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Enhanced Thermal Performance Analysis Of Engine Cooling Fins With Varying Geometries And Materials

[1]Devidi vinay Reddy, [2]N Sujan rao
[1]M. Tech Student, Department of Mechanical Engineering, Nalla Malla Reddy Engineering College, Hyderabad, India,500088, Vickydevidi11@gmail.com
[2]Associate Professor, Department of Mechanical Engineering, Nalla Malla Reddy Engineering College, Hyderabad, India,500088, sijan504@gmail.com

Abstract

The engine cylinder is one of the most heat-intensive components in internal combustion engines, often operating under extreme thermal conditions. To regulate the temperature and maintain performance, air-cooling methods are commonly adopted, where fins are integrated onto the cylinder's exterior to improve heat transfer by increasing surface area. This research investigates how modifications in fin geometry and material composition influence thermal performance. The study explores circular, wavy, and longitudinal rectangular fin configurations, using materials such as cast iron, aluminum 6061, and aluminum 2014. Using ANSYS Space Claim, 3D models were designed, and thermal simulations were carried out in ANSYS to evaluate temperature profiles and heat flux. The findings reveal that wavy fins with AL2014 material provide superior cooling capabilities compared to other shapes and materials due to better heat dissipation efficiency.

I. INTRODUCTION

In internal combustion (IC) engines, the burning of an air-fuel mixture occurs within the engine cylinder, generating hot gases. These gases reach extreme temperatures, typically ranging from 2300°C to 2500°C. If not properly managed, such high heat can degrade the lubricating oil between moving components, leading to problems like piston seizure or failure of piston rings and Compression rings. Additionally, excessive heat can cause damage to the cylinder's structural integrity. Therefore, this temperature must be lowered to approximately 150–200°C to ensure efficient engine operation. Overcooling is also detrimental as it reduces the engine's thermal efficiency. Hence, the role of a cooling system is to maintain the engine at its optimal operating temperature. An engine operates inefficiently when cold; thus, modern cooling systems are designed to delay cooling during the warm-up phase until the engine reaches its ideal operating range.In an IC engine, the energy from high-temperature, high-pressure gases is converted into mechanical work by acting directly on engine components such as pistons, turbine blades, or nozzles. However, only a fraction (about 25%) of the heat generated during combustion is converted into useful mechanical energy. Approximately 30% is lost through the cylinder walls, 35% through exhaust gases, and 10% due to friction. The heat absorbed by the cylinder walls is significant, and without proper removal, it could lead to pre-ignition and other performance issues. Inadequate heat removal can also cause lubricant degradation, leading to piston scuffing or engine damage. Therefore, engines incorporate cooling mechanisms to dissipate this heat. One of the most effective ways to enhance heat dissipation is by using extended surfaces, commonly known as fins. While plain fins can increase surface area, specially shaped fins can also improve the heat transfer coefficient, further enhancing cooling. For liquids, shorter fins are preferred due to their higher heat transfer coefficient; taller fins would reduce efficiency. Examples include both externally and internally finned tubes. Motorbike engines are designed for specific ambient temperatures and should not be overcooled, as this can reduce overall efficiency. Thus, the cooling system must strike a balance—neither too much nor too little cooling.

AIR-COOLING SYSTEM

In air-cooled engines, heat is dissipated directly to the surrounding atmosphere. This

Figure 1.1 Air-Cooling System

LIQUID-COOLING SYSTEM

This system circulates a coolant (typically a water-glycol mixture) through jackets built into the engine cylinder, head, and valves. The coolant absorbs heat from the combustion process and is then passed through a radiator, where it is cooled by air before being recirculated.

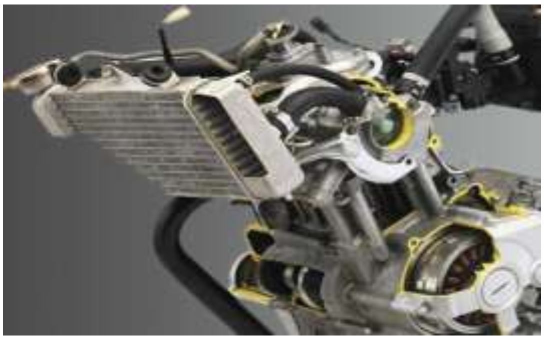

Figure 1.2 Liquid-Cooling System

II. LITERATURE SURVEY

Numerous researchers have examined the thermal performance of IC engine cylinder fins by varying design parameters such as geometry, material, and thickness. Below is a summary of relevant studies that form the basis for this project:

- **A.N. Mohan Das, G. Harish, G. Suraj et al.** investigated how varying the thickness of cylinder fins affects cooling performance. Their analysis revealed that a 3 mm fin thickness delivers improved heat dissipation compared to fins with 2.5 mm and 2 mm thicknesses [1].
- **Mukesh Kumar Singh and H.S. Sahu** explored optimal fin shapes and materials for effective engine cooling. They concluded that pin fins with angled edges enhance heat transfer due to increased airflow disruption [2].
- **M.S.V. Kartheek et al.** focused on modifying fin geometry, spacing, thickness, and materials. Their findings suggested that curvilinear fins improved thermal performance over straight fins, although the complexity of manufacturing curved fins increased production costs [3].
- **Rahul Gupta, Ranjeesh Kumar, and Prateek Kumar Verma** compared aluminum and magnesium alloys for use in engine fins. They reported that magnesium, being less dense, reduced the weight while providing heat transfer efficiency comparable to aluminum [4].
- **R. Suresh, K. Lalith Narayana, and Ch. Lakshmi Poornima** replaced traditional cast iron with Aluminum Alloy 6082 and performed thermal simulations. Their study showed that aluminum alloy yielded better heat dissipation and higher heat flux than cast iron due to superior thermal conductivity [5].
- **G. Babu and M. Lava Kumar** performed a comparative study using aluminum alloys 6061, 204, and magnesium. Their work concluded that wavy fin geometries offer improved heat transfer rates, though they recommended further research for optimization [6].
- **Biermann Arnold E. and Pinkel Benjamin** derived optimal fin dimensions for maximizing heat dissipation using a fixed amount of material. They emphasized that heat transfer efficiency is largely influenced by airflow velocity and spacing between the fins [7].
- **Perlewitz R.E., Lon Mooney, and Wm. Kalweit** analyzed different fin geometries and concluded that the trapezoidal profile approaches ideal efficiency. It offers ease of casting and favorable strength characteristics compared to rectangular and triangular designs [8].
- **Tripathi Pradeep Mani et al.** conducted finite element analysis (FEA) on a cylinder head assembly of a four-stroke engine, including contact conditions and thermal loading. Their model helped evaluate thermal and structural interactions in detail [9].
- **Deshpande A.C. et al.** evaluated the influence of fin pitch, cross-section, thickness, and material on thermal behavior. They focused on engines with single-cylinder configurations and rectangular fins [10].
- **Sorathiya A.S. et al.** presented data on improving the heat transfer coefficient by varying the fin configuration in spark-ignition (SI) engines [11].

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- **Kumar Rajat et al.** studied thermal performance enhancement through changes in fin geometry, materials, and structural layout. They observed that modifications such as fin base thickness and spacing significantly affect thermal results [12].
- **Shareef, S.K. Mohammad et al.** conducted numerical simulations in ANSYS to study the effects of fin geometry and material properties on heat transfer characteristics of engine cylinders [13].
- **Abbood M.H. et al.** performed experiments on fins of varying shapes—square, circular, elliptical, and airfoil—while maintaining uniform thickness and surface area. Using aluminum alloy as the material, they found airfoil-shaped fins demonstrated superior thermal behavior under natural convection with air as the fluid medium [14].
- **Menon Zakirhusen K. et al.** conducted a parametric study on air-cooled motorcycle engine fins using simulation tools. Their research focused on optimizing both the profile and arrangement of fins to achieve better heat dissipation [15].

III. RESULTS AND DISCUSSION

3.1 CIRCULAR FINS

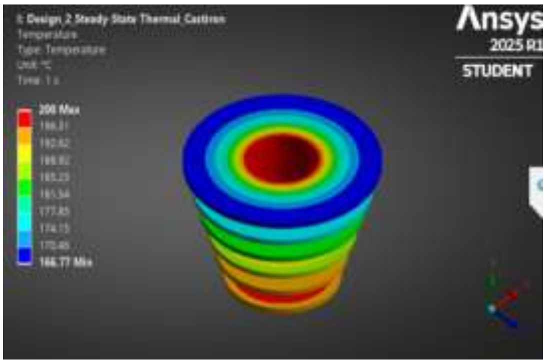

Fig 3.1 : Circular shape Cast iron alloy temperature distribution result

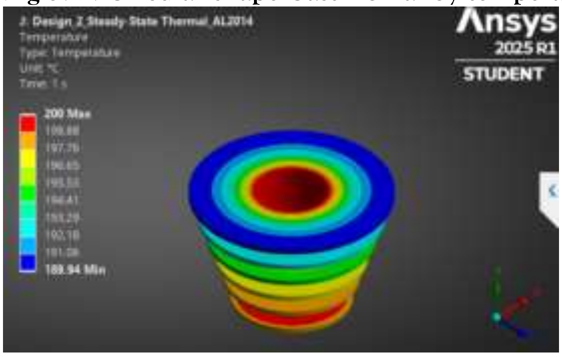

Fig 3.2: Circular Shape Al2014 Temperature Distribution Result

The steady-state thermal simulations were conducted using ANSYS Workbench 2025 R1. Three fin geometries were evaluated—circular, longitudinal rectangular, and wavy—using different materials: Cast Iron, Al6061, and Al2014. The focus was to determine which configuration delivers the highest heat dissipation based on temperature distribution and heat flux

Fig 3.3: Cylindrical Fin results

Fig 3.4 : Longitudinal Fin results

Fig 3.5 : Wavy Fin results

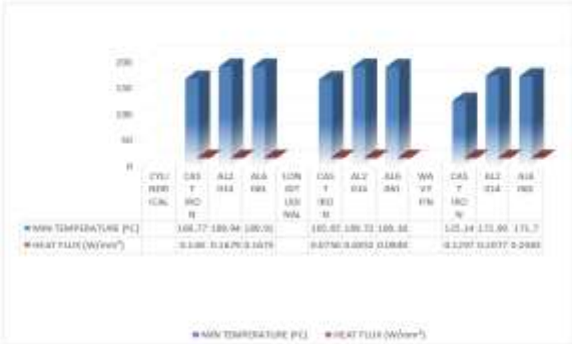

Fig 3.6 : Fins results

IV. CONCLUSION

This project involved the modeling and thermal analysis of internal combustion engine cylinder fins using ANSYS Workbench 2025 R1. The primary goal was to assess the cooling effectiveness of various fin geometries—cylindrical, longitudinal rectangular, and wavy-shaped—fabricated from different materials: Cast Iron, Aluminum 6061, and Aluminum 2014. 3D models were developed using ANSYS SpaceClaim, and simulations were conducted under steady-state thermal conditions. The study evaluated performance based on temperature distribution and total heat flux.

KEY FINDINGS

- Wave-shaped fins demonstrated the most effective cooling characteristics across all materials.
- Aluminum 2014 alloy produced the highest heat flux among all tested materials, indicating superior thermal conductivity and dissipation efficiency.
- The wave-shaped fin combined with Al2014 achieved a maximum heat flux of 0.20768 W/mm², surpassing all other combinations.
- Cast iron, though structurally strong, lagged in thermal performance compared to both aluminum alloys.
- Longitudinal rectangular fins showed modest heat transfer performance but were outperformed by wave fins in all scenarios.

The results clearly indicate that wave-shaped fins outperform circular and longitudinal rectangular designs in terms of thermal efficiency. Among materials, Al2014 alloy demonstrates the best overall performance, especially when used with the wave fin profile. Higher heat flux corresponds to better cooling, and this was achieved with the combination of wave fins + Al2014

Fin Shape	Material	Min. Temperature (°C)	Heat Flux (W/mm²)
Cylindrical	Cast Iron	166.77	0.14795
	Al2014	189.94	0.16790
	Al6061	189.41	0.16750
Longitudinal	Cast Iron	165.65	0.07562
	Al2014	189.72	0.08517
	Al6061	189.18	0.08490
Wavy	Cast Iron	125.14	0.12965
	Al2014	172.99	0.20768
	Al6061	171.70	0.20634

Fig 4.1 Performance Summary Table

Among the various configurations studied, the wave-shaped fins made of Aluminum 2014 offer the best thermal performance. This combination effectively balances heat transfer, material weight, and structural simplicity

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