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Steady State Thermal Analysis of Embossed Spherical Structure on the Surface of Rectangular Fin by Using CFD

Surendra Kumar Patle[1]*, Prof. Atul Shanker Suman [2]*

[1]*(Mechanical Engg. Department, Corporate Institute of Science and Technology, Research Scholar, RGPV Bhopal)
[2]**(Mechanical Engg. Department, Corporate Institute of Science and Technology, Professor, RGPV Bhopal)

ABSTRACT:

Fins are a kind of heat transfer enhancement device that has been used for a while. Fin size optimization is crucial since there is a rising need for fins that are lightweight, thin, and economical. In order to maximize heat extraction while using the least amount of material, fins must be developed while taking into account their simplicity of construction. As a result of each disturbance, the thermal boundary layer is reset, which results in an improvement in heat transfer coefficient. An example of a surface disturbance is embossed patterns on fin plates. The purpose of this study is to examine the temperature decrease across several embossed spherical structures on a rectangular fin with various patterns. Examining fins with an embossed surface involves numerical simulation (ANSYS Fluent code). Additional factors like heat flow and thermal gradient are contrasted over on the continuity of an embossed spherical structure on a rectangular fin. In addition to an improvement in heat transport, it was seen that the temperature dropped significantly. The design of rectangular fin heat exchangers may be improved using the findings.

Keywords: Rectangular fin, Steady State Thermal, ANSYS, Heat flux, Temperature, embossed spherical structure

INTRODUCTION

One of a motor's essential parts, or, to put it another way, high temperature versions and heated loads, is the cylinder. To speed up the rate of heat exchange and cool the cylinder, blades are positioned on its surface. Convective and conductive cooling of different types of structures is done via balances, which are primarily mechanical systems. The warmth transfer in IC motors is notably improved by expanded blades. Construction of air-cooling systems is very simple. In order to achieve consistent temperature in the engine cylinder, it is essential for an air-cooled motor to use the blades appropriately. When a fuel ignites in a flame chamber, a motor is said to be inner burning. Here, the dispersion of the high-temperature and heavy-weight gases created by burns provides coordinated power to a component of the motor, such as a combustion chamber, turbine blades, or a spout. This power converts the section into a separation, generating useful mechanical energy. Although air-cooled motors have lost ground on water-cooled motors in terms of efficiency, all motorbikes continue to utilize air-conditioned engines due to their less weight and lower space requirements. Additionally, a cycle of heat evacuation must be carried out after switching from heat-to-heat control. Warmth is transmitted to the weather by means of liquids like air and moisture. The environment is warmed by engines that use low-temperature liquids. Because of the combustion process, the engine's temperature changes while it is running. If the extra heat is not dissipated, the high temperatures will eventually cause the motor's components to fail.

The temperature of the planet is rising. Heat exchange fins are used to regulate temperature in heat sinks or radiators that trap carbon. When studying heat exchange, fins are surfaces that accelerate convection to or from the earth at a faster pace. By raising the temperature angle between the protest and the soil, the convective heat exchange coefficient, or the protest's surface area, the heat exchange may be extended. Increasing the surface area of a protest by adding a balance might be a workable fix for heat transmission issues.

LITERATURE REVIEW

Various researches carried out in past decade shows that heat transfer through fin depends on number of fins, fin pitch, fin design, wind velocity, material and climate conditions.

Abdul Razak Kaladgi, Faheem Akhtar et al. (2021) Fins are a kind of heat transfer enhancement device that has been used for a while. Fin size optimization is crucial since there is a rising need for fins that are lightweight, thin, and economical. In order to maximize heat extraction while using the least amount of material, fins must be developed while taking into account their simplicity of construction. As a result of each disturbance, the thermal boundary layer is reset, which results in an improvement in heat transfer coefficient. Examples of surface disturbances include fins' perforated plates. This study's objective is to examine how temperature decreases through various circular holes. The examination of fins with perforations uses numerical simulation (ANSYS Fluent code). Equations for turbulent air flow and heat transfer between fins are solved with the help of an FVM programme. Other parameters like heat flow and thermal gradient are compared across a range of circular perforation counts. In addition to an improvement in heat transport, it was seen that the temperature dropped significantly. The design of rectangular fin heat exchangers may be improved using the findings

Chandrakant R Sonawane, Pratyush Rath et al. (2021) The engine is the most crucial component of a car, thus it must be maintained in good operating order under all sorts of weather situations. In order to prevent thermal breakdown and damage to the engine, the heat produced within the combustion chamber must be expelled. At the same time, it is crucial to maintain the temperature inside the chamber at the ideal level needed for combustion to occur. Numerous variables, including the wind speed, the temperature outside, the fins' design, their material, and their exposed surface area, may affect how well they cool an object. The engine maker plans to manage all conceivable variables, such as fin thickness, fin shape, and fin orientation, in order to get a desired result, even if only a few characteristics cannot be adjusted. This research presents a numerical simulation of the finned cylinder to increase the engine's heat dissipation rate. The model is created using Autodesk Fusion 360, and the steady-state thermal analysis is done using ANSYS.

S.K. Mohammad Shareef, M Sai Vikas et al. (2021) Thermal stress and temperature variations are experienced by engine cylinders. On engines, fins are used to increase the rate of heat transmission. The engine cylinder's surface is covered with fins to speed up heat transmission. By increasing its surface area, engine cylinder fins may dissipate heat more quickly. The primary goal of the current numerical inquiry is to evaluate the engine cylinder's thermal characteristics by modifying the shape, composition, and profile of the cylinder fins using Ansys workbench. SolidWorks is used to assist in the creation of the models.

Faheem Akthar, Abdul Razak Kaladgi et al. (2021) Fins have been used for a very long time to enhance heat transmission. A variety of metals, including copper, silver, mild steel, and stainless steel, are used to make fins. As the technology for fins (extended surfaces) develops, new design ideas have emerged, including composite fins, porous materials, interrupted, and perforated plates. Due to the growing need for compact, tiny, and affordable fins, fin size optimization is essential. Because of this, fins need to be designed to extract the most heat from the least amount of material while yet being simple to manufacture. Many different things may have contributed to the rise in heat transfer coefficient. The improvement in heat transfer coefficient is connected to the resetting of the thermal boundary layer after each disturbance. Fins' perforated plates are an example of surface disruption. Estimating the temperature drop through many circular holes is the goal of this paper. Over a range of circular perforation counts, other factors including heat flow and thermal gradient are compared.

S. Padmanabhan, S. Thiagarajan et al. (2021) Many studies on the fin's shape and material have been conducted recently to improve its use. Rectangular, triangular, and trapezoidal fin configurations were favoured in many situations where fins are utilised to speed up the rate of heat transfer from the system. The enlarged surfaces that are purposefully placed in a location from which heat is to be removed are known as fins. The amount of conduction, convection, or radiation a component has affects how much heat it emits. Heat transmission rises when the soil's surface area, the convection of heat coefficient, and the ambient temperature differential between the substance and the atmosphere all rise. This research article examines a numerical analysis for various profiles using aluminium as the material. In order to examine the steady-state temperature distribution at various fin lengths and the rate of heat transfer of these fin materials, an analytical approach was used. The results were then confirmed using CFD analysis. Various fin elements with rectangular and trapezoidal geometries are being investigated, and the best and most suitable material is chosen based on the environmental factors.

B.J. Patil et al. (2021) The key component and beating heart of the engine is the cylinder. The cylinder must have the durability to withstand extreme heat loads and temperature swings. Fins are positioned on the cylinder's surface in order to speed up heat transmission and help cool the cylinder. To determine how much heat is dissipated within the engine cylinder, thermal study of the cylinder fins is useful. On the cylinder's outside, fins are installed to help in heat transfer. We can determine the heat transfer rate by doing a thermal examination of fins. In many applications, including cooling, the fluctuation in temperature distribution over time is of interest. Critical design parameters may be able to be found for better life with the use of a realistic thermal simulation.

GEOMETRY SETUP AND MODELLING

A. Assumptions for analysis

A Steady state thermal analysis calculates the effect of steady thermal load on a system or component, analyst was also doing the steady state analysis before performing the transient analysis. We can use this analysis to determine temperature, thermal gradient, heat flow rates and heat flux in an object that do not vary with time. A Steady state thermal analysis may be either linear with constant material properties or nonlinear with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so analysis is usually nonlinear.

- The temperature of the surrounding air does not change significantly.
- Constant heat transfer coefficient is considered at the air side.
- The heat generation is neglected.
- Loads are constant.
- Most of physical properties are constant

B. Geometry of membrane

The rectangular fin’s geometry was constructed using the CATIA V5 software. Fig. 1.1 shows a simplified CADD diagram of the research rig-based simulation system. The geometry for doing simulation analysis is borrowed from **Abdul Razak Kaladgi et al. (2021).** The rectangular fin's dimensions are the same as the base paper and it has a 15 mm thick and 150 mm long geometry with dimple embossing and modified dimple embossing.

A rectangular fin with modified geometry is using for the analysis. We are embossing the spherical structure and modifying it with holes that have 4x5 and 5x5 pattern using CATIA V5 software. The dimension of the fin is shown in the table I.

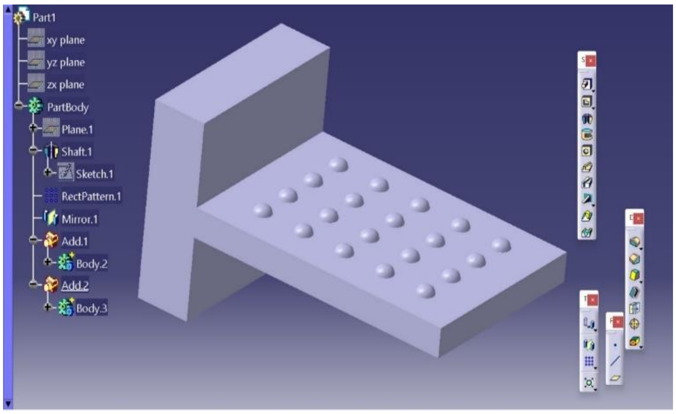

Fig. 1.1 Geometrical Dimensions of the rectangle-shaped fin's embossed spherical shape with 4x5 pattern.

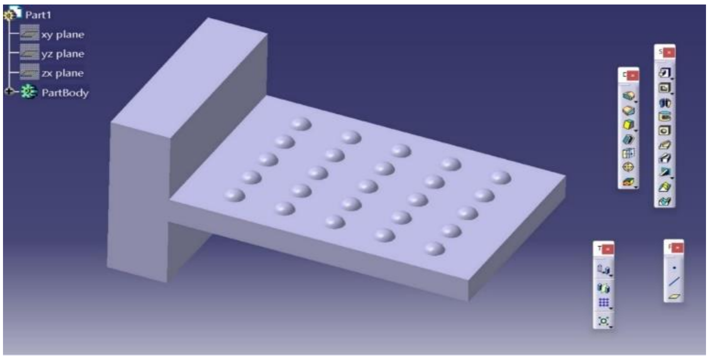

Fig. 1.2 Geometrical Dimensions of the rectangle-shaped fin's embossed spherical shape with 5x5 pattern.

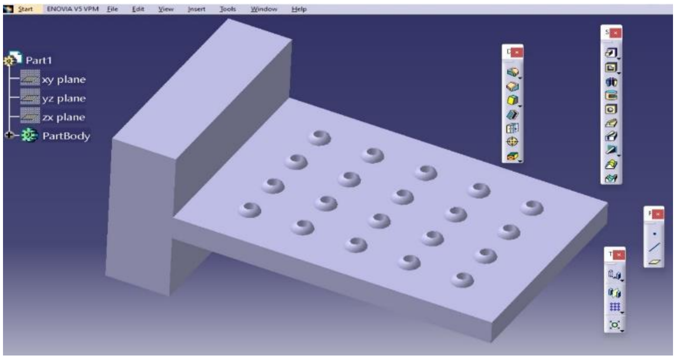

Fig. 1.3 Geometrical Dimensions of the rectangle-shaped fin's embossed modified Spherical shape with 4x5 pattern.

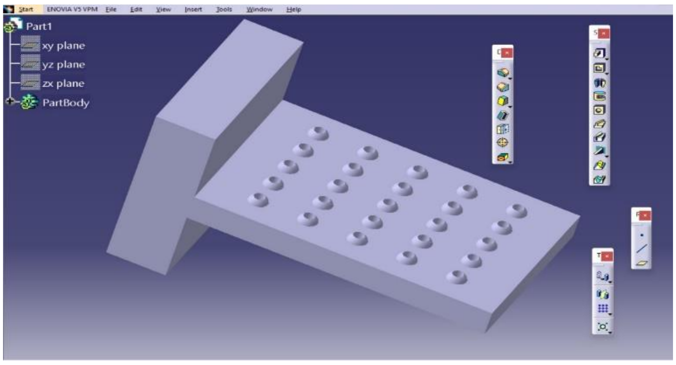

Fig. 1.4 Geometrical Dimensions of the rectangle-shaped fin's embossed modified Spherical shape with 5x5 pattern.

Our research analyzes what a realistic solution would be for the highest heat dissipation from rectangular fin by first identifying the factors that have the most influence on heat transfer and then providing an ideal combination of those variables using an optimization approach. The elements that influence the heat transfer of engine fins are chosen from a large set based on findings gained from a survey of the literature.

Geometrical dimension of the rectangular fin having 15 mm thickness with dimple surface & modified dimple surface given the below table.

TABLE I

Geometry Parameters

S.N.	**Parameter of rectangular fin**	**Value**
1	Length of the rectangular fin	150 mm
2	Width of the rectangular fin	30 mm
3	Thickness of rectangular fin	15 mm
4	Embossed spherical shape with minor axis	3 mm (radius)
5	Embossed spherical shape with major axis	5 mm (radius)
6	Modified Embossed spherical shape hole dimension	2.5 mm (radius)

TABLE III

Properties of the Aluminium Alloy 6061

S.N.	**Materials properties**	**symbol**	**values**
1.	Thermal conductivity	**k**	236 Wm^{-1}K^{-1}
2.	Thermal expansion	**α**	2.32 e^{-5} /K^{-1}
3.	Density	***ρ***	2.7 e^{-3} g/mm^{3}

C. Meshing of geometry

The ANSYS 22R1 pre-processor stage resulted in the creation of a three-dimensional discretized model. The programmed ANSYS creates a fine mesh despite the fact that grid types and simulation results are connected. The final volume discretizes the whole structure as a result of this need. Small-scale ICEM The mesh is composed of Quadratic cells with triangular border faces. In this experiment, a medium fluid curvature and a mesh metric are both employed.

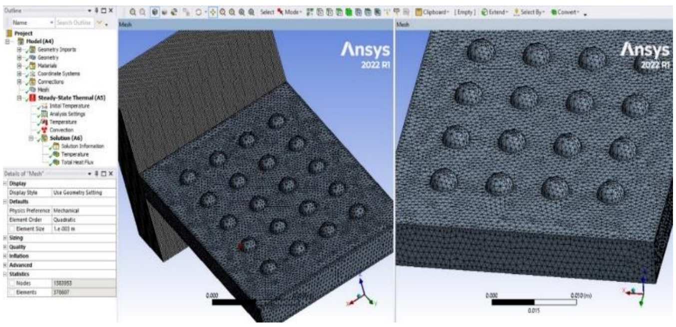

Fig. 1.5. Meshing of Rectangular fin having embossed spherical shape with 4x5 pattern

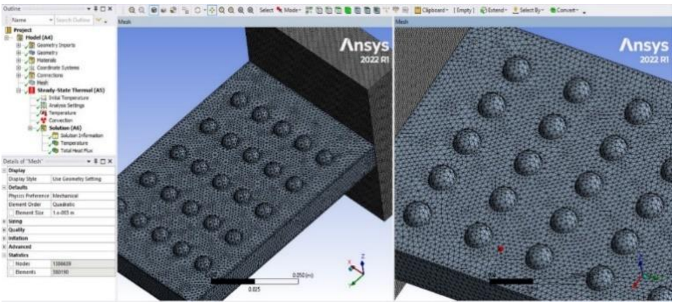

Fig. 1.6. Meshing of Rectangular fin having embossed spherical shape with 5x5 pattern

After meshed the model of rectangular fin having embossed spherical shape, we will mesh another geometry of rectangular fin having embossed spherical shape with 5mm diameter hole.

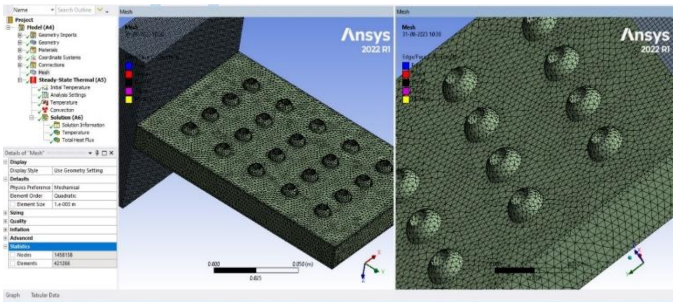

Fig. 1.7. Meshing of Rectangular fin having embossed spherical shape with 4x5 pattern with hole of 5 mm diameter.

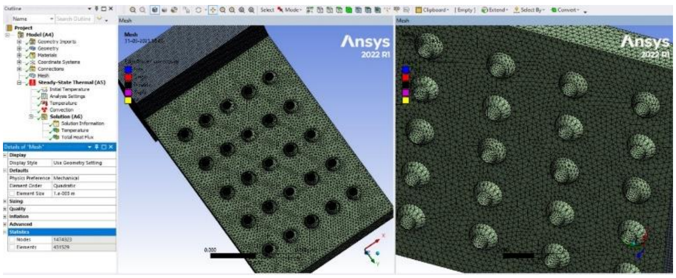

Fig. 1.8. Meshing of Rectangular fin having embossed spherical shape with 5x5 pattern with hole of 5 mm diameter.

D. Technique

After geometry and meshing are successfully finished, setup comes next. In steady-state thermal analysis, the temporal equilibrium of a system with a steady temperature is assessed. To put it another way, steady-state thermal assessment evaluates the level of equilibrium of a system under steady thermal loads and ambient variables. Linear steady-state analysis, in which input characteristics like material qualities are designated to be autonomous variables, is the most basic kind of steady-state analysis.

TABLE IIIII

Meshing detail of model of embossed spherical shape

S. No.	Parameters	With 4X5pattern	With 5X5 pattern
1	Curvature	On	On
2	Smooth	High	High
3	Number of nodes	1383953	1386639
4	Number of elements	378607	380190
5	Mesh metric	None	None
6	Meshing type	Quadratic	Quadratic
7	Element size	1 mm	1 mm

TABLE IVV

Meshing detail of model of embossed spherical shape with hole

S. No.	**Parameters**	**With 4X5pattern**	**With 5X5 pattern**
1	Curvature	On	On
2	Smooth	High	High
3	Number of nodes	1458158	1474323
4	Number of elements	421266	431529
5	Mesh metric	None	None
6	Meshing type	Quadratic	Quadratic
7	Element size	1 mm	1 mm

RESULTS AND DISCUSSIONS

This section is aimed at evaluating the engine cylinder block with modified geometry. The variations in the temperature distribution and heat flux are measured at different modified geometry of cylinder block in order to research the rate of heat transfer

A. Boundary Conditions

Steady state thermal analysis was used to calculate the temperature dispersion and heat flux of rectangular fins with embossed spherical surfaces and modified fins with holes of the same surface. An aluminium alloy was used for the experiment. The following designs of rectangular fins with different spherical surface were investigated to determine which was the best:

a. Rectangular Fins with embossed spherical shape.

b. Rectangular Fins with embossing’s and holes

Following are the simulation's boundary conditions: inlet uniform velocity, estimated temperature, and 10% turbulence intensity. The flow has developed entirely at the outflow. There are non-slip surfaces on the channel and fin walls. A grid independence test was run to see if mesh size had an impact on the outcomes. It was contrasted and studied how the outcomes of four different grid sizes. The results indicated minimal variation in the answer for a certain grid size, it was discovered. Therefore, as seen in Table III & IV, this mesh size was decided upon and used in further research. The convergence criterion for velocity, k, energy, and e is 10^{-4} & 10^{-6}, respectively.

TABLE V

Details of boundary conditions

Detail	**Value**
Rectangular fin	Aluminum Alloy
Thermal model	steady state thermal modal
Film co-efficient	5.489 Wm^{-2} C^{-1}
Inter connected wall of rectangular fin	200^0C

B. Analyse the modified fin geometry

Now, we are modified the rectangular fin geometry. We are providing the embossed spherical shape on the both side surface of the rectangular fin with different pattern & also create modification on the embossed spherical shape. After that apply the same criteria as mention the base paper & find out the value of minimum temperature distribution & heat flux with the help of CFD.

In first scenario, we are using 4x5 pattern of embossed spherical shape on the rectangular fin.

- **Using embossed spherical shape on the both side surface of rectangular fin (4x5 pattern)**

In the case first, we are using embossed spherical shape on the both side surface of rectangular fin & apply the aluminium alloy as a material of the fin. The embossed spherical surface having 4x5 pattern. The boundary condition is applied as same as the base paper.

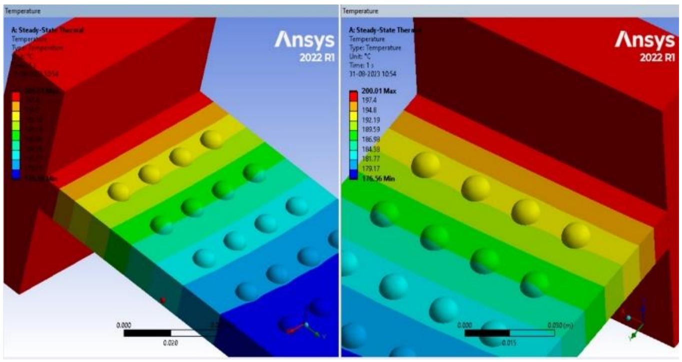

Fig. 1.9. Temperature contour of embossed spherical shape with 4x5 pattern on rectangular fin

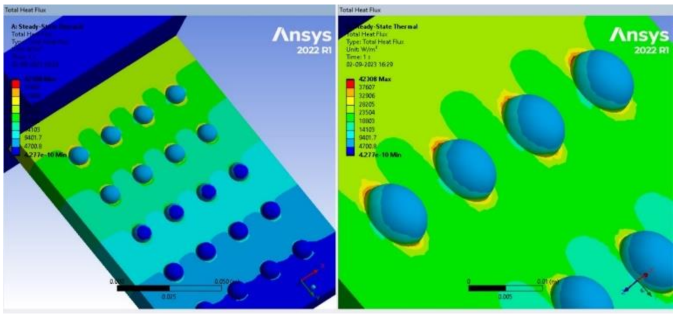

Fig. 1.10. Heat flux contour of embossed spherical shape with 4x5 pattern on rectangular fin

- **Using modified embossed spherical shape on the both side surface of rectangular fin (4x5 pattern)**

In the case second, we are using embossed spherical shape with hole of 5mm diameter on the both side surface of rectangular fin & apply the aluminium alloy as a material of the fin. The embossed spherical surface having 4x5 pattern. The boundary condition is applied as same as the base paper.

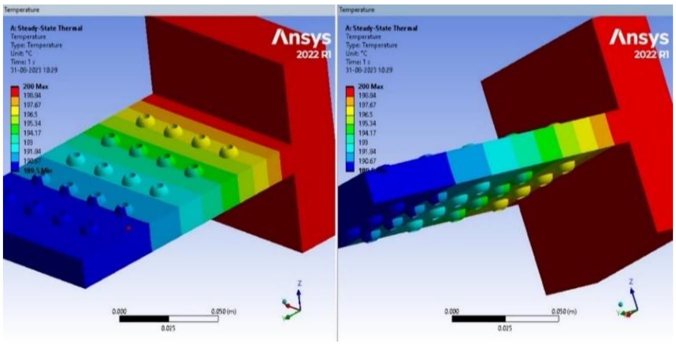

Fig. 1.11. Temperature contour of modified embossed spherical shape with 4x5 pattern on rectangular fin

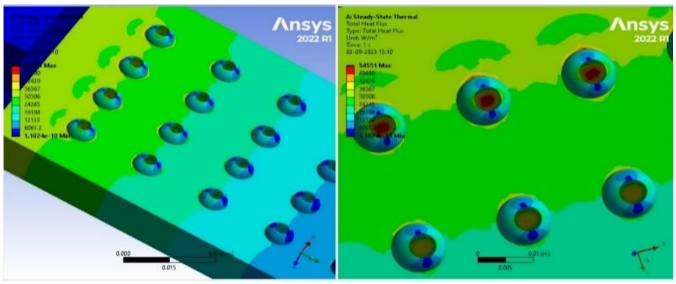

Fig. 1.12. Heat flux contour of modified embossed spherical shape with 4x5 pattern on rectangular fin

In Second scenario, we are using 5x5 pattern of embossed spherical shape on the rectangular fin.

- **Using embossed spherical shape on the both side surface of rectangular fin (5x5 pattern)**

In the case third, we are using embossed spherical shape on the both side surface of rectangular fin & apply the aluminium alloy as a material of the fin. The embossed spherical surface having 5x5 pattern. The boundary condition is applied as same as the base paper.

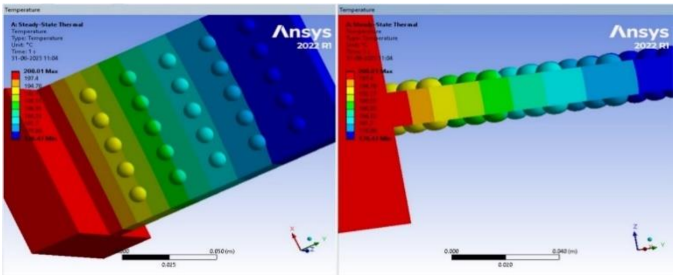

Fig. 1.13. Temperature contour of embossed spherical shape with 5x5 pattern on rectangular fin

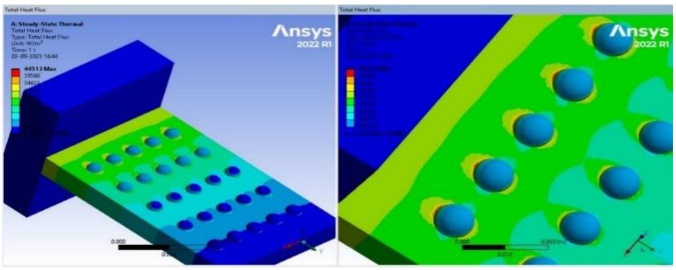

Fig. 1.14. Heat flux contour of embossed spherical shape with 5x5 pattern on rectangular fin

- **Using modified embossed spherical shape on the both side surface of rectangular fin (5x5 pattern)**

In the last case, we are using embossed spherical shape with hole of 5mm diameter on the both side surface of rectangular fin & apply the aluminum alloy as a material of the fin. The embossed spherical surface having 5x5 pattern. The boundary condition is applied as same as the base paper.

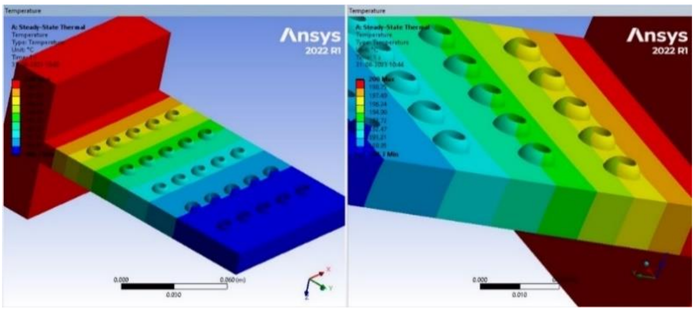

Fig. 1.15. Temperature contour of modified embossed spherical shape with 5x5 pattern on rectangular fin

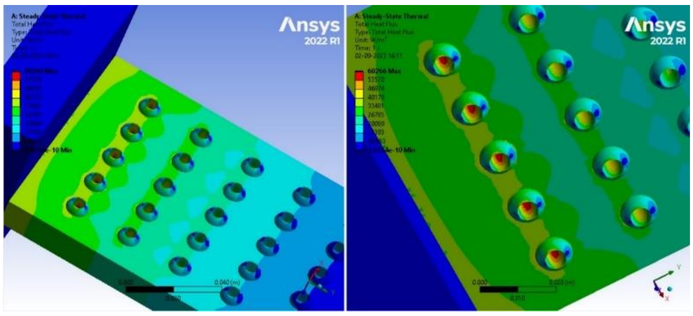

Fig. 1.16. Heat flux contour of modified embossed spherical shape with 5x5 pattern on rectangular fin

C. Effect of the modified geometry of rectangular fin

It is evident from the numerical findings and experimental evidence that the minimum temperature distribution tendencies are qualitatively consistent. As a result, we use different pattern of embossed spherical shape (4x5 and 5x5) with simple shape or modified shape and analyze the impact of the temperature variation at tip of the fin section. The boundary conditions used in this study were same. Table II makes reference to the material characteristics of rectangular fin for determining the impact of heat distribution on the fin.

Table VI Shows the comparison values of temperature distribution & heat flux calculated from the CFD modelling using embossed spherical shape and modified embossed spherical shape geometry on rectangular fin with different pattern.

TABLE VI Meshing detail of model of fin (3 mm thick)

S. No.	**Modified geometry**	**Temperature Distribution at the tip of the fin (^{0}C)**	**Heat flux ($Wm^{-2}\,^0C$)**
		Min.	**Max.**
1	Rectangular fin	191.57	32689
2	Rectangular fin with embossed spherical shape (4x5 pattern)	176.56	42308
3	Rectangular fin with modified embossed spherical shape (4x5 pattern)	189.50	54551
4	Rectangular fin with embossed spherical shape (5x5 pattern)	176.47	44513
5	Rectangular fin with modified embossed spherical shape (5x5 pattern)	188.70	60266

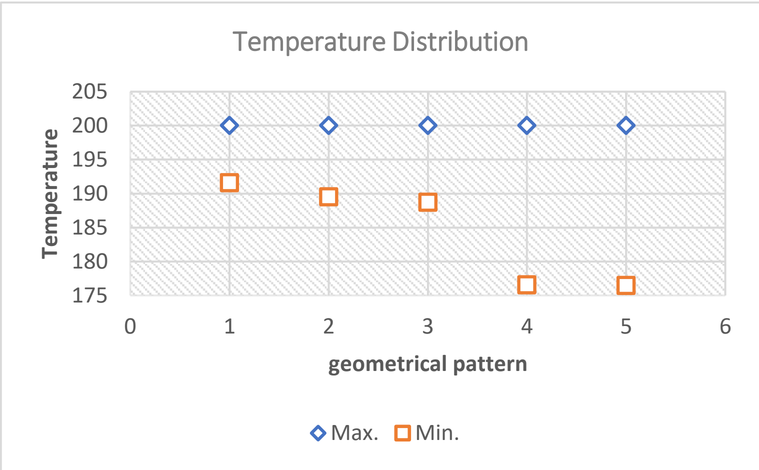

Fig. 1.17. Temperature distribution at the tip of the rectangular fin with embossed spherical structure

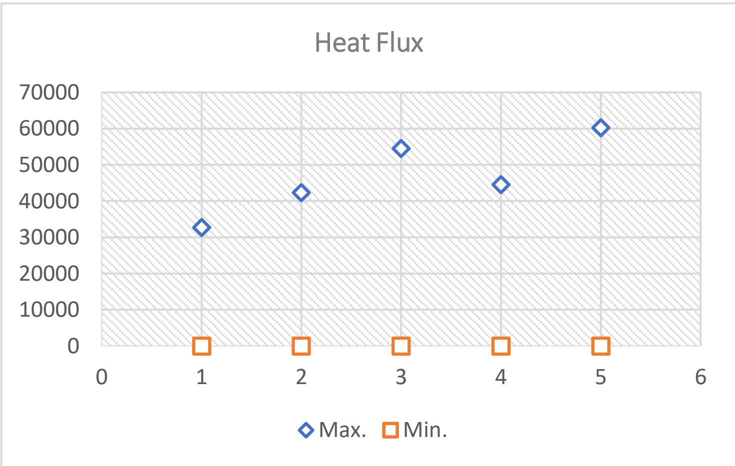

Fig. 1.18. Maximum Heat flux distribution of the rectangular fin with embossed spherical structure

CONCLUSIONS

Fins and other heat transfer enhancement tools have been used for a while. Fin size optimization is crucial due to the rising need for inexpensive, lightweight, and thin fins. After going CFD analysis through the comparison charts shown in the above, we can see that the results are quite encouraging. From the CFD analysis by using properties and boundary conditions the following conclusions are made:

- The embossed spherical shape on surface of the fin with a 4x5 and 5x5 pattern maintains the lowest temperature at the tip of the fin, as seen in the aforementioned graph (Figure 6.16) and table (6.2). For the 4x5 pattern and the 5x5 pattern, the temperature at the tip of the fin was 176.47 °C and 176.56 °C, respectively.
- The lowest temperature will also drop by roughly 0.05% if the embossed spherical form pattern on the fin surface is changed from 4x5 to 5x5.
- After modifying the embossed spherical form with a hole on the fin's surface, we saw that the lowest temperatures at the tips of the fin for 4x5 and 5x5 patterns were 189.50°C and 188.70°C, respectively, which is increase about 0.423%.
- We note that 60266 Wm-2 0C, or the maximum heat flux, is present in the modified embossed spherical form with 5x5 pattern. We have found that the heat flux rises whenever we change the pattern set or modified these patterns set.
- The embossed spherical shape and modified this shape with hole for the 4x5 pattern, the maximum heat flux found 42308 W/m2 0C and 54551 W/m2 0C respectively. And similarly, for the 5x5 pattern the maximum heat flux found 44513 W/m2 0C and 60266 W/m2 0C respectively. And similarly
- The maximum heat flux was determined to be 42308 W/m2 0C for the embossed spherical form and 54551 W/m2 0C for the modified with a hole for the 4x5 pattern, which is an increase of roughly 28.93%. And similarly, for the 5x5 pattern it in increasing about 35.38%.

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