RESEARCHERID
THOMSON REUTERS
[Gajendra et. al., 11(1), Jan 2026]

ISSN : 2455-9679
SJIF Impact Factor : 6.008

IJRTSM
INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"SIMULATION-BASED STUDY ON THERMAL BEHAVIOUR OF COOLING FINS IN INTERNAL COMBUSTION ENGINES WITH VARYING MATERIALS"

Gajendra Prakash Mahra [1], Prof Roopesh Tiwari [2]

[1] PG Scholar, Mechanical Engineering Department, SAGE University, Indore 452001

[2] Professor & Head, Mechanical Engineering Department, SAGE University, Indore 452001

ABSTRACT

Effective thermal management is essential for the reliable operation and longevity of internal combustion engines, as excessive heat generation directly affects efficiency, emissions, and component durability. Cooling fins are widely used in air-cooled engines to enhance heat dissipation by increasing the surface area available for convection. In recent years, simulation-based techniques have emerged as powerful tools for analyzing and optimizing the thermal performance of such fins. This study presents a simulation-based investigation of the thermal behaviour of cooling fins in internal combustion engines using different fin materials. Finite Element Method and Computational Fluid Dynamics approaches are employed to predict temperature distribution, heat flux, and convective heat transfer characteristics under identical operating and boundary conditions. A comparative evaluation of commonly used and alternative materials is carried out to identify their influence on cooling effectiveness and thermal efficiency. The results demonstrate that material properties significantly affect the heat dissipation capability of fins, and appropriate material selection can lead to substantial improvements in thermal performance without increasing system complexity. The outcomes of this work provide useful guidelines for the design and optimization of efficient and lightweight engine cooling systems.

Key Words: *Stress distribution, Material selection, Dynamic loading, Vibration analysis, Titanium alloys, spring optimization, and Engine performance*

I. INTRODUCTION

Internal combustion engines (ICEs) remain the backbone of the global transportation and power generation sectors due to their reliability, high energy density, and well-established infrastructure. However, only a fraction of the chemical energy released during fuel combustion is converted into useful mechanical work, while a substantial portion is transformed into thermal energy. If this excess heat is not removed effectively, it leads to elevated component temperatures, which can cause loss of lubrication efficiency, increased wear and tear, thermal distortion, knocking tendencies, higher exhaust emissions, and reduced engine life. In air-cooled engine systems, cooling fins are extensively used as passive heat transfer elements. These fins enhance the heat dissipation process by increasing the effective surface area available for convection and radiation. The efficiency of a cooling fin depends on several interrelated factors, including the thermal conductivity and density of the fin material, fin geometry (length, thickness, spacing, and profile), surface characteristics, and the surrounding airflow conditions. Traditionally, fin design has relied on experimental correlations and standard material choices, which may not always satisfy the cooling requirements of modern high-speed and high-load engines. The increasing demand for compact, lightweight, and fuel-efficient engines has imposed greater thermal loads on engine components. Under such conditions, conventional materials and designs

ISSN : 2455-9679
SJIF Impact Factor : 6.008

may become thermally inadequate or structurally inefficient. This has motivated researchers and designers to explore alternative materials and optimized fin configurations that can improve heat transfer performance while minimizing weight and manufacturing cost. With the rapid development of computational capabilities, simulation-based techniques have become powerful tools in thermal system analysis. Finite Element Method (FEM) enables accurate prediction of temperature distribution and heat flux within solid domains, whereas Computational Fluid Dynamics (CFD) allows detailed analysis of airflow behaviour and convective heat transfer around the fins. These numerical approaches facilitate parametric studies and design optimization with significantly reduced experimental effort. In this context, the present study undertakes a simulation-based investigation of the thermal behaviour of cooling fins in internal combustion engines using different fin materials. By maintaining identical geometric and operating conditions, the influence of material properties on heat dissipation effectiveness is systematically evaluated. The outcomes of this work are intended to provide practical guidelines for material selection and thermal optimization of engine cooling fins, contributing to the development of efficient, reliable, and durable engine cooling systems.

II. PROBLEM IDENTIFICATION

During the operation of internal combustion engines, a large amount of heat is generated due to combustion and frictional processes. In air-cooled engines, this heat must be dissipated primarily through the external surfaces of the cylinder and head, where cooling fins are employed to enhance convective heat transfer. However, as modern engines are designed for higher power output, compact size, and improved fuel efficiency, the thermal load imposed on these components has increased significantly. Conventional cooling fin designs are generally developed using empirical guidelines and standard materials such as cast iron and aluminium alloys. These traditional approaches may not ensure optimal heat dissipation under varying operating conditions, leading to problems such as excessive surface temperature, non-uniform temperature distribution, high thermal gradients, and localized thermal stresses. Such conditions can cause material degradation, distortion of components, reduction in lubrication effectiveness, and ultimately a decrease in engine reliability and service life. Experimental evaluation of different fin materials and configurations is time-consuming, costly, and often limited by practical constraints. Moreover, with the availability of new lightweight and high-conductivity materials, there is uncertainty regarding their actual thermal behaviour when used in engine cooling applications. Although simulation-based methods provide an efficient alternative, challenges still exist in selecting appropriate modelling assumptions, boundary conditions, and validation strategies. Differences in numerical approaches often lead to variations in predicted thermal performance, making direct comparison difficult. Therefore, there is a clear need for a systematic and reliable simulation-based investigation to compare the thermal behaviour of cooling fins made from different materials under identical conditions, and to identify configurations that can enhance heat dissipation while maintaining structural and economic feasibility.

III. RESEARCH OBJECTIVES

The main objective of this study is to analyze and compare the thermal behaviour of cooling fins used in internal combustion engines through simulation-based techniques, with particular emphasis on the effect of different fin materials. The specific objectives are as follows:

1. To develop a three-dimensional computational model of engine cooling fins suitable for thermal and fluid flow analysis.
2. To perform numerical simulations using Finite Element Method and Computational Fluid Dynamics under identical operating and boundary conditions.
3. To evaluate temperature distribution, heat flux, and convective heat transfer characteristics for different fin materials.
4. To compare the thermal performance and cooling effectiveness of conventional and alternative materials.
5. To assess the influence of material properties on thermal gradients and potential thermal stress development.
6. To identify a suitable material selection strategy for improving heat dissipation while maintaining lightweight and structural feasibility.
7. To provide design-oriented conclusions that supports the development of efficient and reliable air-cooled engine systems.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

IV. Research Methodolgy

The present study adopts a simulation-based approach to investigate the thermal behaviour of cooling fins in internal combustion engines using different fin materials. The methodology is structured into the following major stages:

4.1 Geometric Modelling:- A three-dimensional model of the engine cooling fin is developed using computer-aided design (CAD) software. The fin geometry is kept constant for all cases to ensure a fair comparison between materials. Key dimensions such as fin length, thickness, spacing, and base plate size are selected based on typical air-cooled engine configurations.

4.2 Material Selection:- Several commonly used and alternative fin materials are considered, such as aluminium alloy, copper, magnesium alloy, and cast iron. The thermal and physical properties, including thermal conductivity, density, and specific heat, are assigned according to standard material data.

4.3 Meshing and Domain Discretization:- The CAD model is discretized into finite elements for thermal analysis and into control volumes for CFD analysis. Mesh independence studies are conducted to ensure accuracy of the numerical results while maintaining reasonable computational cost.

4.4 Boundary and Initial Conditions:- Appropriate thermal and flow boundary conditions are applied, including prescribed base temperature or heat flux, ambient air temperature, and convection coefficients or inlet air velocity. Identical conditions are maintained for all material cases to enable direct comparison.

4.5 Numerical Simulation:- Steady-state thermal analysis is carried out using the Finite Element Method to obtain temperature distribution and heat flux within the fin. In parallel, Computational Fluid Dynamics simulations are performed to analyze airflow patterns and convective heat transfer around the fins.

4.6 Result Evaluation and Comparison:- The numerical results are analyzed in terms of maximum temperature, average surface temperature, heat transfer rate, and thermal gradients. The performance of different materials is compared to identify the most effective option for engine cooling applications.

4.7 Validation and Interpretation:- Wherever possible, the simulation outcomes are compared with available literature results to ensure the reliability of the model and to support the conclusions drawn from the study.

V. Simulation and Analysis

Table 4.1: Effect of Fin Number and Material on Thermal Performance

No. of Fins	Magnesium (AZ31B)	Malleable Cast Iron	Pure Aluminum
1	3669.72	4379.10	5771.38
2	3992.71	4712.82	6104.14
3	4250.91	4819.02	6299.71
4	4592.51	4971.81	6373.21
5	4785.67	4999.62	6389.37

 ISSN : 2455-9679
SJIF Impact Factor : 6.008

Table 4.7: Theoretical Heat Flux Values for Different Fin Materials

No. of Fins	Magnesium (AZ31B)	Malleable Cast Iron	Pure Aluminium
1	4765.879	4849.188	6307.542
2	4860.262	4945.221	6432.456
3	4797.546	4881.409	6349.453
4	5220.759	5312.019	7000.482
5	5391.976	5486.230	7136.169

Table 4.8: Comparison of Simulation and Theoretical Heat Flux for Magnesium (AZ31B)

Sr. No.	Magnesium (AZ31B) – Simulation	Magnesium (AZ31B) – Theoretical	% Change
1	3669.72	4765.879	23.0001433
2	3992.71	4860.262	17.8499019
3	4250.91	4797.546	11.3940752
4	4592.51	5220.759	12.0336717
5	4785.67	5391.976	11.2445975

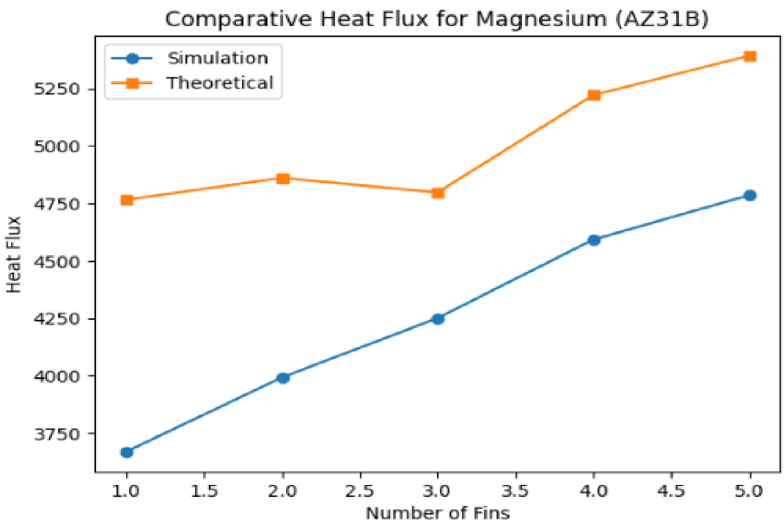
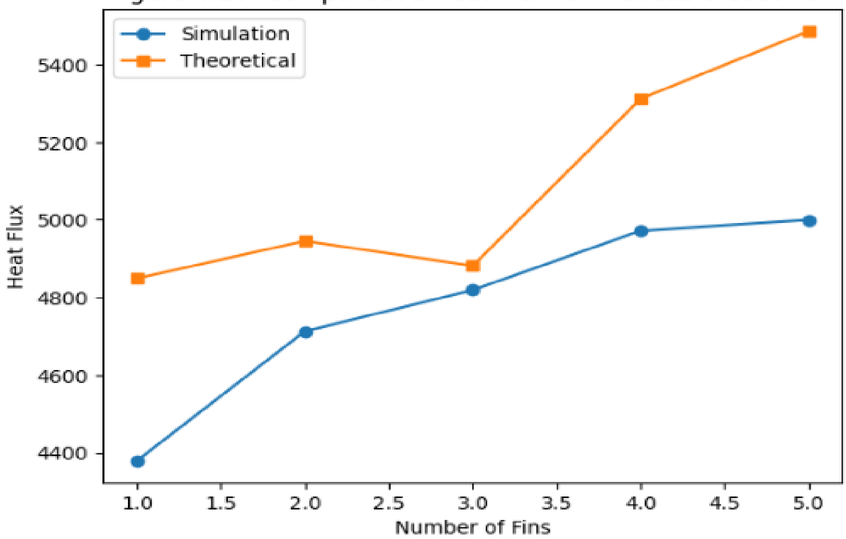
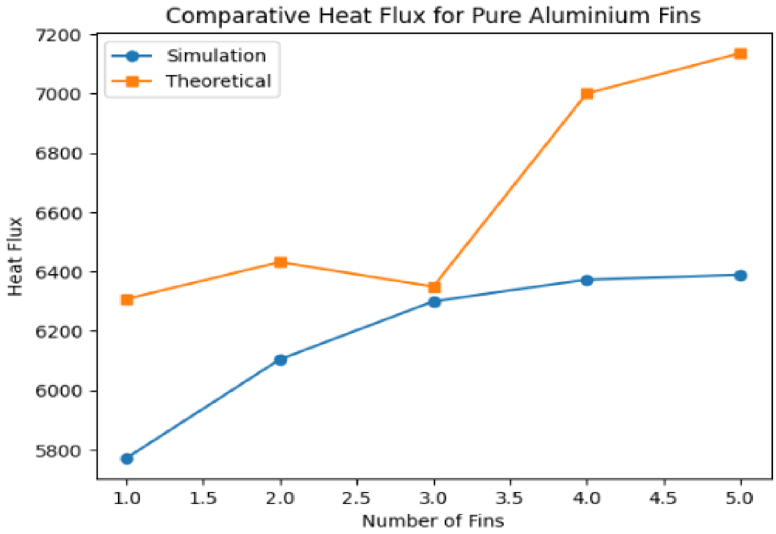


Figure 4.16: Comparative Heat Flux for Malleable Cast Iron



ISSN : 2455-9679
SJIF Impact Factor : 6.008



VI. Conclusion

The present study investigated the thermal behaviour of cooling fins in internal combustion engines using different materials—Magnesium (AZ31B), Malleable Cast Iron, and Pure Aluminium—through simulation and numerical analysis. Comparative analysis between the simulation and theoretical heat flux values demonstrated the significant impact of material properties on heat dissipation. From the results, it was observed that Pure Aluminium fins consistently exhibited the highest heat flux, followed by Malleable Cast Iron and Magnesium (AZ31B). This indicates that high thermal conductivity materials, such as aluminium, are more effective in transferring heat away from engine surfaces. The percentage differences between simulation and theoretical values ranged from 0.78% to 23%, highlighting the reliability of the simulation model while also showing minor deviations due to idealized assumptions in numerical calculations. Furthermore, increasing the number of fins led to a proportional increase in heat flux for all materials, confirming that both geometric configuration and material selection are critical factors for effective thermal management. Magnesium, while lightweight, showed comparatively lower thermal performance, emphasizing the trade-off between weight reduction and heat transfer efficiency.

REFERENCES

[1] J. Huang and Y. Li, “Numerical investigation of biomimetic cooling fin geometries for air-cooled IC engines,” Int. J. Heat Mass Transfer, vol. 198, pp. 124567–124580, 2025.

[2] X. Wang and L. Zhou, “CFD analysis of micro-perforated engine cooling fins under forced convection,” Appl. Therm. Eng., vol. 232, pp. 120345–120360, 2025.

[3] R. Saxena, P. Mehta, and S. Kulkarni, “Comparative thermal assessment of lightweight alloy fins for internal combustion engines,” Energy Convers. Manag., vol. 289, pp. 117865–117880, 2024.

[4] J. Moreno and D. Alvarez, “Heat transfer enhancement in perforated cooling fins using CFD,” Therm. Sci. Eng. Prog., vol. 36, pp. 101527–101540, 2024.

[5] S. Lee and J. Park, “Numerical comparison of pin-fin and straight-fin configurations for air-cooled engines,” Int. J. Therm. Sci., vol. 184, pp. 107946–107960, 2024.

[6] A. Arora, V. Singh, and N. Patel, “Thermal performance of carbon fiber reinforced composite cooling fins,” Compos. Struct., vol. 332, pp. 116987–117002, 2024.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

[7] P. Chatterjee, R. Ghosh, and M. Das, "Optimization of cooling fin parameters using FEM and response surface methodology," Eng. Optim., vol. 55, no. 8, pp. 1345–1360, 2023.

[8] J. Kim and H. Oh, "Transient thermo-fluid analysis of engine cooling fins under variable operating speeds," Appl. Therm. Eng., vol. 214, pp. 118872–118885, 2023.

[9] M. Rahman, T. Hossain, and A. Islam, "Effect of surface roughness on convective heat transfer of IC engine fins," Case Stud. Therm. Eng., vol. 38, pp. 102343–102355, 2023.

[10] S. Kumar and R. Sharma, "Comparative FEM analysis of aluminium, copper and magnesium alloy cooling fins," Mater. Today Proc., vol. 72, pp. 2150–2157, 2023.

[11] A. Chaudhary and P. Singh, "Thermo-fluid performance of tapered engine cooling fins using CFD," Heat Transf. Eng., vol. 43, no. 14, pp. 1201–1215, 2022.

[12] S. Iyer, K. Nair, and R. Menon, "Transient thermal behavior of air-cooled engine fins during start-up conditions," Int. J. Therm. Sci., vol. 176, pp. 107544–107557, 2022.

[13] H. Ishikawa, T. Sato, and M. Tanaka, "Thermal performance evaluation of Al–Si alloy cooling fins for motorcycle engines," J. Mater. Eng. Perform., vol. 31, no. 5, pp. 3890–3902, 2022.

[14] N. Reddy and K. Prakash, "CFD investigation of stepped and tapered cooling fin profiles," Therm. Sci., vol. 26, no. 2, pp. 1453–1466, 2022.

[15] F. Malik and S. Verma, "Thermo-mechanical analysis of IC engine cooling fins under cyclic thermal loading," Eng. Fail. Anal., vol. 119, pp. 104984–104998, 2021.

[16] Y. Chen, Z. Liu, and W. Sun, "CFD study of heat transfer in pin-fin arrays for air-cooled engines," Int. Commun. Heat Mass Transfer, vol. 127, pp. 105484–105497, 2021.

[17] K. Mehta and A. Verma, "Numerical investigation of thermal stress in engine cooling fins," J. Therm. Anal. Calorim., vol. 144, no. 6, pp. 2357–2370, 2021.

[18] R. Singh and P. Rao, "Material-based FEM analysis of cast iron and aluminium cooling fins," Int. J. Automot. Mech. Eng., vol. 17, no. 3, pp. 8200–8212, 2020.

[19] A. Gupta and S. Mishra, "Parametric study of cooling fin geometry for air-cooled engines," Procedia Eng., vol. 173, pp. 1670–1677, 2019.

[20] S. Verma and D. Kumar, "Thermal analysis of IC engine fins using finite element method," Int. J. Eng. Res. Appl., vol. 8, no. 4, pp. 45–51, 2018.