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Computational Modelling and Performance Analysis of Finned Cylinders

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Abstract: *The engine cylinder is a key component of an engine that undergoes significant temperature differences and thermal stresses. In air-cooled internal combustion (I.C.) engines, extended surfaces, known as fins, are added around the cylinder to enhance the rate of heat transfer. These fins are attached to the cylinder surface to improve the amount of heat exchanged through convection. The cooling process of an air-cooled engine largely depends on the design of these fins. Cooling fins are used to increase the rate of heat transfer from specific areas. Parameters of the fins such as length, spacing, thickness, quantity, width, and material significantly affect the rate of heat transfer. Therefore, if the goal is to increase the heat transfer rate, the shape of the fin will have a major impact on the cylinder block's ability to lose heat, even for the same size and material of the cylinder. Initially, an analytical calculation is performed to estimate the theoretical amount of heat lost through the fins. The internal wall temperature is assumed to be approximately 2000°C to maintain the engine's operating cycle. The outer wall temperature and surface temperature of the fins are calculated both theoretically and computationally. Based on a literature review, circular and wavy-shaped fins are considered for the analysis. Additionally, aluminium, aluminium 6061, and aluminium 2014 are selected for comparative analysis with the aforementioned shapes. The CAD models are created using SOLIDWORKS 2020, and the analysis of the fins are conducted using ANSYS 2022 Student version. The results from this analysis showed that wavy fins provided better performance when compared to circular fins.*

Keywords: Engine Cylinder Block, Fins, Heat Transfer, Optimization, SolidWorks, ANSYS

I. INTRODUCTION

Cooling of hot surfaces using metal fins can be achieved in two ways: one through the convection of heat from the fin surfaces by an air stream, and the other through the conduction of heat through the fins to reach the surface. The rate at which heat is transferred from a fin surface by air is typically expressed as a surface heat transfer coefficient. Nearly all modern motorcycle engines use liquid cooling, except for some motorbike engines. Although air-cooling is more challenging than liquid-cooling to effectively cool an engine, constructing an air-cooled engine is simpler. In an air-cooled engine, the fins conduct heat from the cylinder to the surrounding air. Therefore, it is important to use fins effectively to ensure proper engine cooling and uniform temperature distribution around the cylinder.

In the case of internal combustion (I.C.) engines, combustion of the fuel-air mixture takes place inside the engine cylinder, generating hot gases. In two-wheeler engines, the temperature inside the cylinder can range from 3000 to 10000°C. Due to this high temperature, gaskets or films may burn, and the fins help to reduce the temperature around the cylinder to approximately 1800 – 2500°C. The design of metal fins increases the surface area of the engine, thereby improving the cooling rate through convection. However, excessive cooling of the cylinder can reduce thermal efficiency. Thus, the objective of the cooling system is to maintain the engine at its optimal operating temperature. It is important to note that the engine is less efficient when it is cold, so the cooling system is designed in a way that prevents cooling during the initial warm-up period until the engine reaches its most efficient operating temperature. The design of an air-cooled engine involves various engineering considerations, such as the cooling rate, total mass, and geometric constraints.

Internal combustion engines reject most of the heat from the fuel they burn, which is not converted into useful power. The importance of this rejected heat is often overlooked, but it is the primary cause of most engine problems and a key factor in determining the engine's performance rating. Some of this heat is carried away by the exhaust gases, while the rest passes through the metallic walls surrounding the combustion chamber, such as the piston, cylinder walls, piston rings, injectors, spark plugs, and exhaust passages. The heat passing through these parts increases their temperatures, causing them to expand, weaken, and experience stress. Each component has a limit to how much heat it can transfer internally, and excessive cooling can create significant internal stresses in the materials. Thus, one of the main goals in the development of any internal combustion engine is to achieve the highest possible thermal efficiency to minimize the flow of heat through the engine components.The necessity of a cooling system in I.C. engines is evident, as not all heat from fuel ignition is converted into useful power at the crankshaft. Useful work at the crankshaft = 25 – 40%, Loss to the cylinder walls = 10 – 30, Loss in exhaust gases = 20 – 45%, Loss in friction and radiation = 10 – 35%. It is evident that the amount of heat transferred to the chamber walls is significant. If this heat is not dissipated, it may cause pre-ignition of the fuel-air mixture. Moreover, the lubricating oil can also burn under extreme heat, leading to engine seizure. Excessive heating can also damage the chamber material. To prevent thermal breakdown of the lubricating oil, it is essential to maintain the cylinder wall temperatures within the range of 180°C to 200°C. As lubrication technology improves and better oils are used, the maximum allowable wall temperature can be maintained.

Aircooled system is generally used in small engines say up to 15-20 kW and in aero-plane engines. In this setup, fins or extended surfaces are included on the walls of the cylinder, the cylinder head, and other related areas. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air. The amount of heat dissipated to air depends uponA fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, and radiation of an object determines the amount of heat it transfers. Increasing the temperature difference between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not economical, or it is not feasible to change the first two options. Adding a fin to the object, however, increases the surface area and can sometimes be economical solution to heat transfer problems. The surface area over the cylinder gets bigger by means of fins. These fins are either cast as an integral part of the cylinder or different finned barrels are placed over the cylinder barrel. Sometimes particularly in aero engines, the fins are machined from the forged cylinder blanks. As a rule, the fins are usually made of about the cylinder wall thickness at theirroots, tapering down to about one-half the root thickness. The length of the fins varies from one-quarter to one-third of the cylinder diameter. The distance between the two fin centres is about one-quarter to one-third of their length. The total length of the finned cylinder barrel is from 1 to 1½ times the cylinder bore.

II. LITERATURE SURVEY

Tripathi Pradeep Mani et al (2014) [1] presented a paper on thermal analysis of the cylinder head assembly of the four-stroke engine. They created a detailed FE model consisting of main parts of the cylinder head assembly and it includes a description of thermal and mechanical loads and contact interaction between its parts. The model considers a temperature dependency of a heat transfer coefficient on wall in cooling passages as fins. They carried out analysis using the FEM program. The finite element method is applied to find the temperature distribution field from the parts of the cylinder head of SI engine.

Deshpande A.C. et.al (2015) [2] investigated the effect on heat transfer rate by changing the cross-section, fin pitch, fin Material and fin thickness. The vehicles they considered have single cylinder air cooled engines with a set of rectangular fins mounted on the cylinder block. They measured temperature generated at steady state from the fin surface through experiments and used the value as key parameter, heat dissipated and calculated heat flux through fins using empirical formulations. They also validated by using the FEA approach.

Yellaji Bade et.al. (2017) [3] conducted thermal analysis on heat distribution in fins of compressor cylinder by varying profile using FEM. They altered geometrical shapes of fins for analysis and select most effective cooling fin. They have work on rectangular, triangular, concave & convex profile fin of aluminium nitride and aluminium alloy A204 preferred for analysis. The parameters for analysis heat transfer rate through fin, fin efficiency and effectiveness through free and forced convection heat transfer mode. The results obtained with concave fin with material aluminium alloy A204 is better since heat transfer rate of the fin is more. By using concave fins, the weight of the fin body reduces compared to existing rectangular engine cylinder fin.

N. Arul et.al. (2017) [4] conducted experimental and computational analysis of various types of fins. Using CFD software the fluid analysis is done with existing design. The dimensions of the cylinder length, cylinder thickness, cylinder inner and outer diameter are initialized by us to a certain value corresponding to the existing available design.

K. Sathishkumar et.al (2017) [5] computational analysis of heat transfer through fins with different types of notches in which the fins with various configurations were modelledusing CREO 2.0 and analyses are done by using CFD – Fluent in order to find out the heat transfer rate.

Sorathiya A. S. et.al. (2017) [6] presented the augmentation of heat transfer coefficient for varying fins configuration of cylinder block of SI engine.

Kumar Rajat et.al. (2020) [7] studied enhancement of the thermal properties by shifting geometry, material, and design of fins. The thermal analysis of fins by modifying its certain parameters such as geometry and plate fins and pin fins has been completed and by observing the analysis results, they say using conical draft pin fins with material aluminium alloy 1060 is better since the temperature drop and the heat transfer rate in a conical draft pin fins much more, compared to plate fin.

Shareef, S. K. Mohammad et.al. (2021) [8] presented numerical investigation of thermal properties of engine cylinder by varying geometry properties material and profile of cylinder using ANSYS workbench.

Abbood M. H. et.al. (2021) [9] conducted investigation on the effects of fin geometry on motorcycle cylinder cooling by adding eight fins with different shapes around the cylinder. They use Fluent software (ANSYS 19.0) for investigation. In investigation they varied Reynolds numbers (4, 6, and 8 x 104) under constant heat flux (6, 12, 25 kW/m^2). Four types of fins, square, circular, elliptical, and air foil, all with the same thickness (5 mm), pitch gap between each fin (3 mm), and surface area (0.0745 m^2) were investigated. The metal used for the fin bodies was aluminium alloy, with a thermal conductivity of 237 W/m-K. The working fluid used was air. They concluded that the best case was seen in the cylinder with square fins, which obtained the highest value of heat transfer coefficient, and the rate of the heat transfer increases when the Reynolds number increases.

III. PROBLEM DEFINITION

Internal combustion engines reject most of the heat content of the fuel which they burn in that part which they turn into power. The importance of the heat which is rejected is often not recognized, but this heat is the cause of most engine troubles and is the basic determinant of the rating of an engine. Part of the heat which is rejected by the engine is carried away by the exhaust gas and the remaining must pass through the metallic walls which surround the combustion chamber that is, the piston, the cylinder walls, the piston rings, injector, spark plugs, and exhaust passages. The heat which is rejected through the metallic parts raises their temperatures and in passing through these parts expands, weakens, and stresses them. Each part has a limited capacity to flow heat through itself and in general more drastic cooling creates internal stresses in the materials. Thus, one of the principal objectives in the development of any internal combustion engine is to obtain the highest possible thermal efficiency to reduce the flow of heat through the engine parts.

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IV. OBJECTIVES

1. Creation of conceptual CAD model for study.
2. To enhance the heat transfer rate by making following changes
i) Change the geometry of fins i.e. circular & wavy shape fins in which the thickness of fin was kept constant i.e. 2 mm
ii) Change the material of the fin and selecting various materials for further process i.e. Aluminium, Aluminium 6061 & Aluminium 2014
4. Evaluate fin surface temperature computationally.

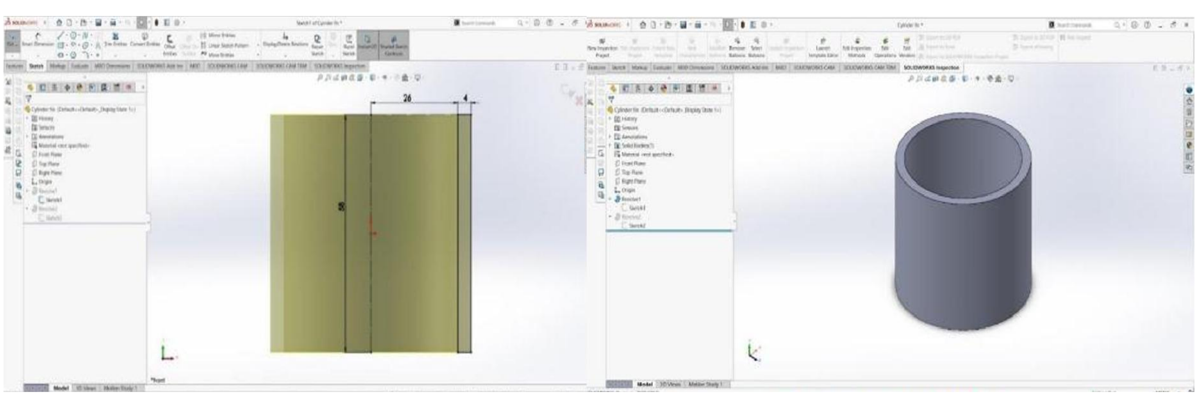
V. DESIGN OF FINS

For design we have selected the 125cc engine was selected and its specifications are as follows.

Table No. 5.1

Sr. No.	Model Name	Honda Shine
1	CC	125
2	Stroke (mm)	58
3	Bore (mm)	51
4	Number of fins	6
5	Fin pitch (mm)	10
6	Fin thickness	2.5
7	Fin material	Al Alloy
8	Position of fins w.r.t cylinder axis	Perpendicular

1.Thickness of cylinder = 0.045D +1.6 mm
= 0.045 × 51 + 1.6 mm
= 3.89 mm
= 4 mm
2. Maximum length of fin = 22 mm
3. Minimum length of fin = 7 mm
4. Circular fin profiles have 2 mm thick fins were modelled.
5. The number of fins for each model are 6.
6. The distance between the two top surfaces of the fins is maintained at 10 mm.
7. The engine cylinder's length is 58 mm; the outer and inner bore diameters are 60 and 51 mm.



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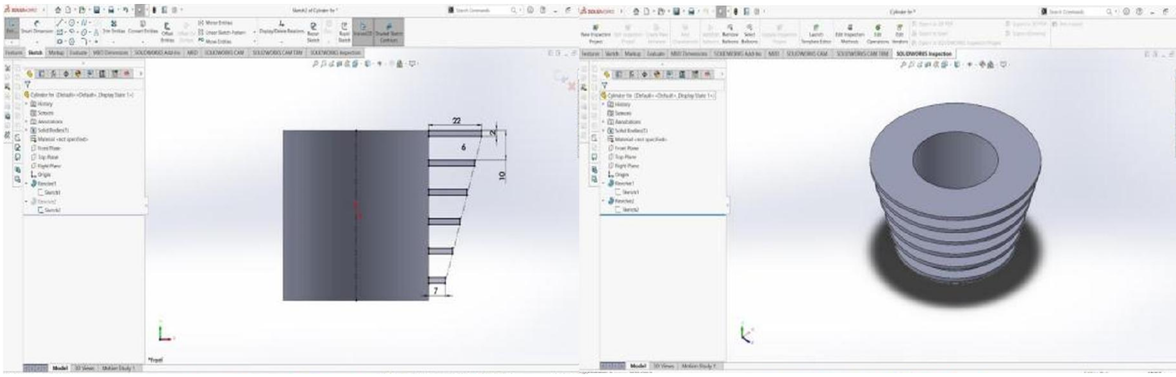
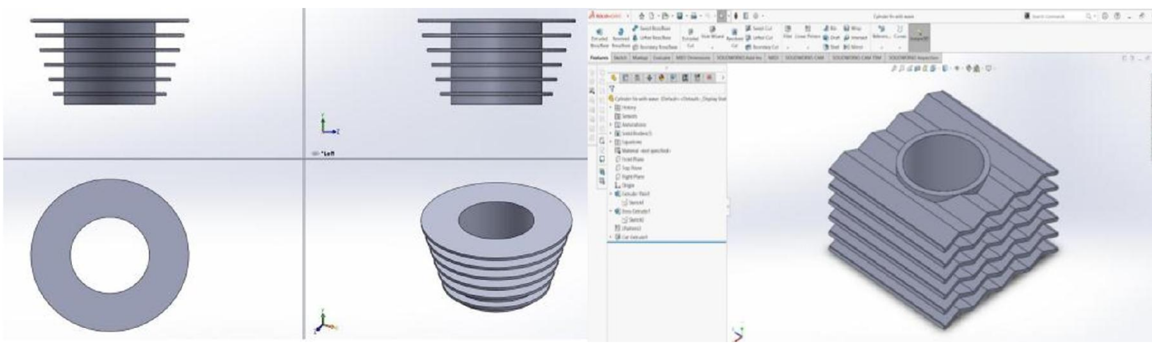
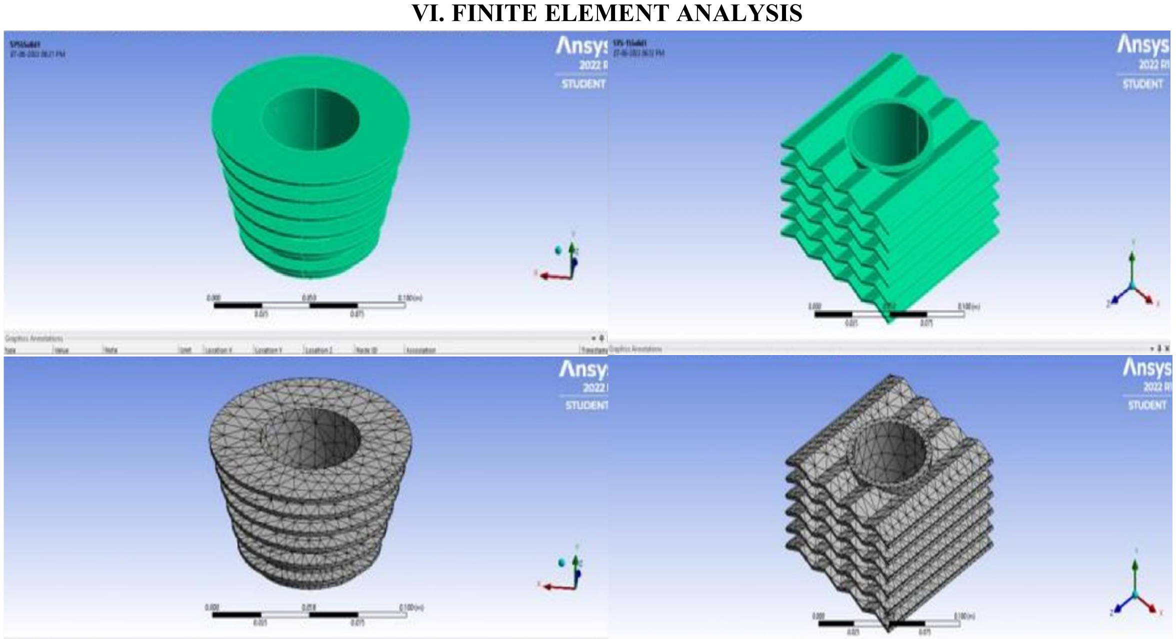




VI. FINITE ELEMENT ANALYSIS



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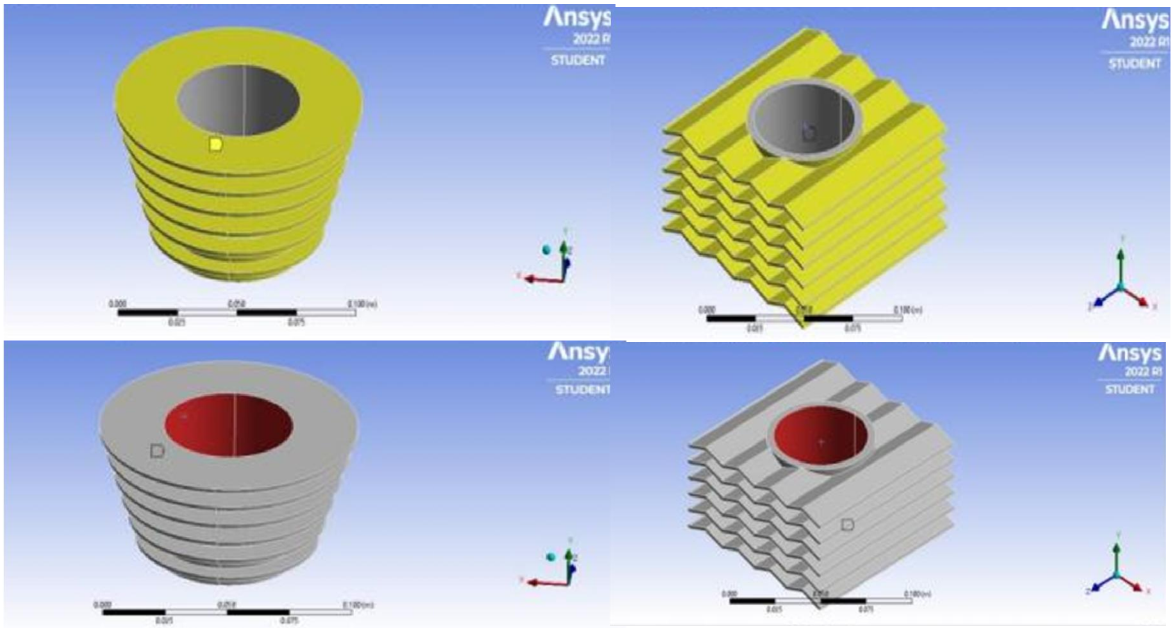
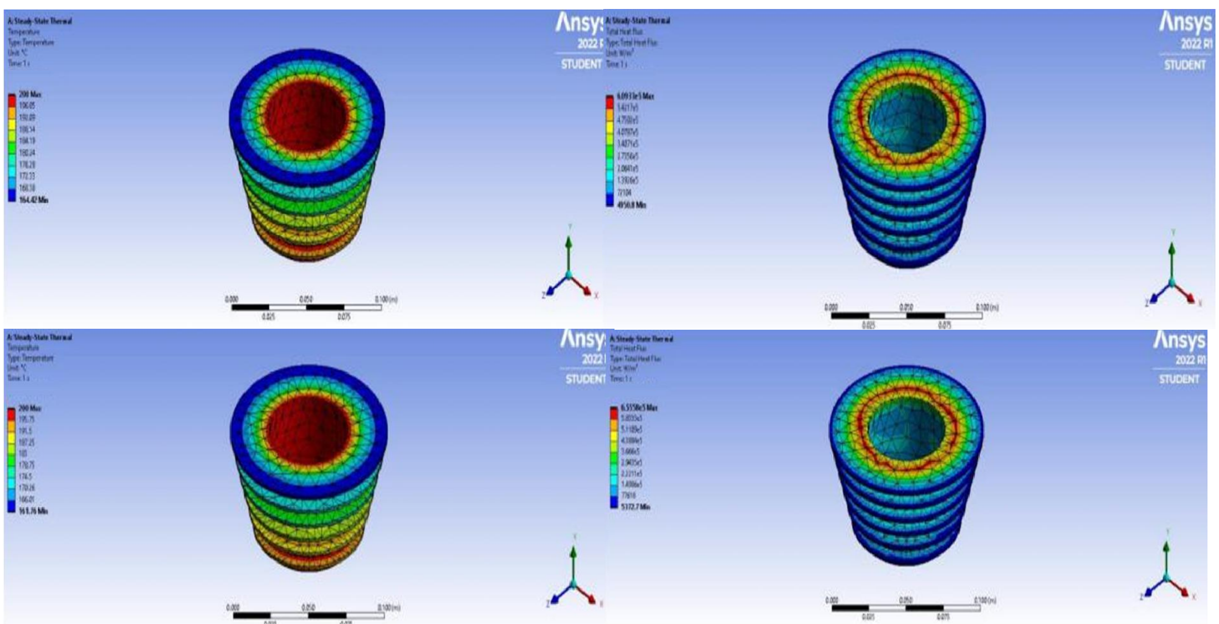


VII. RESULTS AND DISCUSSIONS



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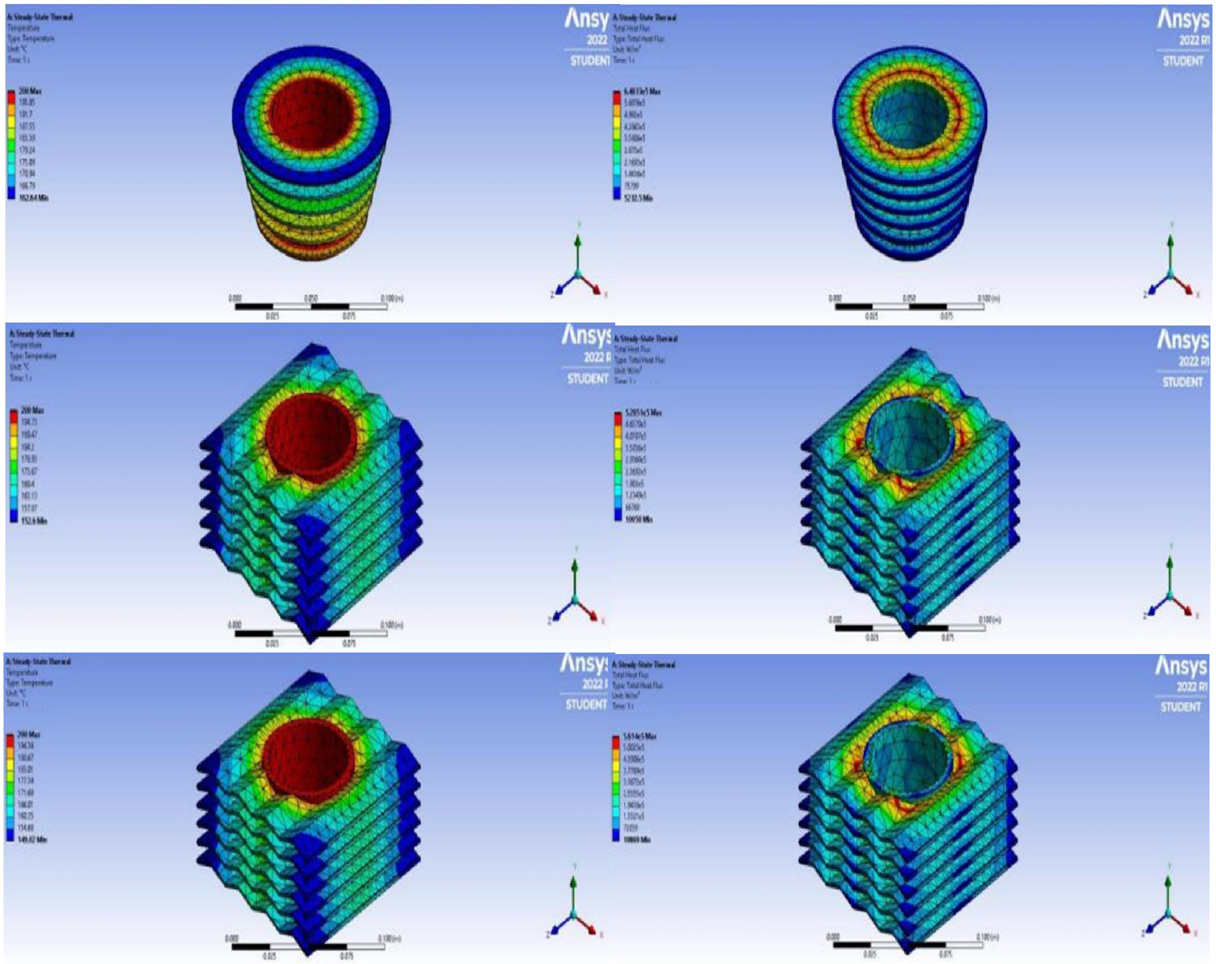

VIII. CONCLUSION

From the thermal analysis of cylinder fin, it is concluded that wavy fins with aluminium 6061 is more effective as compared to other fins, for which the fin temperature is found to be 149.020C and its maximum & minimum heat flux is 5.614 x 105 W/m2 & 10869 W/m2 respectively. Thus, wavy shape fins can replace the circular fins, so as to achieve effective heat transfer.

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