Investigation of Thermal performance of engine cylinder with Fins using different Aluminum alloys

Sunil Shinde, Piyush Kawade, Akshaan Kaware, Harshada Kulkarni, Kshitija Kulkarni, Aarya Kurlekar

[1,2,3,4,5,6]*Vishwakarma Institute of Technology, Pune.*

sunil.shinde@vit.edu, piyush.kawade20@vit.edu, akshaan.kaware20@vit.edu, harshadakulkarni20@vit.edu, kshitija.kulkarni20@vit.edu, aarya.kurlekar20@vit.edu

Abstract

Internal combustion engines generate a significant amount of heat during their operation and it is crucial to dissipate this heat efficiently to prevent engine failure or reduced efficiency. The use of fins improves the heat transfer rate in IC engines by increasing the surface area available for heat transfer. The selection of appropriate materials for fins is critical to their thermal performance. Aluminum and its alloys are commonly used due to their favorable material properties such as high thermal conductivity, good machinability and good strength, low cost and low weight. This paper aimed to determine the thermal behavior of annular fins of a 125 cc single cylinder air cooled motorcycle engine cylinder block using ANSYS for various aluminum alloys. The study analyzed the results to identify the optimal material that provides a higher heat transfer rate while also being lightweight.

Keywords: *Heat dissipation; Fins; Thermal conductivity; Aluminum alloys; Thermal analysis*

1. Introduction

Internal Combustion engines, the heart of automobile vehicles work on energy conversion principle. Air-fuel mixture burning results in heat energy which is then converted to mechanical work. Of the total heat energy created, 30% is converted into useful work while the remaining 70% needs to be ejected from the engine [1]. Heat removal in an efficient way is crucial in order to avoid damage to components and eventually result in engine deterioration and failure. Typically, liquid cooled engine and air cooled engine are the two methods employed for engine cooling. The complexity of liquid cooled engines makes them difficult to manufacture and cost ineffective. Hence air cooled engines are preferred. Extended surfaces or fins thus play a focal role in efficient heat dissipation [2]. The heat transfer efficiency mostly depends upon the thermal conductivity of the engine cylinder material. Ideally, cylinder material should have high thermal conductivity, low thermal expansion, low density, relatively cheap and feasible to machine, should have good abrasion and corrosion resistance and should retain strength at high operating temperatures. Grey cast iron, Mg alloys exhibit efficient heat transfer but due to their more weight, they are not preferred for light motor vehicles [3].

2. Technical Study

2.1) Literature review:

Aluminum alloys exhibit high thermal conductivities, are lightweight in nature and enable practical machining. An aluminum-alloy composition that is commonly used includes approximately 11.5% silicon, 0.5% manganese, and 0.4% magnesium, with the remaining portion being aluminum. The addition of high levels of silicon to the alloy helps to improve castability, strength, and abrasion resistance while reducing expansion. Manganese and magnesium are also added to reinforce the aluminum structure. Although this alloy demonstrates good corrosion resistance, it has limited capacity to withstand high levels of shock loads [4-6]. M. Esfahanian et al considered Al6060 in their study because of its favorable characteristics, such as high thermal conductivity and temperature resistance, low cost compared to other aluminum alloys as well as strong mechanical properties. Al6060 is commonly used in a variety of applications, including engine fins [7]. It was observed that by employing circular fins and reducing the thickness of the fin, the weight of the fin body reduces thereby increasing the heat transfer rate and efficiency of the fin. Using circular fins with material Al 6061, which has high thermal conductivity showed better results as heat transfer rate of the fin is more. Al 6061 is also comparatively cheaper and easily available which makes it more suitable for this application [8-10]. S. M. Akbarally et al evaluated the thermal performance of the fins made of three different aluminum alloys: Al6061, Al6063, and Al7075. Thermal performance of engine fins suggested that Al6063 had the highest heat transfer coefficient and the best overall thermal performance, while Al7075 may not be the best choice due to its low thermal performance [11].

2.2) Methodology:

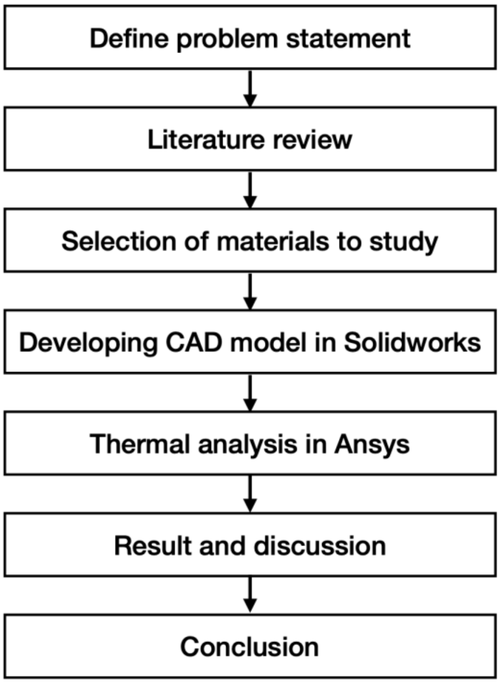


Fig.1: Flow chart illustrating research approach

2.3) Selected materials:

Properties	Materials				
	Al6060-T6	Al6061-T6	Al6063-T6	Al6065-T6	Al2014-T6
Density (kg/m3)	2700	2700	2700	2780	2800
Ultimate Tensile Strength (MPa)	220	310	241	310	483
Young's Modulus (GPa)	68	73	68.9	68	73.1
Specific heat (J/kg.K)	900	1256	900	890	880
Thermal Conductivity (W/m.K)	210	167	200	170	154

2.4) Geometry Modeling:

Air cooled bike engine cylinder block with annular fins is considered for thermal analysis. The model is generated using SolidWorks and analysis is conducted using ANSYS software. The engine is 150 mm long, and has 15 fins of length 20 mm and thickness 6 mm. The inner diameter of the cylinder is 40mm and outer diameter is 50mm.

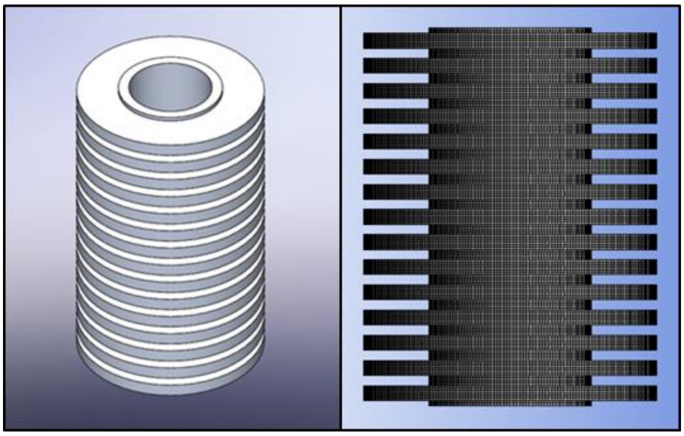
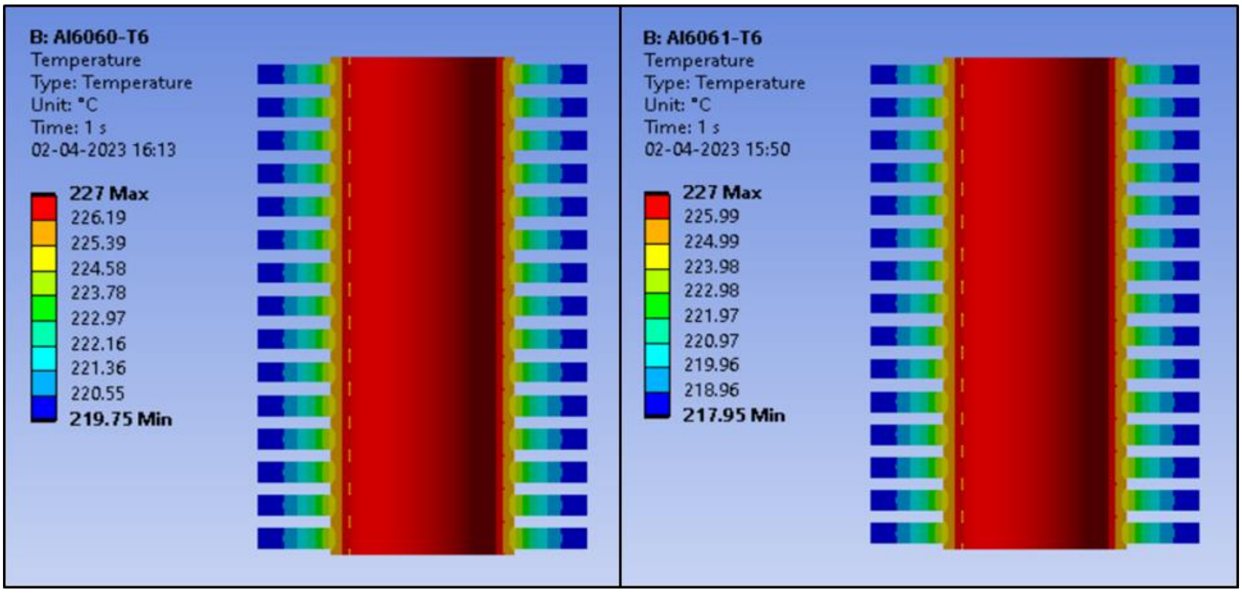


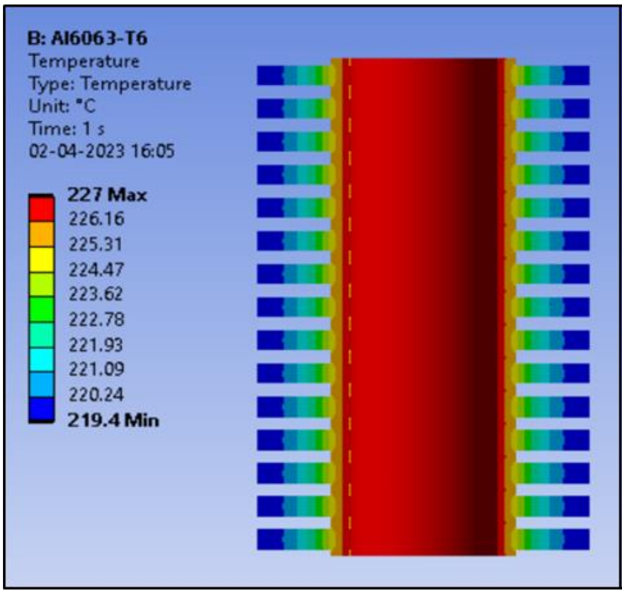
Fig.2: (a) Engine cylinder model SolidWorks; (b) Meshed geometry in ANSYS

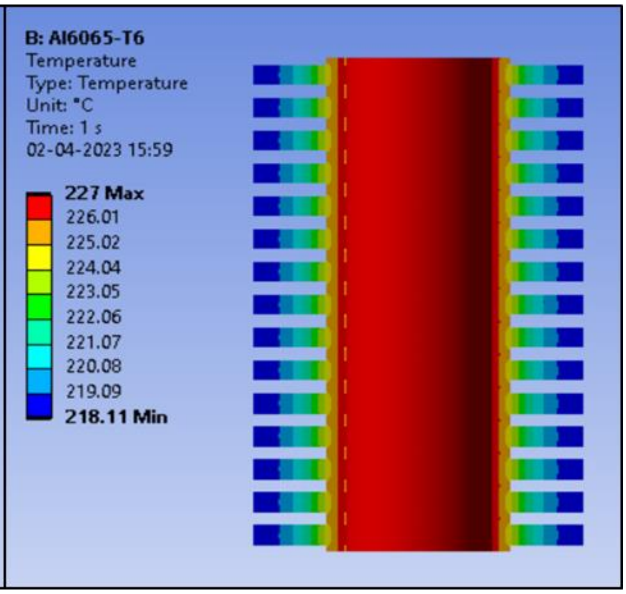
3. Result and Discussion

After the geometry creation, the 3D model is then imported to ANSYS Mechanical, where a hexahedral dominated mesh is generated. The orthogonal quality is maintained at 0.896 while the skew-ness at 0.184 to generate better results. Following the mesh generation, the inner wall is given a temperature of 227 °C and convection heat transfer of 50 W/m^2-K as boundary conditions. Steady state thermal analysis is then conducted on the model. The process is repeated with constant boundary conditions for each Aluminum alloy under discussion.

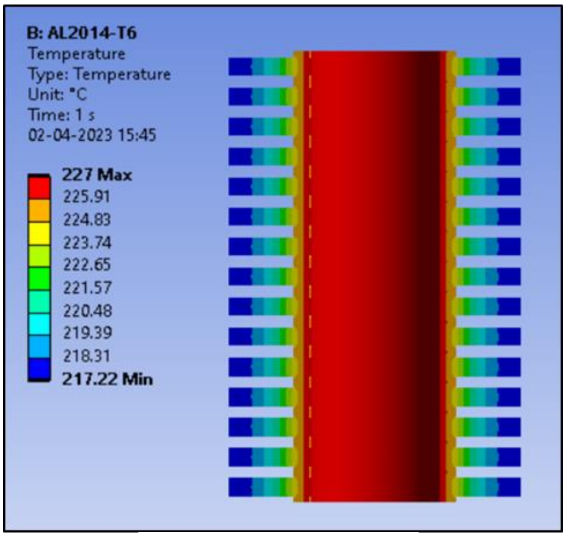


b) Al 6060-T6 a) Al 6061-T6



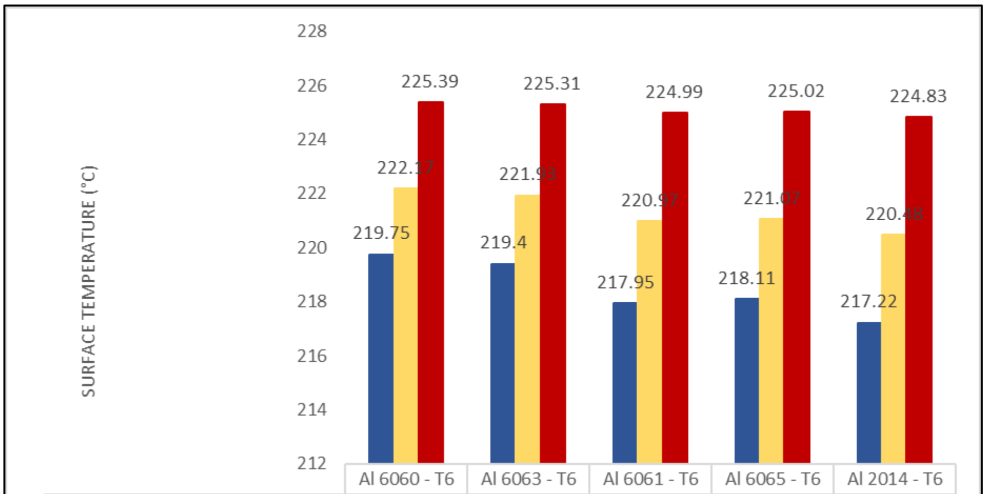


d) Al 6063-T6 c) Al 6065-T6



e) Al 2014-T6

Fig.3: Nodal temperature distribution of various alloys



	Al 6060 - T6	Al 6063 - T6	Al 6061 - T6	Al 6065 - T6	Al 2014 - T6
Minimum Temperature (°C)	219.75	219.4	217.95	218.11	217.22
Average Surface Temperature (°C)	222.17	221.93	220.97	221.07	220.48
Maximum Temperature (°C)	225.39	225.31	224.99	225.02	224.83

Fig.4: Minimum, average and maximum temperatures of cylinder fins obtained for each aluminum alloy

The nodal temperature contours of all alloys (Fig.3) were used to create a bar chart (Fig.4) for easy interpretation of the results. It was observed that Al6060 exhibited the highest average surface temperature and the highest minimum temperature at the fin tips. Both Al6060 and Al6063 showed better heat distribution due to their high thermal conductivities. Since cylinder blocks are subjected to high thermal stresses and vibrations, material strength is also an important factor to consider. To assess the ultimate tensile strength of the selected alloys, a column chart was prepared and shown in Fig.5.

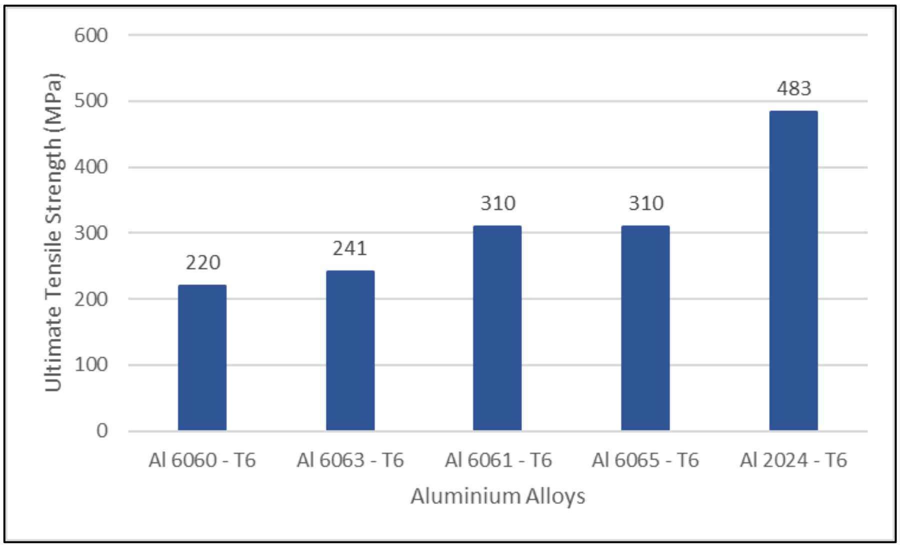


Fig.5: Ultimate tensile strength of Aluminum alloys

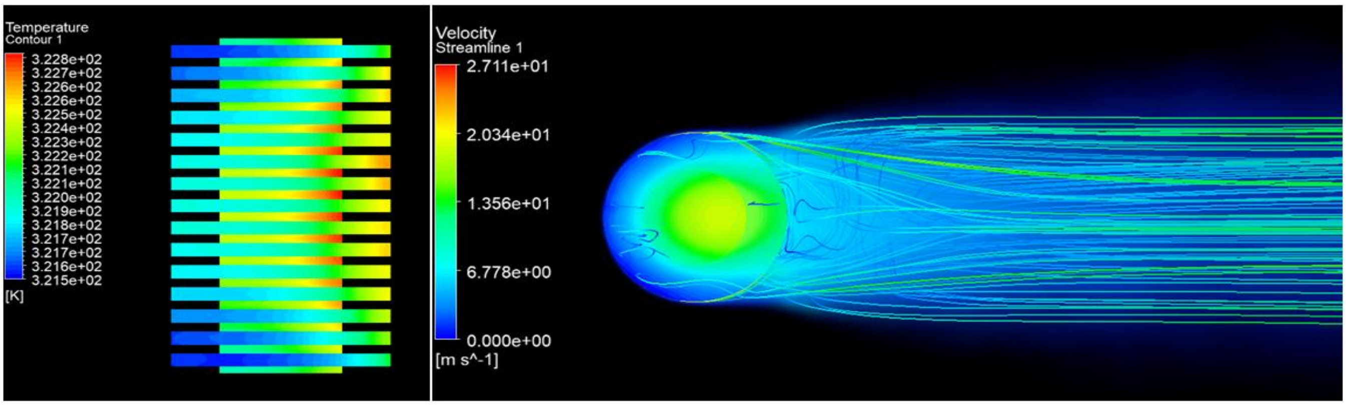


Fig.6: CFD analysis

CFD analysis was conducted to examine the interaction between the cylinder and air, revealing that the leading surface of the cylinder experiences optimal air flow and cooling. However, the flow separates ahead of the midpoint, leading to the formation of a recirculation zone or wake at the cylinder's rear. This zone exhibits eddy formation and poor heat transfer rates, resulting in significantly higher temperatures at the back of the cylinder compared to the front. To address this issue and ensure more uniform heat distribution, baffle systems can be implemented in the design [12]. Studies have shown that such systems are effective in improving engine performance and reducing engine temperature by promoting better airflow over the rear surface of the engine. Additionally, research has demonstrated that increasing the length of the rear fins can enhance engine cooling efficiency [13].

4. Future Scope

This paper studies different materials based on their thermal conductivities, strength and other physical factors to understand which alloys exhibits better heat dissipation. In future, modifications to the fin geometry can be conducted to achieve better thermal performance. Fin geometry can be modified to enhance heat transfer and save material wherever possible as well.

5. Conclusion

In this study, thermal analysis of finned engine cylinder for various Aluminum alloys is conducted to find out the best alloy considering surface heat distribution, weight and machinability factors. For this study annular finned air cooled bike engine cylinder block was modeled in SolidWorks and analysis was conducted in ANSYS software. From the above results it was observed:

- Al6060-T6 and Al6063-T6 exhibit the most efficient temperature distribution and heat transfer due to their high thermal conductivities.
- Al2014-T6 has high strength but exhibits poorest heat distribution compared with other alloys.
- Poor air circulation at the cylinder rear results in inefficient heat transfer and heat accumulation at the back of cylinder.

Currently, Al6061-T6 and A2014-T6 are preferred for engine fin material. These materials could be replaced by Al6060-T6 or Al6063-T6. Along with high thermal conductivity, both alloys exhibit better weld-ability, corrosion resistance and surface finish at similar costs when compared to Al6061-T6 and Al2014-T6. The only drawback of these alloys is that they have lower strength and wear resistance when compared to Al6061-T6 and Al2014-T6.

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