and innovative arrangements have been developed to further enhance system efficiency. The geometry of a pin fin plays a major role in heat transfer, as it affects both heat conduction within the fin and the airflow patterns around it. Different shapes can generate varying levels of turbulence, which directly influence convective heat transfer. Studies conducted on pin fins placed within flow channels show that fin shape has a significant impact on overall performance. Based on a review of existing research, results suggest that rectangular plate fins provide a higher total heat-transfer rate than cylindrical pin fins when operating under the same boundary conditions and control parameters. In fact, rectangular fins have been reported to be approximately 40% more efficient than cylindrical pin fins [5].

TYPE OF PIN FINS	APPLICATIONS
Circular, square, hexagonal, elliptical, rounded cube, and flat-ended rectangular fins	Heat exchangers, automotive systems, heating, and cooling (HVAC) equipment
Chamfered or rounded, grooved, or slotted designs	Electronics such as CPUs, GPUs, and compact thermal operation systems
Air foil or elliptic fins	Aerospace components, drone cooling system, and unmanned aerial vehicles (UAVs)
Helical or twisted fins	High-performance computing platforms and power electronic modules
Hollow, cut-out, or trapezoidal fins	Space applications, drones, and systems where weight reduction is critical

Table-1. Types of fins and applications [5]

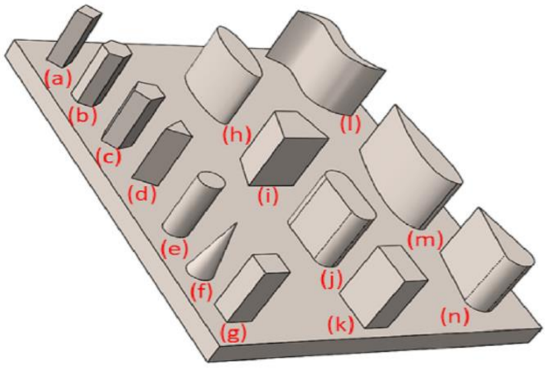


Fig 2- (a) diamond, (b) hexagonal, (c) pentagonal, (d) triangular, (e) cylindrical, (f) conical, (g) square, (h) elliptical, (i) trapezoidal, (j) oblong, (k) cuboidal, (l) S-shaped, (m) hydrofoil, and (n) cone-shaped cross-section designs [6].

C. Parameters influencing heat transfer performance:

The efficiency of heat transfer in finned surfaces is affected by several interrelated factors, including:

- Shape of the fin (type or profile of the fin)
- Key geometric characteristics such as perimeter, length, & aspect ratio
- The total number of fins used
- Material selected for the fin
- Clearance or spacing between fins
- Position of flow modifiers or obstacles in forced convection
- Type of fluid flowing over the fins
- Surface finish of the fins

D. Advantages & disadvantages:

- Compact and space saving design
- High efficiency in heat transfer
- Suitable for use with a variety of coolants
- Economical and cost-effective solution
- Larger effective surface area
- Higher pressure drops across the system
- Increased manufacturing complexity
- Possibility of deformation or bending under stress

II. LITERATURE SURVEY

A. Literature review:

Sreedhar Vullo Ju [7] investigated the effect of surface coating on the heat transfer performance of stainless-steel pin fins using brass and aluminium coatings. Twin wire arc coating was employed to deposit a uniform coating layer, and experiments were carried out at different heat inputs using a pin fin apparatus. The study examined important thermal performance indicators, including the Reynolds number, Nusselt number, heat-transfer coefficient, and fin efficiency.

Material	**Reynold Number**	**Nusselt number**	**Thermal conductivity**	**Fin Efficiency**
Stainless steel	164.87	6.55	28	50.4
Stainless steel with Brass coating	165.1	6.6	75.4	76.5
Stainless steel with Aluminium coating	176.19	6.69	166.75	87.5

Table 2- Result parameters of All specimen [7]

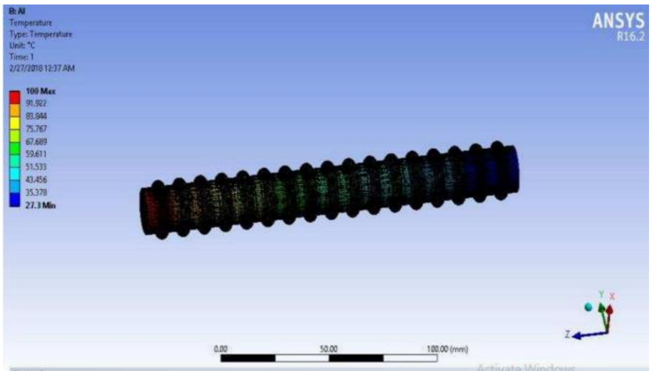
Results showed that aluminium-coated fins exhibited superior thermal performance compared to brass-coated and uncoated fins. A noticeable improvement in fin efficiency and thermal conductivity was observed due to the high conductive nature of aluminium. The findings highlight that surface coating is an effective method for enhancing heat dissipation without altering fin geometry. This work provides useful insights for improving the thermal performance of fins in compact heat exchanger applications.

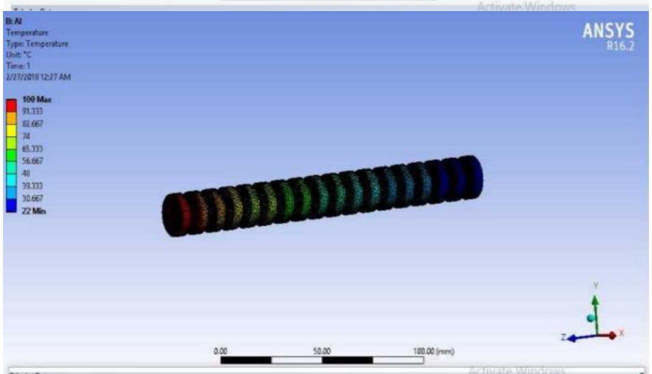
Venkateswara Reddy Kolagotla [8] carried out a comparative thermal analysis of circular fins manufactured using pure copper, pure aluminium, and aluminium alloys 6063 and 7068 through numerical simulation. The study focused on evaluating temperature distribution and heat flux under steady-state conditions using ANSYS software. Results revealed that material selection plays a crucial role in fin performance, with copper showing the highest heat flux and better temperature reduction along the fin length. Aluminium and its alloys also demonstrated effective heat dissipation but with comparatively lower thermal performance. The analysis highlighted that higher thermal conductivity directly enhances fin effectiveness in circular geometries. The findings emphasize the importance of material optimization in fin design for improved heat transfer. This work provides valuable guidance for selecting fin materials in compact thermal management systems.

Sr.no	Material	Temperature (°C)		Heat flux (W/m^2)	
		Maximum	Minimum	Maximum	Minimum
1	Copper	300	290.35	1.6059 x 10^5	1231.3
2	Aluminium	300	283.99	1.5796 x 10^5	1198.4
3	Aluminium alloy 6063	300	282.04	1.5715 x 10^5	1190.2
4	Aluminium Alloy 7068	300	280.26	1.5641 x 10^5	1183.4

Table 3 – Temperature distribution and heat flux for pin fins [8]

Arun Eldhose [9] performed a numerical investigation to study the influence of pin fin geometry and material on heat transfer performance using ANSYS software. The model was first validated with experimental data, showing good agreement in terms of fin efficiency and temperature distribution. Different pin fin shapes such as grooved, ringed, helical, and rectangular profiles were analyzed to identify their thermal effectiveness. The study revealed that fin geometry significantly affects heat transfer due to changes in surface area and airflow interaction. Material variation also played a key role, with higher thermal conductivity materials showing improved efficiency. Composite and high-conductivity materials demonstrated superior heat transfer compared to conventional aluminium fins. The results emphasize that both material selection and geometric modification are effective methods for enhancing pin fin performance in thermal systems.





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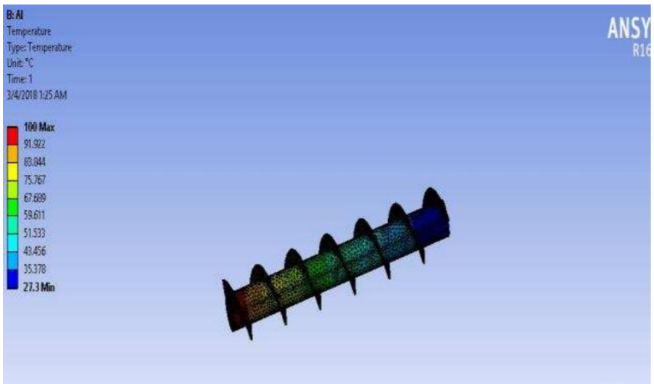

Fig-3 Temperature distribution of cylindrical pin fin with rings, with rectangular fin & with helix [9]

I T Nazzal [10] presented a numerical study focusing on the thermal behaviour of pin fins with different geometric configurations under forced convection conditions. The analysis emphasized how variations in fin shape influence temperature distribution, heat transfer coefficient, and overall fin efficiency. Simulation results indicated that modified pin fin geometries enhance heat dissipation by increasing the effective surface area and improving airflow interaction. The study highlighted that optimized fin design can significantly reduce thermal resistance without increasing material usage. Results also showed a strong dependency of heat transfer performance on flow conditions and fin geometry. The findings suggest that numerical modelling is an effective tool for predicting fin performance prior to experimental validation. This work contributes useful design insights for compact heat exchanger and electronic cooling applications.

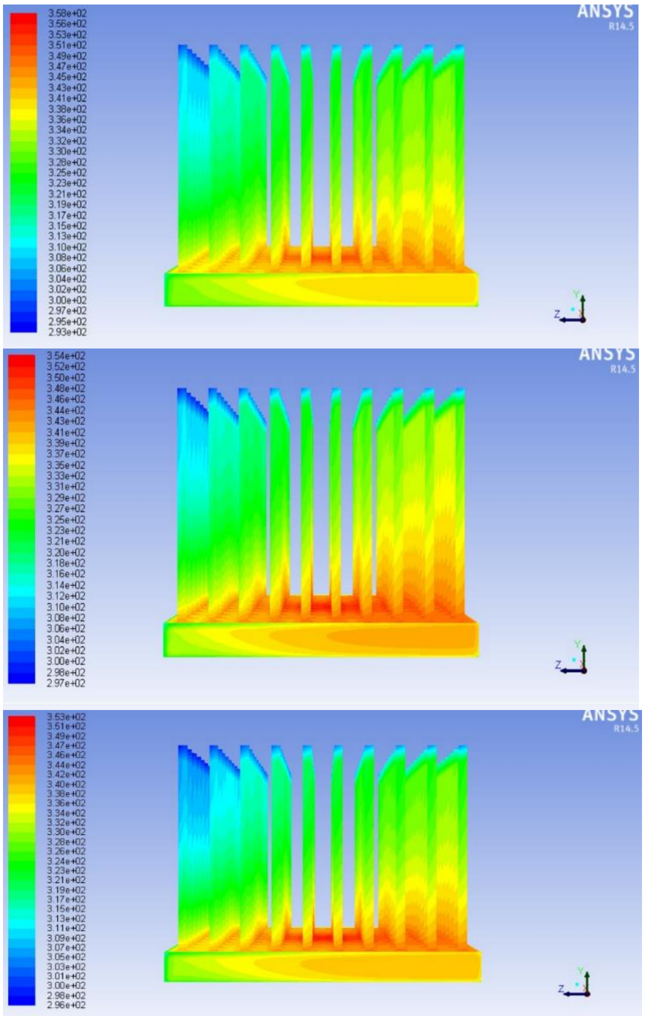

Fig-4 Temperature distribution for pin fin heat sink for pure Al, Cu-Al & Be-Al [10]

Karana Sangaj [11] conducted an experimental and numerical investigation to evaluate the thermal performance of pin fins with different geometries and materials under forced convection. The study compared temperature distribution and heat transfer rates using ANSYS and experimental measurements. Results showed that fin geometry and material selection significantly influence heat dissipation, with copper and optimized shapes providing better performance. The work highlights the importance of parametric optimization in designing efficient pin-fin cooling systems.

Prem Chandra [12] presents a clear comparison between pin-fin and straight-fin heat sinks under identical operating conditions. It highlights that pin-fin designs achieve superior heat transfer due to increased surface area and airflow turbulence, making them suitable for high-performance cooling. In contrast, straight-fin heat sinks are shown to be simpler, more economical, and effective in applications with directed airflow and lower pressure drop requirements. Overall, the paper contributes practical insights for selecting appropriate heat sink geometries in modern electronic thermal management.

P. Kaviyarasu [13] experimentally examined how surface roughness influences convective heat transfer in Aluminium 6063 pin-fin systems. Their results show that rough and lightly roughened fins consistently enhance heat transfer coefficients and heat dissipation rates compared to smooth fins, under both free and forced convection. The improvement is mainly attributed to increased turbulence and better air–surface interaction caused by surface irregularities. This study offers practical design insights for improving air-cooled thermal systems, particularly in automotive and engine applications.

Md. Abdul Raheem Junaidi [14] used CFD simulations to evaluate the thermal performance of standard, splayed, and hybrid pin-fin heat sinks for electronic cooling. Their findings show that splayed pin fins significantly improve airflow penetration and heat dissipation, especially under low airspeed and natural convection conditions. The study further demonstrates that hybrid pin-fin designs (aluminium fins with a copper base) achieve lower thermal resistance while reducing weight compared to fully copper heat sinks. Overall, the work highlights how geometric modification of pin fins can deliver 20–30% better cooling efficiency.

Yichi Zhang [15] carried out a detailed numerical comparison of finned-tube heat exchangers using aluminium tubes versus conventional copper tubes, focusing on both thermal performance and cost effectiveness. The study shows that although aluminium tubes exhibit slightly lower heat transfer efficiency than copper, the difference remains modest under varying airflow conditions. Importantly, the aluminium-based design delivers significantly higher heat transfer per unit mass at a fraction of the material cost, making it an attractive alternative. The findings provide strong justification for adopting aluminium finned-tube heat exchangers in cost-sensitive air-conditioning applications.

Ruby Haldar [16] experimentally investigated heat transfer behaviour in pin fins made of aluminium and brass under both natural and forced convection conditions. The study demonstrates that forced convection significantly enhances heat dissipation compared to natural convection, with material properties playing a key role in performance. Aluminium fins showed better overall heat transfer efficiency due to their higher thermal conductivity-to-weight advantage. The work provides useful experimental insight for selecting pin-fin materials and convection modes in practical thermal management systems.

A Dewan [17] conducted a detailed numerical investigation to understand how fin spacing and fin material influence the thermal and hydraulic performance of circular pin-fin heat sinks. Their results showed that closer fin spacing significantly enhances heat transfer, although it leads to higher pressure drop. The study also highlighted that high-conductivity materials such as aluminium outperform steel and nickel by delivering greater heat transfer without a noticeable increase in flow resistance. Overall, the work emphasizes achieving an optimal balance between heat transfer enhancement and pressure drop for efficient heat exchanger design.

K. Subahan [18] performed a CFD-based investigation to evaluate the thermal performance of pin-fin heat sinks used in electronic devices under both natural and forced convection. The study compared different fin geometries and arrangements, showing that pin-fin shape and alignment strongly influence heat dissipation and pressure drop. Their results indicate that rhombus prism pin fins provide better cooling performance than pyramid-shaped fins due to increased surface area and improved airflow interaction. This work offers practical design guidance for optimizing heat sink geometry in compact electronic cooling applications.

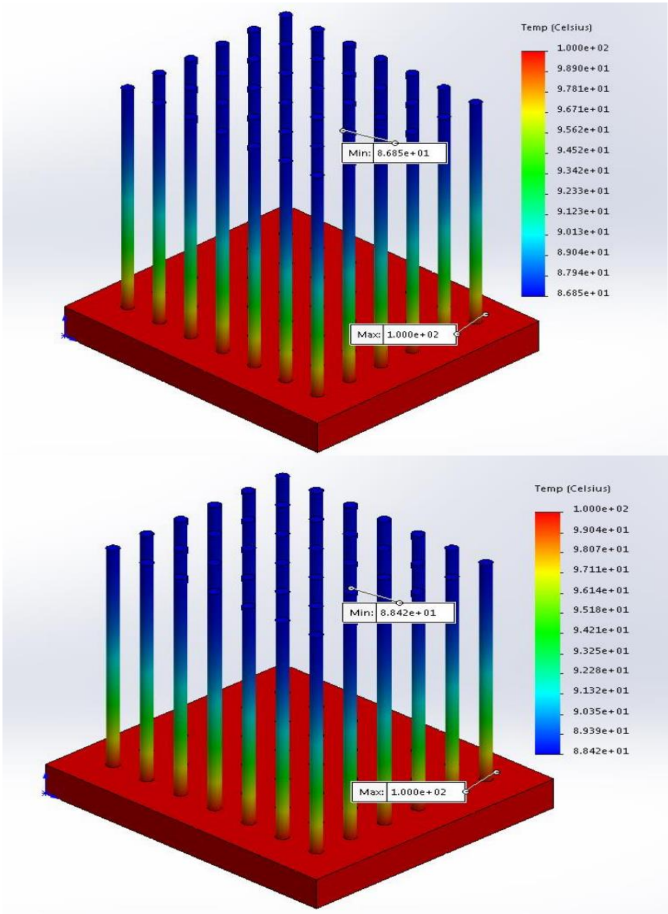

Fig- 5 Temperature distribution of Al 6063-T83 & Al 7075-O(SS) [17]

Darshan J V [19] had done CFD analysis and optimization of pin fin heat sink and came to results that Rhombus prism pin fins provide the best thermal performance among tested designs. Copper is more thermally efficient compared to aluminium, but aluminium may still be preferred due to weight/cost. Staggered pin arrangement significantly improves heat transfer over inline arrangements. Forced convection greatly enhances cooling capability and reduces temperatures.

Dr. Pankaj Kumar [20] has focused on using CFD tools to evaluate and improve the thermal performance of pin-fin heat sinks for electronic cooling applications. Studies comparing different fin materials under natural convection conditions indicate that material properties significantly influence temperature distribution and heat transfer efficiency.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 01 , January - 2026

Numerical investigations also show that circular pin-fin configurations provide better airflow interaction compared to plate fins. These findings highlight the importance of material optimization, along with geometric design, to achieve cost-effective and efficient heat sink performance.

I. Lakshmi Anusha [21] had done CFD analysis of splayed pin fin heat sink using advanced composite materials and found that Splayed pin fin design is effective in improving heat dissipation for electronics compared to straight fins. Composite materials offer comparable junction temperatures to copper/aluminium, reduced weight and potential for cost reduction and custom shaping. Thermal performance is not compared despite lighter materials.

B. Summary of literature review:

Previous studies extensively highlight that pin-fin heat transfer performance is strongly influenced by material selection, surface treatment, and geometric design. Researchers have shown that high-conductivity materials such as copper and aluminium generally provide superior heat dissipation, while aluminium alloys offer a favourable balance between thermal performance, weight, and cost.

Surface modifications like aluminium coatings and controlled roughness further enhance heat transfer by improving thermal conductivity and promoting airflow turbulence, without changing the fin geometry. Both experimental and numerical investigations consistently confirm that material optimization plays a critical role in improving fin efficiency and reducing thermal resistance.

Several numerical and CFD-based studies emphasize that pin-fin geometry and arrangement significantly affect airflow interaction and heat transfer rates. Modified geometries such as splayed, rhombus, grooved, helical, and staggered pin fins improve cooling performance by increasing effective surface area and enhancing airflow penetration.

Results indicate that forced convection conditions substantially outperform natural convection, while optimized fin spacing improves heat transfer at the cost of increased pressure drop. Advanced composite and hybrid designs demonstrate comparable thermal performance to traditional metals with the added advantage of reduced weight.

Overall, the reviewed literature demonstrates that an integrated approach combining material selection, geometric optimization, surface modification, and convection control is essential for designing efficient pin-fin heat sinks.

CFD tools have proven effective in predicting thermal behaviour and guiding design decisions prior to experimental validation. These findings provide valuable insights for developing compact, lightweight, and cost-effective thermal management systems for electronic cooling and heat exchanger applications.

III. MATERIALS USED FOR PIN FIN

A. Materials used for pin fin and its characteristics:

Table-4 Materials used for pin fin and its characteristics

Materials	Thermal conductivity (W/m. K)	Density(kg/m³)	Corrosion Resistance	Mechanical Strength	Cost	Key Advantages
Aluminium (Al)	200-235	~2700	Good	Moderate	Low	Lightweight, easy to manufacture, good heat transfer
Copper (Cu)	385-400	~8960	Moderate(oxidizes)	High	High	Excellent Thermal conductivity
Stainless steel	14-25	~8000	Excellent	High	Medium-high	Strong, corrosion resistant
Carbon steel	45-60	~7850	Poor (needs coating)	Very high	Low	Strong, inexpensive
Titanium (Ti)	20-25	~4500	Excellent	Very high	Very high	High strength-to-weight ratio, corrosion resistant
Brass	100-130	~8500	Good	Moderate	Medium	Machinable corrosion resistant
Graphite/Carbon composite	150-400	~1800-2200	Excellent	Low-Moderate	High	Lightweight, high directional conductivity
Polymer (Thermally conductive plastics)	1-10	~1200-1600	Excellent	Low	Low-Medium	Lightweight, electrically insulating

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 01 , January - 2026

B. Pin fin materials, possible geometrical variations, & its usefulness:

Table-5 Pin fin materials, possible variations, & its usefulness

Materials	**Possible Geometrical Variations**	**Applications**
Aluminium (Al)	Cylindrical, square, elliptical, tapered, slotted, staggered arrays, micro pin fins	Electronics cooling, LED heat sinks, automotive radiators; lightweight fins allow dense and complex geometries for enhanced convection
Copper (Cu)	Cylindrical, square, micro-pin fins, staggered arrays, perforated pins	High-power electronics, CPU/GPU heat sinks, power modules; micro and dense pins maximize heat removal due to high thermal conductivity
Stainless steel	Cylindrical, square, inline arrays	Heat exchangers in corrosive or high-temperature environments; simpler shapes reduce pressure drop and improve durability
Carbon Steel	Cylindrical, square, inline or staggered arrays	Industrial heat exchangers and boilers; robust geometries suited for high mechanical loads and cost-sensitive systems
Titanium	Cylindrical, tapered, elliptical, lattice/branched pins	Aerospace and marine heat exchangers; tapered and lattice forms reduce weight while maintaining strength and corrosion resistance
Brass	Cylindrical, square, elliptical	Specialized heat exchangers requiring moderate conductivity and good corrosion resistance
Graphite/ Carbon composites	Cylindrical, plate-type pins, porous structures	Aerospace and advanced electronics; porous and directional fins exploit high in-plane conductivity and low weight
Theramlly conductive polymers	Cylindrical, square, hollow pins	Low-power electronics and electrically insulated systems; simple shapes ensure manufacturability and low cost

IV. CONCLUSION

Based on the reviewed literature, it is evident that the thermal performance of heat sink is influenced by a combination of material properties, geometric design, and flow conditions rather than by any single parameter alone. Materials with high thermal conductivity, particularly aluminium and copper, consistently demonstrate superior heat dissipation capabilities. Among these, aluminium and its alloys emerge as the most practical choice for engineering applications, as they provide a well-balanced combination of good thermal performance, low weight, ease of fabrication, and economic feasibility. In addition to material selection, surface treatments such as aluminium coatings and controlled surface roughness have been shown to significantly enhance heat transfer by improving surface interaction with the surrounding fluid, without the need to alter the basic fin geometry.

The literature also highlights that pin-fin geometry and arrangement play a decisive role in thermal enhancement. Configurations such as splayed, rhombus, grooved, staggered, and helical pin fins improve airflow mixing and increase the effective heat transfer area, leading to improved thermal performance.

Forced convection conditions generally result in much higher heat transfer rates compared to natural convection; however, careful design is required to control the associated pressure drop and pumping power. Optimizing fin spacing further enhances heat dissipation, but this must be approached cautiously to avoid excessive flow resistance that can negate thermal gains.

Recent studies indicate that composite and hybrid materials can achieve thermal performance comparable to conventional metallic fins while offering added benefits such as reduced weight and greater design flexibility. Moreover, computational fluid dynamics and numerical simulations have proven to be reliable and efficient tools for predicting thermal behaviour, enabling designers to refine pin-fin configurations prior to experimental testing.

Overall, the findings emphasize that an integrated design strategy combining appropriate material selection, optimized geometry, surface modification, and airflow management is essential for achieving high-performance and energy-efficient pin-fin heat sink systems.

V. REFERENCES

[1] Heat Transfer-A Practical Approach by Y. A. Cengel – 2nd Edition.
[2] Theodore L. Bergman, Adrienne S. Lavine, Frank P. Incropera, David P. DeWitt - Fundamentals of Heat and Mass Transfer-Wiley (2017)
[3] Yogesh Sharama, “Analysis of heat transfer through Conduction, Convection, and radiation” International Journal of all research education and scientific methods (2016).
[4] Vaishnav Madhavdas, Dibyarup Das, Kaustubh Anand Mohta, S. Senthur Prabu “Comparative analysis on heat transfer of various fin profile using solid works: A systematic review” IOP Publishing (2021).
[5] Gaurav Kumar R. Tandel, Mr. Manish Patel, Dr. Harshit Bhavsar, Mr. Rakesh Prajapati “Experimental Investigation of Transient Thermal

Behaviour in Microchannel Pin Fin Heat Sink Under Heat Flux Conditions-A Review Study" International Journal of Scientific Development and Research (2025).

[6] Prabhakar Bhandari, Kamal S. Rawat, Yogesh K. Prajapati, Diwakar Padalia, Lalit Ranakoti, Tej Singh, "Design modifications in micro pin fin configuration of microchannel heat sink for single phase liquid flow: A review" Journal of Energy Storage (2023)

[7] Sreedhar Vullo Ju, P.S. Kishore, Mukul Shrivastava, "Enhancement of heat transfer characteristics of plain fin coated with brass and aluminium" International journal of recent technology and engineering-2019.

[8] Venkateswara Reddy Kolagotla, Sai babu Kolahalam, Emmanuel Buradagunta, Naresh Babu Nelakuditi, Pichi Reddy Seelam, Dhana Raju Valla Pudi, Mallikarjuna Rao Dandu, "Comparative thermal analysis by using simulation of circular fin manufactured with several materials" Nano World Journal-2023.

[9] Arun Eldhose, Dr. Benny Paul, Jelvin Tom Sebastian, "Numerical analysis of pin fin by varying shape and materials" International Research journal of engineering and technology-2018.

[10] I T Nazzal, T K Salem, R R J Al Doury, "Theoretical investigation of a pin fin heat sink performance for electronic cooling using different alloys materials" IOP publishing-2020.

[11] Karana Sangaj, Sudarshan Shinde, Aditya Suryawanshi, Rameez Shanediwan, Apurva Potda," Thermal and parametric analysis of pin fin: Vol 1" International research journal of engineering and technology-2018.

[12] Prem Chandra, Kanishk Sharma," Comparison of a pin fin and straight fin heat sink" International research journal on advanced science hub-2025.

[13] P. Kaviyarasu, C. Saravanan. "Experimental investigation of convective heat transfer through rough and smooth surfaced aluminium 6063 pin fin apparatus" International research journal of advanced engineering and science-2017.

[14] Md. Abdul Raheem Junaidi, Raghavendra Rao, S. Irfan Sadaq, Mohd Moinuddin Ansari," Thermal analysis of splayed pin fin heat sink" International journal of modern communication technologies & research-2014.

[15] Fang Wang, Yuding Li, Mengwei Liu, Dongqing Pang, Weifeng Du, Yichi Zhang, Xiaoqain Cheng, Tangtang Gu, Wenliang Guo, "Comprehensive evaluation of the performance of heat exchangers with aluminium and copper finned tubes" Hindawi International journal of chemical engineering-2023.

[16] Ruby Haldar, Abhimanyu Kumar, Trishit Janah, Prabir Biswas, "Experimental investigation of heat transfer by forced and natural convection in a pin fin for different materials" International journal for research in applied science & engineering technology-2022.

[17] A Dewan, P Patro, I Khan, P Mahanta, "The effect of fin spacing and materials on the performance of a heat sink with circular pin fins" Sage Journals- 2009.

[18] K. Subahan, E. Siva Reddy, R. Meenakshi Reddy, "CFD Analysis of pin fin heat sink used in electronic devices" International journal of scientific & technology research-2019.

[19] Darshan J V, Pavan D," CFD analysis and optimization of pin fin heat sink" International journal of scientific & engineering research-2020.

[20] Dr. Pankaj Kumar, Naresh Prasad Choudhry, "Experimental investigation of heat transfer by using in fin of different materials in forced convection" International Journal of advanced research and development-2017.

[21] I. Lakshmi Anusha, S. Murali, P. Srinivas Rao, P. Padmavathi," CFD analysis of splayed pin fin heat sink using advanced composite materials" International journal of current engineering and technology-2014.

[22] Ellison G N Thermal Computations for Electronics: Conductive, Radiative, and Convective Air Cooling-2011.

[23] Haghighi, S. S., Goshayeshi, H. R., & Safaei, M. R Natural convection heat transfer enhancement in new designs of plate-fin based heat sinks. International Journal of Heat and Mass Transfer, 125, 640-647.

[24] Goldstein, R. J., & Sparrow, E. M. (1977). Heat transfer characteristics of pin fin arrays. Journal of Heat Transfer, 99(2), 187–194.

[25] Metzger, D. E., Fan, C. S., & Yu, Y. (1984). Effects of pin shape and array orientation on heat transfer and pressure loss. Journal of Engineering for Gas Turbines and Power, 106(2), 252–257.

[26] Armstrong, J., & Winstanley, D. (1988). A review of staggered and inline pin fin heat transfer. Heat Transfer Engineering, 9(1), 14–28.

[27] Yang, Y. T., & Peng, H. S. (2008). Numerical study of pin-fin heat sink with unsteady flow. International Journal of Heat and Mass Transfer, 51, 4788–4801.

[28] Chyu, M. K., & Siw, S. C. (2002). Heat transfer enhancement of pin fin arrays with surface roughness. Journal of Turbomachinery, 124(4), 636–642.

[29] Bar-Cohen, A., & Kraus, A. D. (1995). Advances in Thermal Modelling of Electronic Components and Systems. ASME Press.

[30] Roy, S., & Saha, S. (2012). Experimental investigation of heat transfer in aluminium pin fins. Applied Thermal Engineering, 37, 256–264.

[31] Das, S., & Sahoo, P. (2014). Heat transfer performance of rectangular pin fin heat sinks. International Journal of Thermal Sciences, 80, 111–120.

[32] Singh, R., & Ekkad, S. (2016). Effect of pin-fin geometry on heat transfer enhancement. Experimental Thermal and Fluid Science, 72, 34–44.

[33] Prabhu, S. V., & Vedula, R. P. (2009). Heat transfer and pressure drop studies on pin-fin arrays. Heat and Mass Transfer, 45, 873–881.

[34] Rao, A. K., & Krishna, M. V. (2015). Thermal performance of perforated pin fins. International Journal of Mechanical Engineering and Technology, 6(9), 45–53.

[35] Sharma, A., & Shukla, K. N. (2017). Review on heat transfer enhancement using pin fins. Renewable and Sustainable Energy Reviews, 73, 120–135.