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HEAT TRANSFER ANALYSIS OF ENGINE FINS BY VARYING MATERIALS

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1. Introduction

Internal Combustion (IC) engines, as exemplary heat engines, encompass a combustion chamber where oxidizer-induced combustion occurs, inducing high-pressure, high-temperature gas expansion. This process drives forces onto crucial engine components, such as turbines, rotors, nozzles, and pistons, thus converting chemical energy into mechanical work. Originating in the 19th century, these engines, pioneered by Etienne Lenoir and further developed by Nicolas Otto, have evolved into varied configurations like 2-stroke, 4-stroke, 6-stroke piston engines, and the Wankel rotary engine.

The distinction between intermittent combustion in piston engines and continuous combustion in jet, rocket, and gas turbines delineates their applications and operational efficiencies. Primarily powered by gasoline or diesel, IC engines, notably the 2-stroke and 4-stroke variants, find extensive use in vehicles, with 2-stroke engines exhibiting advantages in ship propulsion owing to their efficiency, torque-to-weight ratio, and cost-effectiveness.

Understanding the complex interplay between fuel combustion, energy conversion, and cooling mechanisms becomes paramount to ensure the IC engine's optimal functionality. The combustion's high temperatures, averaging between 2300-2500°C, necessitate an efficient cooling system to avert engine seizures while preserving its thermal efficiency.

This research paper meticulously delves into the multifaceted realm of IC engine cooling, exploring two primary methods: liquid cooling, utilizing water or coolant to regulate temperatures within a closed-circuit system, and air cooling, relying on natural convection to dissipate heat. The intricacies of radiator mechanisms, coolant composition, thermosyphon cooling systems, and extended surface areas (fins) augmenting heat transfer efficiency are thoroughly examined. The selection of materials for fins, such as Al6061 and Al6063 alloys, is also elucidated, considering their thermal conductivity, corrosion resistance, and mechanical properties.

Through a comprehensive exploration of these cooling systems and materials, this paper aims to elucidate their significance in maintaining the delicate thermal balance within IC engines, ultimately enhancing their longevity, efficiency, and overall performance.

This review provides a detailed insight into the nuances of IC engine cooling, laying a solid foundation for further research and advancements in optimizing these critical systems for future automotive and industrial applications.

The research landscape on Internal Combustion (IC) engine fins has witnessed a myriad of studies exploring diverse aspects to enhance heat transfer efficiency and optimize engine performance. Dubey et al. [11] embarked on a study experimenting with Bajaj Caliber motorcycle fins, employing Solidworks for 3D fin modeling and Ansys Software for analysis. Their investigation highlighted the relationship between fin slot sizes and heat transfer rates, cautioning against excessive slot enlargement for fear of diminished heat transfer efficiency.

In a similar vein, Chaitanya et al. [17] focused on thermal properties through Ansys Workbench, examining various aluminum alloy grades and geometric variations. They concluded favorably for Al6061, noting its augmented heat transfer capacity, particularly with altered geometric shapes, showcasing circular fins as promising in increasing efficiency.

Sagar et al. [9] delved into engine fin heat transfer by varying surface roughness, revealing that increased roughness led to escalated heat dissipation rates. Meanwhile, Reddy et al. [10] scrutinized thermal analysis on cylinder blocks, advocating for aluminum alloys like Al380 due to their superior heat dissipation capabilities for lighter vehicles.

Further research by Natrayan et al. [13] emphasized the significance of airflow contact time with fins, highlighting wavy-shaped cylinders as effective in augmenting heat transfer. Conversely, G. Babu et al. [8] explored the impact of fin thickness and material on thermal efficiency, recommending curved shapes for enhanced heat transfer.

Mohsin et al. [18] suggested modifications in fin geometry and shape for improved heat transfer rates, echoing the importance of airflow contact time. Kirubadurai et al. [19] and Madhavi et al. [20] centered their studies on increasing the engine's lifetime by modifying fin shapes and materials, emphasizing the significance of heat transfer rates in optimizing engine performance.

Amidst these studies, a gap emerges in the literature regarding steady-state analyses of engine fins, a crucial consideration during the prolonged running of engines. Presently, this research aims to fill this void by analyzing engine fins in a steady-state manner using Al204 and comparing it with Al6061 and Al663 alloys. This investigation seeks to offer insights into steady-state thermal behaviors crucial for real-time operational conditions, thereby contributing valuable insights to the ongoing discourse on optimizing engine performance through fin design and material selection.

2. METHODOLOGY

2.1 Proposed Methodology

Automobile engines undergo wear and tear due to intense heat during combustion, especially in air-cooled engines where heat transfer is limited. To address this, extended surfaces, known as fins, are utilized to enhance heat dissipation. This study focuses on the material aspect of fins for Super Splendor bike. A steady-state analysis using Finite Element Analysis (FEA) is conducted, varying materials to determine the most effective for heat transfer

2.2 Fin Profile

A rectangular fin, characterized by length (L), thickness (2δ), and width (W), is considered with unidirectional heat flow along its length.

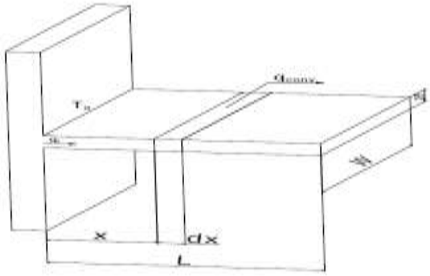

Figure 1: Rectangular fin profile [16]

2.3 Mathematical Formula

Heat lost by the fin is calculated using the formula:

$$\boxed{Q = kA_c m\theta_0 \frac{h\cosh mL + km\sinh mL}{km\cosh mL + h\sinh mL}}$$

Where:

k = thermal conductivity, W/mK

Ac= cross section area of fin, m^2

m = fin parameter, ($\sqrt{hP/kA_c}$)

P= perimeter of the fin, (2W+4δ), m

θ_0= temperature difference, K

h = heat transfer coefficient, W/m^2K [16]

2.4 Working Principle

Around 40% of engine heat disperses into fins through convection heat transfer. Steady-state analysis is employed considering the vehicle in running condition.

2.5 Assumptions

Several assumptions are made:

- Steady-state heat conduction.
- No internal heat generation within the fin.
- Uniform heat transfer coefficient over the fin surface.
- Isotropic and homogeneous fin material.
- Negligible contact thermal resistance.
- One-dimensional heat conduction.
- Negligible radiation [12].

2.6 Analysis Procedure

The Super Splendor motorcycle's engine fin is modeled using Solidworks software, imported into ANSYS for steady-state thermal analysis. Steps include:

1. Creating the rectangular fin model.
2. Importing geometry into ANSYS.
3. Generating tetrahedral volume mesh for curved surfaces.
4. Applying boundary conditions.
5. Solver setup and monitoring for solution.
6. Calculating heat flux and temperature distribution.
7. Comparing results and visualization.
8. Report creation.

Figure 2: Rectangular Fin

2.7 Boundary Conditions

For steady-state thermal analysis:

- Input temperature: Running engine temperature set at 250°C (ramped) [22].
- Initial convection parameters:
    - Atmospheric temperature: 24°C.
    - Heat transfer coefficient: 25W/m²K.

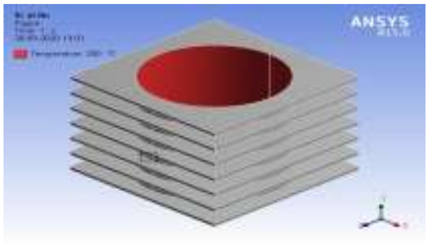

Figure 3: Temperature Input for analysis

Table 1: DESIGN FOR THE SPECIFICATION [38]

Bore	52.4 mm
Stroke	57.8 mm
Thickness of fins	2 mm
Pitch	9 mm
Cylinder Wall thickness	3 mm
Length of fin	68.4 mm

3. RESULTS AND DISCUSSION

A rectangular fin, designed according to Hero Super Splendor motorcycle specifications, was modeled using Solidworks. Temperature distribution and heat flux analyses were conducted using Ansys software for three different materials: Al 204 alloy, Al6061 alloy, and Mg alloy**.**

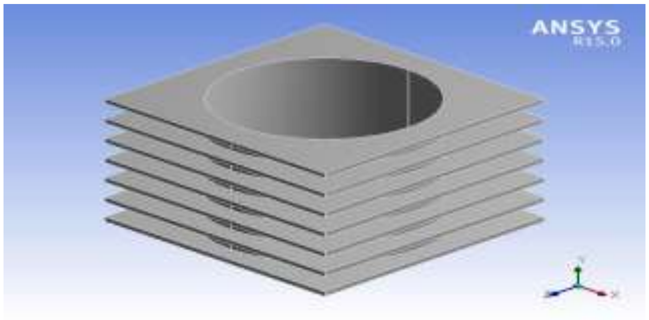

Figure 4: Geometry of modeled rectangular fin

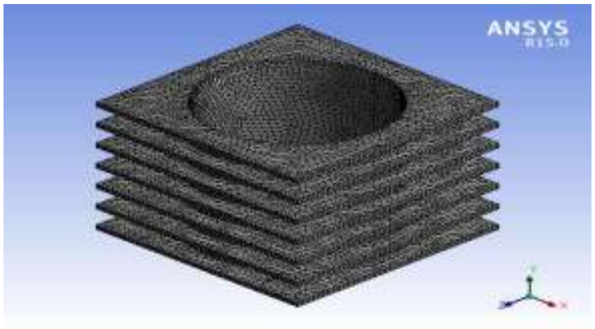

Figure 5: Mesh in Rectangular fin

Table 2: Nodes and elements

Rectangular Fin	
Nodes	Elements
178913	101744

3.1 Al204 Alloy Results Al204 alloy properties:

Table 3: Material Properties: [11]

Property	**Value**
Density(Kg/m^3)	2800
Specific heat (J/Kg/^{0}c)	960
Thermal Conductivity (Watt/m/^{0}c)	120

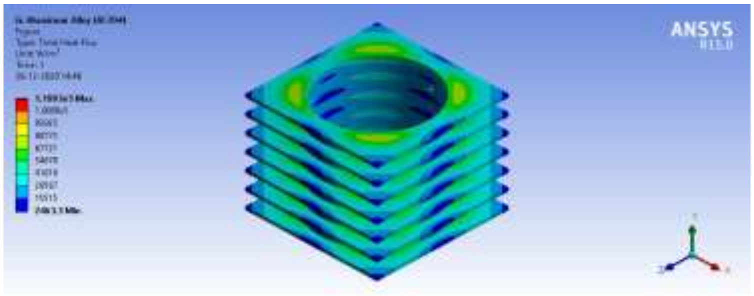

Figure 6: Total heat flux in Al204 alloy

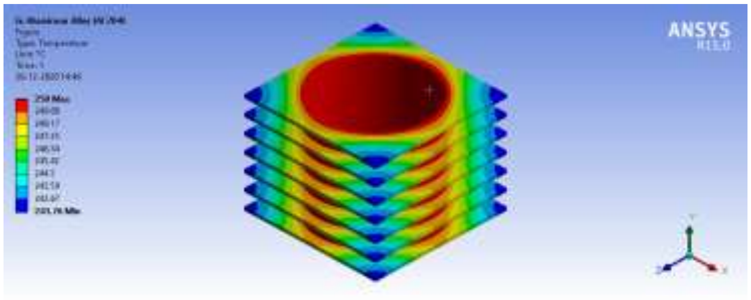

Figure 7: Temperature distribution of Al204 fin

Table 4 : Temperature and total heat flux in Al204Alloy

Value	**Temperature (^{0}C)**	**Total heat flux (W/m^2)**
Max.	250	1.1993e+005
Min.	241.76	2463.3

The temperature and total heat flux for Al204 alloy fins are detailed in Table 4 The maximum and minimum temperatures recorded were 250°C and 241.76°C, respectively, with a total heat flux of 1.1993e+005 W/m².

3.2 Al6061 Alloy Results Al6061 alloy properties:

Table 5: Material Properties: [10]

Property	**Value**
Density(Kg/m^3)	2700
Specific heat (J/Kg/^{0}c)	1256
Thermal Conductivity (Watt/m/^{0}c)	167

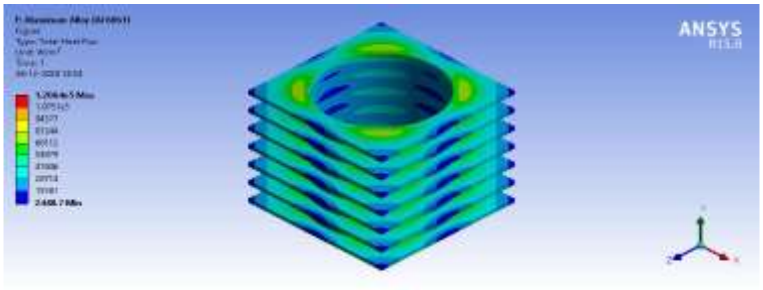

Figure 8: Total heat flux of Al6061 alloy

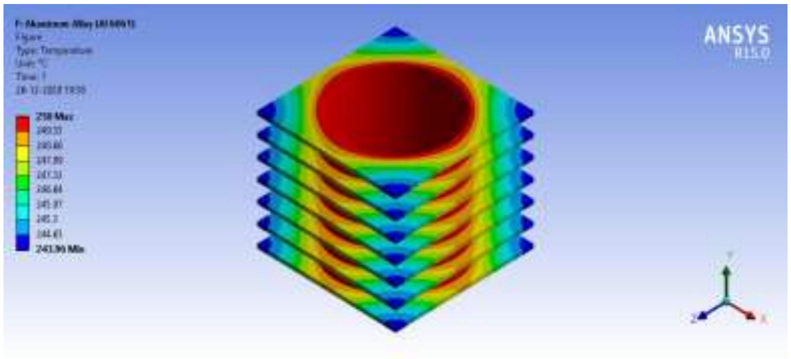

Figure 9: Temperature of Al6061 alloy

Table 6: Temperature and total heat flux in Al6061 alloy

Value	Temperature (^{0}C)	Total heat flux (W/m^2)
Max.	250	1.2064e+005
Min.	243.96	2448.7

Table 6 outlines the temperature and total heat flux for Al6061 alloy fins. The maximum and minimum temperatures observed were 250°C and 243.96°C, respectively, with a total heat flux of 1.2064e+005 W/m².

3.3 Al6063 Alloy Results Al6063 alloy properties:

Table 7: Material Properties. [23]

Property	Value
Density (Kg/m^3)	**2770**
Specific heat (J/Kg/^{0}c)	**875**
Thermal Conductivity (Watt/m/^{0}c)	**170**

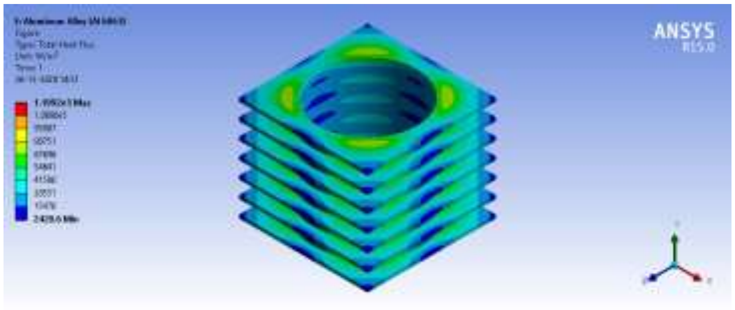

Figure 10: Total heat flux in Al6063 alloy fin

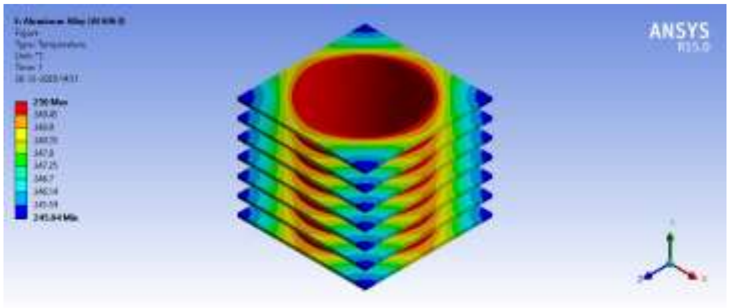

Figure 11: Temperature distribution in Al6063 alloy

Table 8: Temperature and total heat flux in Al6063 Alloy:

Value	Temperature (^{0}C)	Total heat flux (W/m^{2})
Max.	250	1.1992e+005
Min.	245.04	2420.6

Table 9: Comparison of all types of fin:

Type of Fin	Input Temp(^{0}C)	Output Temp (^{0}C)	Heat Flux (W/m^{2}) Max.
Al204 Alloy	250	241.76	1.1993e+005
A6061 Alloy	250	243.96	1.2064e+005
Al6063 Alloy	250	245.04	1.1992e+005

Table 8 illustrates the temperature and total heat flux for Al6063 alloy fins. The maximum and minimum temperatures noted were 250°C and 245.04°C, respectively, with a total heat flux of 1.1992e+005 W/m².

3.4 Comparison of Fin Types Table 9 summarizes the comparison of all three fin types based on their input and output temperatures, along with the maximum heat flux recorded. The results indicate that Al204 alloy experienced the lowest output temperature but had the highest heat flux, followed by Al6061 and Al6063 alloys.

3.5 Graphical Representation The graphical representation shows the temperature drop and maximum heat flux for Al alloy fins. It's evident from the graphs that Al204 had the highest temperature drop, followed by Al6061, while Al6063 exhibited the least drop in temperature. Regarding heat flux, Al6061 had the highest, trailed by Al204 and Al6063 alloys.

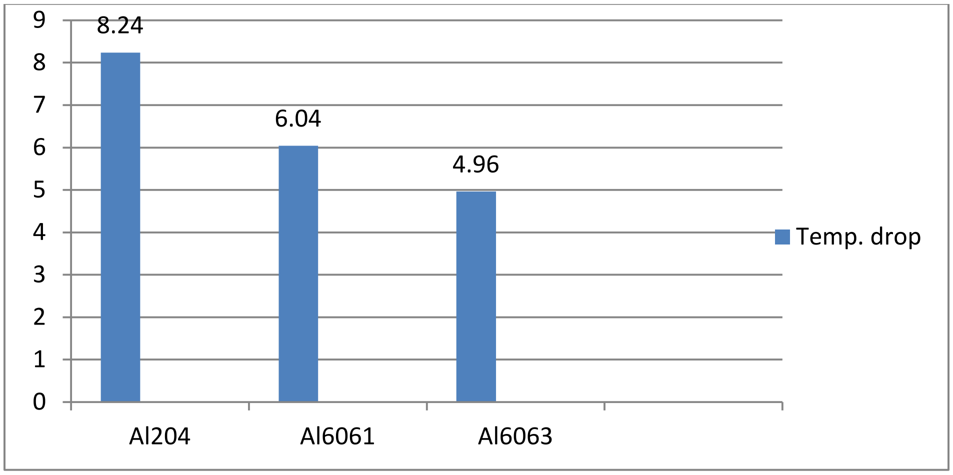

Figure 12: Temperature drop for Al Alloy Fin

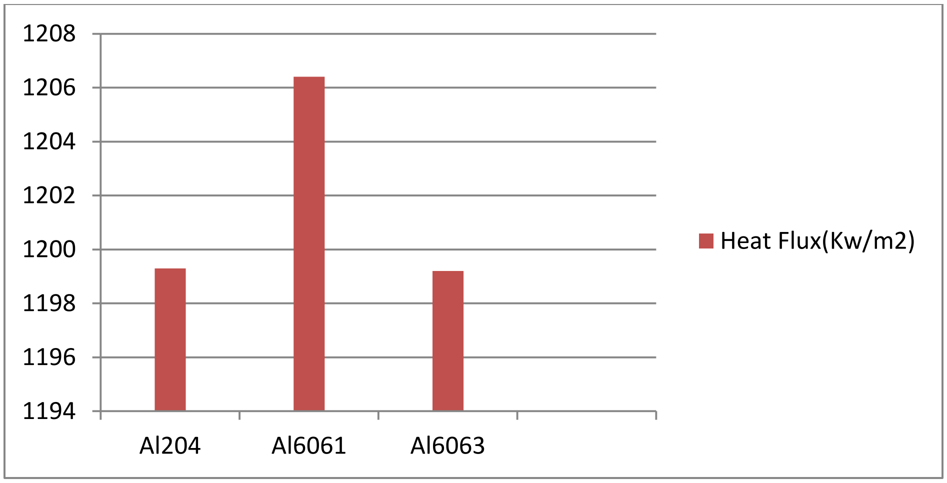

Figure 13: Maximum heat flux for Al Alloy Fins

This comparative analysis showcases the temperature and heat flux behavior of different materials for the motorcycle's fin design, providing insights into their thermal performance under steady-state conditions.

4. CONCLUSION & FUTURE SCOPE

The modeling and thermal analysis of the Hero Super Splendor motorcycle's rectangular fin using Solidworks and Ansys software revealed crucial insights. Al204, the current material, was compared with Al6061 and Al6063, which shared similar density characteristics. The examination demonstrated that Al204 exhibited the best temperature distribution range, while Al6061 showcased superior heat flux.

The graphical representation accentuated the prominence of heat flux variation over temperature drop, with Al6061 displaying the highest. Additionally, Al6061, slightly lighter than Al204 in density, stood out as a potential material due to its excellent heat transfer, commendable strength, and relatively lower weight.

Thus, in the pursuit of an optimal material for lightweight vehicles, prioritizing high heat transfer, strength, and reduced weight, Al6061 emerges as the most suitable choice among the tested materials.

Future Scope

The study opens avenues for further exploration. Subsequent analyses could encompass diverse sets of Al alloys, examining transient as well as steady-state conditions. Integrating structural and economic considerations into the evaluation would offer a comprehensive understanding, aiding in the selection of the most efficient and cost-effective material for enhanced performance in two-wheeler applications.

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