DESIGN AND ANALYSIS OF FINS USING FINITE ELEMENT ANALYSIS

A project report submitted in partial fulfillment of the requirements for the Award of the Degree of

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

by

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CERTIFICATE

This is to certify that the Project Report entitled "**Design and Analysis of Fins using Finite Element Analysis**" has been carried out by **K.Lalith Shankar(315126520281)**, **A.Durga Prasad (315126520239)**, **V.Sai Mohan(315126520233)**, **L.Venkata Sai(315126520273)**, **Y.Aneel Chandra(315126520286)**, in partial fulfillment of the requirements of award of Degree of **Bachelor of Technology in Mechanical Engineering of ANITS (A)**. It is a record of bona fide work carried out under the esteemed guidance and supervision of **Dr. K. SIVA PRASAD**, Professor Department of Mechanical Engineering-ANITS during the academic year 2018-2019.

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It is a privilege for us to submit project report on **DESIGN AND ANALYSIS OF FIN USING FINITE ELEMENT ANALYSIS** submitted to MECHANICAL ENGINEERING SECTION in partial fulfillment for the award of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING** from **ANIL NEERUKONKDA INSTITUTE OF TECHNOLOGICAL SCIENCES-SANGHIVALASA.**

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ABSTRACT

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or environment to maintain the system in a steady state condition. In many engineering applications large quantities of heat has to be dissipated from small areas. Heat transfer by convection between the surface and fluid surrounding it can be increased by attaching to surface thin strips of metal called fins. The fins increase the effective are of surface thereby increasing the heat transfer by convection. The fins are also referred as 'extended surfaces'.

The fins are designed and manufactured in many shapes and forms. They are manufactured in different geometries depending upon the practical applications. The shape of fins must be optimized such that the heat transfer density is maximized when the space and materials used for finned surfaces are constraints in present day applications.

There is a necessity for investigation of temperature distribution in a fin as thermal management is critical aspect of design process. As miniaturization continues the solutions of providing the best heat transfer for today's modern is important. In present work analysis of cylindrical fin was done.

The project aims to analyze the temperature distribution along the length of cylindrical fin of various geometric forms made of different materials which is 150mm in length. The work includes the calculation of experimental values of temperature distribution for cylindrical fin of 12mm diameter and 150mm length which is made of aluminuim using forced convection. The work also includes the calculation of theoretical values of temperature distribution of pin fin of various cylindrical shapes. Theoretical, Experimental, FEA analysis of fin was carried out and results were compared. The 3D solid modeling of pin fin is carried out using SOLID WORKS and imported into ANSYS15.0 for calculation of temperature distribution.

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NOMENCLATURE

A	Area, m2
A_g	Geometric mean area,m^2
A_m	log mean area,m^2
B_i	Biot number
C_p	Specific heat at constant pressure, J/kg K
C_v	Specific heat at constant volume, J/kg K
D, d	Diameter, m
G_r	Grashof number
g	Gravitational acceleration, m/s^2
I	Electric current, A; radiation intensity W/m^2 sr
k	Thermal conductivity, W/m K
m	Mass, kg
N	Number of surfaces in an enclosure
N_u	Nusselt number
NTU	Number of transfer units
P	Perimeter, m
P_e	Peclet number
P_r	Prandtl number
p	Pressure N/ m^2
Q	Heat transfer rate, W
Q_g	Heat generation, W
R_e	Reynolds number
St	Stanton number
T	Temperature ,K
s	Time, seconds ; thickness, m
U	Overall heat transfer coefficient
u,v,w	Fluid velocity ,m/s
V	Volume , m^3
v	Specific volume, m$^{3\ /kg}$
W,w	Width, m
X,Y,Z	Dimensionless coordinates
α	Thermal diffusivity, m^2/s
β	Volumetric thermal expansion coefficient 1/K
ε	Heat exchanger effectiveness
η	Similarity variable
η_{fin}	Fin efficiency
σ	Stefan boltzman constant W/ m^2 K^4
cond	Conduction
conv	Convection
sat	Saturated conditions
ss	Stainless steel

CHAPTER I

INTRODUCTION

1.1 Introduction to fins

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or environment to maintain the system in steady state condition. In many engineering applications large quantities of heat have to be dissipated from small areas. Heat transfer by convection between a surface and fluid surrounding it can be increased by attaching to the surface thin strips of metal called fins. The fins increase the effective area of the surface thereby increasing the heat transfer by convection. The fins are also referred as ‘extended surfaces’. Fins are manufactured in different geometries, depending upon practical applications.

The fins may be uniform or variable of cross section. They have many different practical applications, viz., cooling of electronic components, cooling of motor cycle engines, compressors, electric motors, transformers, refrigerators, high efficiency boiler super heater tubes, etc. Solid gas turbine blades are often acts as fins, conducting heat down their length to cool the disc. Use of fin theory is also made in estimating the error in temperature measurement by thermometers or thermocouples. Kern and Krause give a very detailed account of extended surface of heat transfer.

The problem of determination of heat flow through a fin required the knowledge of temperature distribution through it. This can be obtained by regarding the fin as a metallic plate connected at its base to a heated wall and transferring heat to fluid by convection. The heat flow through the fins is by conduction. Thus the temperature distribution in a fin will depend upon the properties of both the fin material and the surrounding the fluid.

The Fin is a major component used in many systems for increasing the rate of heat transfer. In order to cool the system, fins are provided on the surface of the system to increase the rate of heat transfer. By doing thermal analysis on the fins, it is helpful to know the heat dissipation and rate of heat transfer in different types of fin. We know that, by increasing the surface area of pin configuration we can increase the heat dissipation rate of this process, so designing such a large complex systems is very difficult. Therefore fins are provided on the surface of the system to increase heat transfer. A fin of circular, square and rectangular surface that extends from a pin configuration to increase the rate of heat transfer from the environment by increasing convection. For this principle of conduction, convection, radiation of a fin configuration determines the amount of heat and its transfers. Increasing the temperature difference between the fin configuration and the depends on the environment, slightly increasing the convection heat transfer coefficient, or slightly increasing the surface area of the pin configuration 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 configuration, however, increases the surface area of circular, square and rectangular can sometimes be economical solution to heat transfer problems.

1.2 Definition of a fin

Fins are the extended surface protruding from a surface or body and they are meant for increasing the heat transfer rate between the surface and the surrounding fluid by increasing heat transfer area. Sometimes they are also referred as ‘ Extended surfaces ’.

Fig 1.1 Fin

1.3 Working principle

1. In many engineering application, large quantities of heat have to be dissipated from small areas.
2. The fins increase the effective area of surface thereby increasing the heat transfer by convection.
3. In other words, the shape of fin must be optimized such that the heat transfer density is maximized when the space and materials used for dins are constraints.

1.4 Methods of incresing heat transfer

1. By increasing the surface area in contact with air or providing fins.
2. By increasing the heat transfer coefficient for the surface.
3. By increasing the temperature of hot surface or by increasing the temperature difference between the hot and cold bodies.

1.5 Types of fins by design

The fins are designed and manufactured in many shapes and forms. They are manufactured based on parametrical applications.

1. The ribs attached along the length of tubes are termed as ‘ Longitudinal fins ‘
2. The concentric annular or disc around a tube are termed as ‘ Circular or Annular fins ‘
3. Pin fins or spines are rods protruding from a surface

1.5.1 Straight fins

A straight fin is any extended surface that is attach to plane wall it may be uniform sectional area or its cross-section area varies with distance x from the wall.

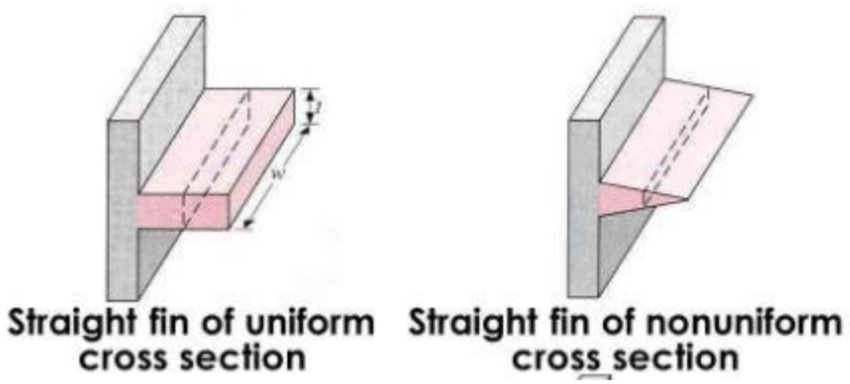

Fig 1.2 Straight fins

1.5.2 Annular fins

An annular fin is one that is circumferentially attached to the cylinder and its cross-section varies with radius from the wall of the cylinder.

Fig.1.3 Annular fin

1.5.3 Trapezoidal fins

Heat is transferred by convection between a surface and the fluid surrounding can be increased by attaching to the surface thin metallic strips.

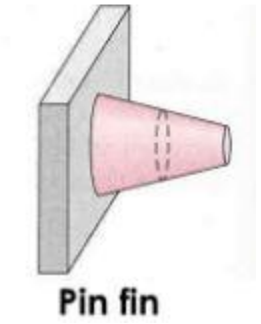

Fig.1.4 Trapezoidal fin

1.6 `Applications of fins

1. Common applications of finned surfaces are with cooling of electronic components.
2. Condensers and economizers of thermal power plant
3. Radiators for automobiles
4. Dry type cooling towers
5. Air cooled cylinders of compressors, IC engines
6. Evaporators and condensers of refrigeration and air conditioning system

Fig.1.5 Transformer fins

Fig.1.6 Electronic cooling

1.7 Advantages of fins

1. Heat transfer rate can be increased without any preventive maintenance by using fins
2. It is the cheapest way for increasing the heat transfer from hot bodies.

1.8 Disadvantages of using fins

1. The larger length of fin causes bending of fin
2. The larger length of fin also increases in weight of engine.
3. The overall efficiency will go down with increase in length

1.9 Fins performance

Fins performance can be described in three different ways

1.9.1 Fin effectiveness

Fin effectiveness is the ratio of fin heat transfer rate to the heat transfer rate of object if it had no fin

1.9.2 Fin efficiency

This is ratio of the fin heat transfer rate to the heat transfer rate of fin if the entire fin was at base temperature that is fin with infinite thermal conductivity

The fin efficiency is always less than one.

1.9.3 Overall surface efficiency

The overall surface efficiency is the ratio of total heat transfer of all fins to heat transfer of fins if there were no fins

1.10 Materials used for fins

There are abundant materials available on earth for making fins but a few serve our purposes let us see some of the common materials used for fins

1.10.1 Aluminium

These properties of aluminium make it suitable for using as fin. They are listed below.

1. Good corrosion resistance
2. Formability
3. High thermal conductivity
4. Good endurance under normal environmental conditions
5. Marine quality aluminium has improved resistance to humid and salty conditions.

Applications

1. Residential applications

2. Vehicles of all kind
3. Large coils of central system
4. Freeze and deep freeze
5. Coils of mining equipment, marine equipment

1.10.2 Copper

The properties of copper which makes it suitable as fin material are listed below

1. High thermal conductivity
2. Resistance to air and water corrosion superior to aluminium
3. Mechanical strength
4. Maximum service life

Applications

1. Coolant for special industrial machines
2. High technological environment

1.10.3 Bronze

The properties of bronze which make them suitable as fin material are listed below

1. Stronger and harder than copper
2. Good conductor of heat
3. Formability, low cost, low weight, long life
4. Corrosion resistant to salt water

Applications

1. Radiators

1.10.4 Bronze

The properties of bronze which make it suitable as fin material are listed below

1. Highly ductile
2. Corrosion resistance to salt waters
3. Can be used in explosion and flammable environments

Applications

1. Under water applications
2. Electrical equipment

1.10.5 Stainless steel

The properties of stainless steel which make it suitable as fin material are listed below

1. Low cost, light weight
2. Superior corrosion resistance and high reliability
3. Good heat transfer performance
4. Fast, complete, energy efficient defrosting
5. Excellent clean ability

Applications

1. Heat exchangers

1.11 Physical properties of various materials

Tab 1.1 Physical properties of various materials

Material	Temperature	Thermal conductivity	Density	Specific heat
Aluminium	27 º C	177.7 W/m-k	2770 Kg/ m^3	875 J kg^{-1} C^{-1}
Copper	27 º C	401 W/m-k	8300 Kg/ m^3	385 J kg^{-1} C^{-1}
Brass	27 º C	110 W/m-k	8600 Kg/ m^3	162 J kg^{-1} C^{-1}
Silver	27 º C	429 W/m-k	10500 Kg/ m^3	235 J kg^{-1} C^{-1}
Stainless steel	27 º C	15.1 W/m-k	7750 Kg/ m^3	480 J kg^{-1} C^{-1}

1.12 Derivations and equations of fins

1.12.1 Governing equations of fins

Assumptions

1. Steady state conduction with no heat generation in the fin
2. Thickness is small compared to length and width, i.e. one-dimensional conduction in x-direction only
3. Thermal conductivity of fin material is constant
4. Isotropic (i.e. const. k in all directions) and homogeneous (i.e. const. density) material
5. Uniform heat transfer coefficient over the entire length of fin and the base wall
6. Negligible radiation effect

Differential equation

The principle heat conduction is along the x-axis whereas the convection loss takes place from the upper and under surfaces of the fin. Assuming the base temperature To, of the fin to be uniform and thermal conditions at the tip of the fin to be non-variant in z-direction, and a constant thermal conductivity of the fin material with its thickness to be small compared to its length, steady state conditions will prevail. Effectively, one-dimensional heat conduction will exist and the temperature distribution will be function of x-coordinate, the properties of the fin, and the convective heat transfer coefficient.

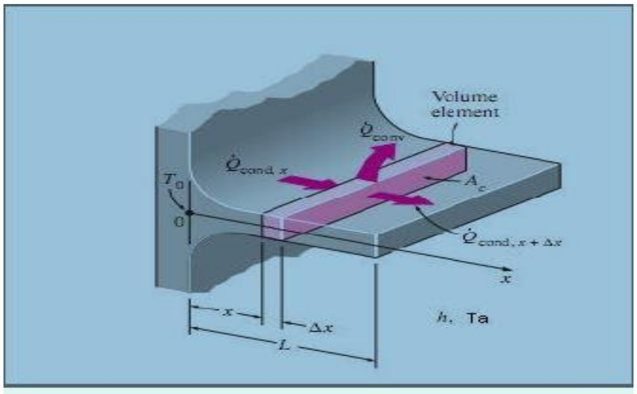

Fig.1.7 Governing equations of fin

To determine the governing equation of fin consider a differential element of the fin of length dx. Let Qx is the heat conducted in to the element along x-direction given by

$$\mathbf{Q_x = -KA\frac{dT}{dX}(from\ Fourier\ law\ of\ heat\ conduction)\ ---\rightarrow (1)}$$

Where k = thermal conductivity of fin material A_c= Area of cross section of the fin

Let Q_{x+dx}= heat conducted out of the element along x-direction

$$\mathbf{Q_{x+dx} = Q_x + \frac{\partial Q_x}{\partial x}\ dx ---\rightarrow (2)}$$

$Q_{convected}$ = heat transfer by convection from the surface of element to fluid

$$\mathbf{Q_{convected} = h(A_{convected})(T - T_\infty) \qquad ---\rightarrow (3)}$$

A_{conv} (convection area) = perimeter of fin length of element = P dx

T = temperature of differential element

Assume steady state conditions and writing the energy balance equations for the element

Heat conducted in to the element = heat conducted out of the element + heat convected from the element to fluid

$$\mathbf{Q_x = Q_{x+dx} + \ Q_{convected}}$$

$$\mathbf{Q_x = Q_x + \frac{\partial Q_x}{\partial x} + h(A_{convected})(T - T_\infty)\ \ [from\ eqation\ 1, 2, 3]}$$

$$\mathbf{0\ = \frac{\partial}{\partial x}(-KA\frac{dT}{dx})dx + \ h(P\ dx)(T - T_\infty)}$$

Assuming k constant, we get

$$\mathbf{\frac{dt^2}{dx^2} - \frac{hp}{KA_c}(T - T_\infty) = \ 0}$$

Put T - T_∞=0 , then

$$\mathbf{\frac{dT}{dX} = \frac{d\theta}{dx}\ and\ \frac{d^2t}{dx^2} = \frac{d^2\theta}{dx^2}}$$

This is a standard format of 2nd order differential equation in whose general solution can be given as

$$\mathbf{\Theta = C_1\ e^{-mx} + C_2 e^{mx}}$$

Where

$$m = \sqrt{\frac{hp}{KA_c}}$$

And C1 and C2 are constant of integration that are to be obtained from boundary conditions.

Note:

For pin fin, the values of Ac and P will be different

Two boundary conditions are required to solve for the unknown C1 and C2. Let us now consider three different cases of fins each yielding a set of two boundary conditions

1.12.1.1 Long fins

Boundary conditions:

(a) One common boundary condition is

At x = 0 (root), $T = T_o$ and $\Theta = \Theta_o = T_o - T_\infty$

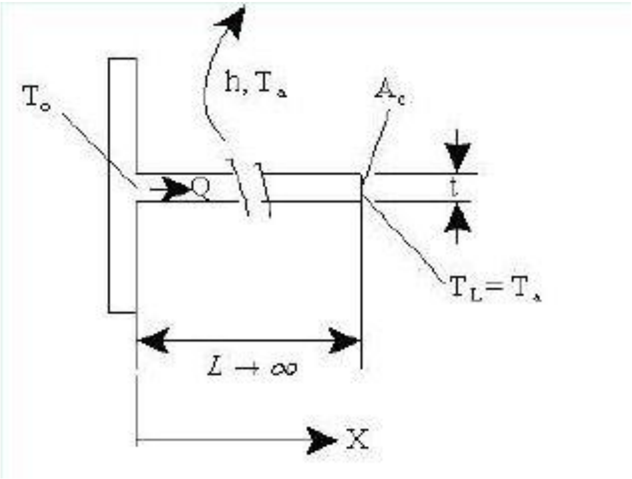

Fig.1.8 Long fins

The other boundary condition i.e. at the tip depends upon three different cases which are as follows:

When the fin is infinitely long then the temperature at the tip of the fin will be essentially that of the fluid.

Boundary conditions for fin infinitely long

At $x = \infty$, $\Theta = T_o - T_\infty = 0$

The mathematical formulation of the thin fin becomes

$$\boldsymbol{\frac{d^2\theta}{dx^2} - m^2\theta = 0 \quad x \geq 0}$$

The general solution is of the form

$$\mathbf{\Theta = C_1 e^{-mx} + C_2 e^{mx}}$$

$$\boldsymbol{\theta = T_o - T_\infty = \theta_o \; at \; x = 0}$$

$$\boldsymbol{\theta \rightarrow 0 \; as \; x \rightarrow \infty}$$

Applying the second boundary condition to the solution,$\Theta = C_1 e^{-mx} + C_2 e^{mx}$, we get

$$C_2 = 0$$

Then the application of first boundary condition gives

$C_1 = \Theta_o$, and the solution becomes $\Theta = \Theta_o e^{-mx}$

$$\boldsymbol{\frac{T - T_\infty}{T_o - T_\infty} = e^{-mx}}$$

After Knowing the temperature distribution, the heat flow through the fin is obtained either by integrating the heat lost by convection over the entire fin surface by the following relation

$$\int_0^\infty hP(\boldsymbol{T_o} - \boldsymbol{T}_\infty)dx$$

Or by evaluating the conductive heat flow at the fin base according to the relation

$$\boldsymbol{Q = -KA\left(\frac{dT}{dX}\right)_{x=0}}$$

using equations , we get

$$Q = \int_0^\infty hP\boldsymbol{\theta_o e^{-mx}}dx = \left[\frac{1}{m}hP(\boldsymbol{\theta_o e^{-mx}})\right]_0^\infty$$

$$= +\frac{1}{m}hP\theta_o = \sqrt{hPKA}\theta_o = \sqrt{hPKA}(T_o - T_\infty)$$

Now using the equations, we get

$$Q = mKA[\theta_o e^{-mx}]_{x=0} = mka\theta_o = \sqrt{hPKA}\theta_o = \sqrt{hPKA}(T_o - T_\infty)$$

Which is same equation.

1.12.1.2 Fin with insulated tip

Boundary conditions:

(a) One common boundary condition is

At x = 0 (root), T = T_o and $\Theta = \Theta_o = T_o - T_\infty$

The other boundary condition i.e. at the tip depends upon three different cases which are as follows:

When the fin tip is insulated then

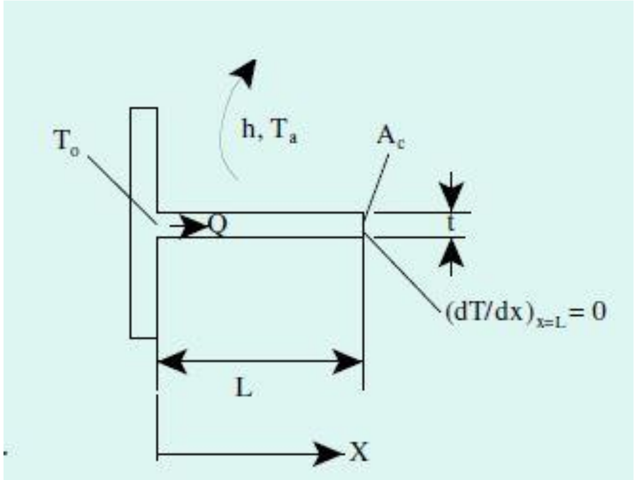

Fig.1.9 Fin with insulated tip

mathematical formulation of this problem becomes.

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \quad 0 \le x \le L$$

$$\boldsymbol{\theta = T_o - T_\infty = \theta_o \; at \; x = 0}$$

$$\boldsymbol{\frac{d\theta}{dx} = 0 \; at \; x = L}$$

To solve this situation, we start with the general solution

$$\Theta = C_1 e^{-mx} + C_2 e^{mx}$$

Application of first boundary condition gives

$$\Theta_o = C_1 + C_2$$

And applying the second boundary condition, we get

$$\boldsymbol{\frac{d\theta}{dx} = -mC_1e^{-mx} + mC_1e^{mx}}$$

$$\boldsymbol{0 \; = \; -mC_1e^{-mL} + mC_1e^{mL}}$$

$$\boldsymbol{C_1 = \; C_2e^{2mL}}$$

Combining Equations

$$\boldsymbol{\theta_o \; = \; C_2(1 + e^{2mL})}$$

$$\boldsymbol{C_2 = \frac{\theta_o}{(1 + e^{2mL})} \; and \; C_1 = \frac{\theta_o}{(1 + e^{-2mL})}}$$

$$\boldsymbol{\theta \; = \; \theta_o\left[\frac{\theta_o}{(1 + e^{2mL})} + \frac{\theta_o}{(1 + e^{-2mL})}\right]}$$

Equation can be written in a more compact form by multiplying the numerator and denominator of the first term on R.H.S by e^{ml} and those of the second term by e^{-ml}, giving

$$\boldsymbol{\theta \; = \; \theta_o\left[\frac{e^{-m(x-L)}}{(e^{mL} + e^{-mL})} + \frac{e^{m(x-L)}}{(e^{mL} + e^{-mL})}\right]}$$

$$\boldsymbol{\theta = \theta_o \left[\frac{e^{m(L-x)} + e^{-m(L-x)}}{(e^{mL} + e^{-mL})}\right] = \theta_o \frac{\cosh m(L-x)}{\cosh mL}}$$

Since $\boldsymbol{\cos h\, \beta} = \frac{e^{\beta}+e^{-\beta}}{2}$

$$\boldsymbol{\frac{T - T_\infty}{T_o - T_\infty} = \frac{\cosh[m(L-x)]}{\cosh(mL)}}$$

The heat flow Q is given by

$$\boldsymbol{Q = -KA\frac{d\theta}{dX}\bigg|_{x=0} = -KA\theta_o \frac{[-m \sin h\, m\,(L-x)]}{\cos h\, mL}\bigg|_{x=0}}$$

$$\boldsymbol{= -KAm\theta_o \tan h\,(mL)}$$

Note that equation reduces to above equation for very long fins since

$\boldsymbol{\tan h\,(mL) \to 1}$ for large value of mL.

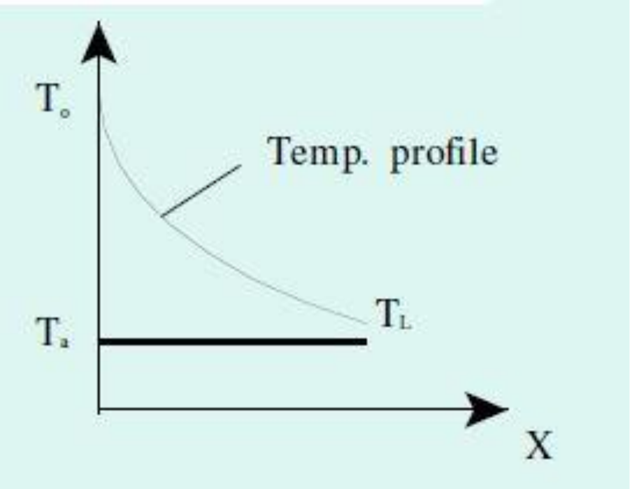

Fig.1.10 Temperature profile for insulated tip

1.12.1.3 Fins with convection of the ends

Boundary conditions:

(a) One common boundary condition is

At x = 0 (root), T = T_o and Θ =Θ_o = T_o - T_∞

The other boundary condition i.e. at the tip depends upon three different cases which are as follows: The mathematical formulation of the problem is

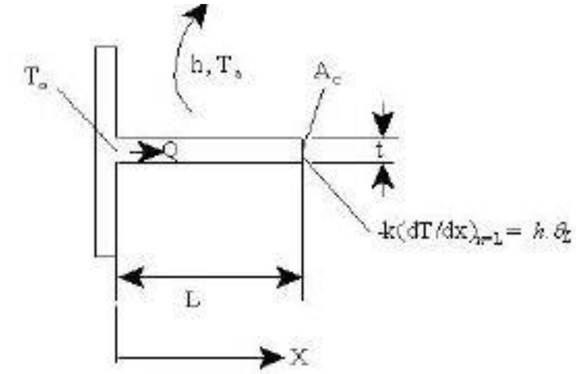

Fig.1.11 Fin with convection of the ends

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \quad 0 \le x \le L$$

$$\theta = T_o - T_\infty = \theta_o \; at \; x = 0$$

$$-KA\frac{d\theta}{dx} = hA\theta \; at \; x = L$$

$$KA\frac{d\theta}{dx} + hA\theta = 0 \; at \; x = L$$

Applying these conditions to the general solution

$$\theta = C_1e^{-mx} + C_2e^{mx} \; , we \; get$$

$$x = 0: \theta_o = C_1 + C_2$$

$$x = L \,; m[-C_1e^{-mL} + C_2e^{mL}] = -\frac{h}{k}[-C_1e^{-mL} + C_2e^{mL}]$$

Which yields C$_1$ and C$_2$ as

$$C_2 = \theta_o - C_1$$

$$C_1 = \frac{\theta_o\left(1+\frac{h}{mk}\right)e^{mL}}{(e^{mL}+e^{-mL})+\left(\frac{h}{mk}\right)(e^{mL}-e^{-mL})}$$

Which when substituted back into general solution, after simplification, yields

$$\theta = \theta_o \frac{\cos h\, m(L-x)+\left(\frac{h}{mk}\right)\ \sinh m\,(L-x)}{\cos h(mL)+\left(\frac{h}{mk}\right)\sin h\,(mL)}$$

For a fin with a negligible heat transfer at the tip, h = 0, and above equation reduces to the result given by equation

$$Q = -KA\frac{d\theta}{dX}\bigg|_{x=0} = -KA\theta_o \frac{-m\sin h\,(mL)-\left(\frac{h}{mk}\right)m\cos h\,(mL)}{\cosh\,(mL)+\left(\frac{h}{mk}\right)\sin h(\,mL)}$$

$$Q = \sqrt{hPKA}\theta_o\,\frac{\sin h(mL)+\frac{h}{mk}\ \cosh\,(mL)}{\cosh(mL)+\frac{h}{mk}\sin h(mL)}$$

$$= \sqrt{hPKA}\theta_o\,\frac{\tan h(mL)+\frac{h}{mk}}{1+\frac{h}{mk}\tan h(mL)}$$

Referring back to figure for a rectangular fin of constant cross-section,

$$A = Wt$$

$$P = 2(W+t)$$

Where **W** is the width of the fin

$$\boldsymbol{m = \sqrt{\frac{hp}{KA}} = \sqrt{\frac{2h(W+t)}{kWt}} = \sqrt{\frac{2h}{kt}}(for\ thin\ fins)}$$

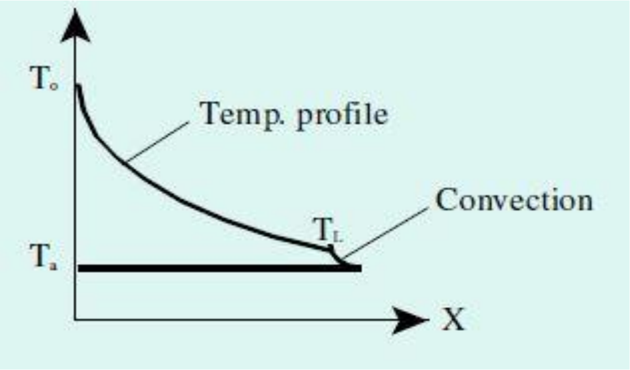

Fig.1.12 Temperature profile for convection of ends

1.12.2 Efficiency of fins

It is defined as the ration of actual heat transfer rate taking place through the fin and the maximum possible heat transfer rate that could occur through the fin i.e. when the entire fin is at its root temperature or base temperature. The entire fin will be at its root temperature only when the material of the fin has infinite thermal conductivity.

Where A_{fin} = convection heat transfer area of fin = perimeter of fin (P) length of fin (L)

The maximum heat transfer would occur if the temperature of the extended surface was equal to base tempereature, T_o at all points.

$$\boldsymbol{\eta_{fin} = \frac{Q_{fin}}{Q_{max}}}$$

For an infinite rectangular fin

$$\boldsymbol{\eta_{fin} = \frac{\sqrt{hPkA}\theta_o}{hPL\theta_o} = \sqrt{\frac{kA}{hPL^2}} = \frac{1}{mL}}$$

For a rectangular fin with an insulated tip

$$\eta_{fin} = \frac{\sqrt{hPkA}\theta_o \tanh(mL)}{hPL\theta_o}$$

$$\eta_{fin} = \frac{\tanh(mL)}{mL}$$

Where $mL = \sqrt{\frac{hp}{KA}}L = \sqrt{\frac{h(2W+2t)}{kWt}}L$

Now is the fin is sufficiently wide, then the term 2W will be large compared to 2t, then

$$mL = \sqrt{\frac{2hW}{ktW}}L = \sqrt{\frac{2h}{ktL}}L^{3/2} = \sqrt{\frac{2h}{kA_m}}L^{3/2}$$

Where t.L = A_m = profile area of fin.

Thus we see that the fin efficiency is a function of mL.

$$\sqrt{\frac{2h}{kA_m}}L^{3/2}$$

For a real rectangular fin which is long, wide and thins the efficiency can be calculated by equation provided L is replaced by a corrected length L_c, see Gardner and Kothandaraman

$$L_c = L + \frac{t}{2}$$

This is corrected length compensates for the fact that there is a convective loss of heat from the tip of a real fin. The fin efficiency is written as

$$\eta_{fin} = \frac{\tanh[\sqrt{\frac{2h}{kt}}\ (L + t/2)]}{\sqrt{\frac{2h}{kt}}\ (L + t/2)}$$

And the heat flow becomes

$$Q = \sqrt{hPKA}\theta_o \tan h\left[\sqrt{\frac{2h}{kt}}\ (L + t/2)\right]$$

$$= \eta \,.\, hPL_c\theta_o$$

Figures give fin efficiencies for straight rectangular and triangular fins and for circumferential fins of rectangular profiles. Note that the corrected fin length L_c and profile are A_m have been used and defined in these figures. The procedure for calculating the heat flow rates from real fins is as follows

1. Calculate L_c and A_m
    - I. For a straight rectangular fin

$$L_c = L + \frac{t}{2}$$

$$A_m = tL_c$$

    - II. For a triangular fin

$$L_c = L$$

$$A_m = L_c(t/2)$$

    - III. For a circumferential fin of rectangular cross-section

$$L = r_2 - r_1$$

$$L_c = L + \frac{t}{2}$$

$$r_{2c} = r_1 + L_c$$

$$A_m = (r_2 - r_1)t$$

Find $\frac{r_{2c}}{r_1}$ to read figure

2. Calculate $L^{3/2}\sqrt{\frac{h}{kA_m}}$

3. Using Figures obtain $\boldsymbol{\eta_{fin}}$
4. Calculate $\boldsymbol{Q_{max}}$
    I. For a rectangular or triangular fin if unit depth

$$Q_{max} = hPL_c\theta_o$$

    II. For a circumferential fin of rectangular cross-section

$$Q_{max} = 2\pi h(r_{2c}^2 - r_1^2)\theta_o$$

5. $\boldsymbol{Q_{fin} = \eta_{fin} \cdot Q_{max}}$

The total heat transferred from a finned surface is

$$Q_{total} = Q_{primary\,surface} + Q_{fin}$$
$$= A_o h\,\theta_o + A_f h\eta_{fin}\theta_o$$
$$= h(A_o + A_f\eta_{fin})\theta_o$$

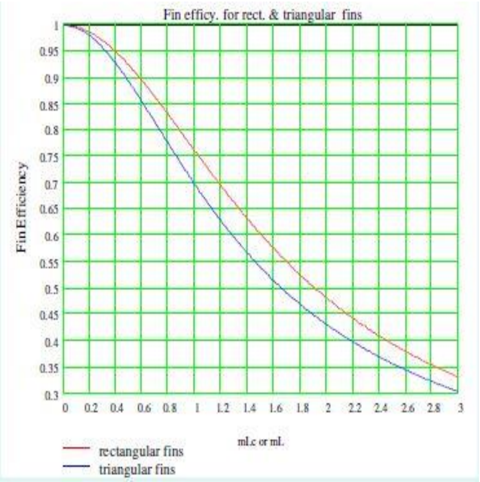

Fig.1.13 Efficiency graph for rectangular and triangular fin

1.12.3 Effectiveness of fins

A curious but interesting question is whether the addition of fins to a surface always results in increased heat transfer. There may be situations where adding fins may actually decrease heat transfer from a given surface. This may be explained asfollows. Compare the heat transfer rate from a surface with fin ti that which would be obtained without the fin. Calling this ratio as effectiveness.

$$\boldsymbol{E = \frac{Q_{with\,fin}}{Q_{without\,fin}} = \frac{\eta_{fin}\,.\,\,A_f\,.\,\,h\theta_o}{hA_o\theta_o}}$$

Where A_b is the base area. For the insulated tip fin,

$A_f = PL$, $A_b = A$

And

$$\boldsymbol{\frac{Q_{with\,fin}}{Q_{without\,fin}} = \frac{\sqrt{hPkA}\theta_o \tan h\,(mL)}{hA\theta_o} = \frac{\tanh(\,mL)}{\sqrt{\frac{hA}{kP}}}}$$

If (mL) is sufficiently large, tan h (mL) ≈1.0, then

$$\boldsymbol{E = \frac{1}{\sqrt{\frac{hA}{kP}}} = \sqrt{\frac{kP}{hA}}(should\ be\ \geq 1)}$$

The effectiveness of fins must be greater than unity to justify their addition to surfaces dissipating heat to surroundings. In practice, however, finning is hardly justified unless h is less than 0.25 (KP/a). In other words, finning is only justified where h is small. If the value of *h* is large as, experienced in boiling, condensation and high velocity liquids, the fins may actually produce a reduction in heat transfer. It is also apparent that finning will be more effective with materials of large thermal conductivities

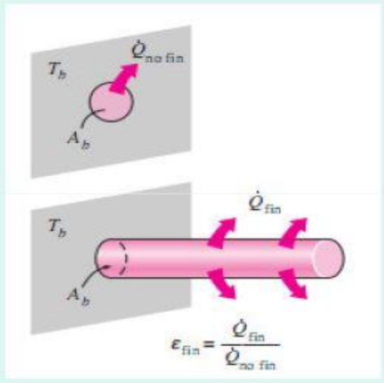

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Fig.1.14 Effectiveness of fin

CHAPTER II

LITERATURE REVIEW

2.1 Details of work conducted by various authors

This chapter describes the work reported by earlier researchers

Abdullah, H. Alessaet.al. [1] studied the natural convection heat transfer enhancement from a horizontal rectangular fin embedded with equilateral triangular perforations in comparison with the equivalent solid fin. The thermal and geometrical properties of the fin were studied in detail and concluded that, for certain values of triangular dimensions, the perforated fin can result in better heat transfer. **Ashok TukaramPise et.al [2]** conducted the experiment to compare the rate of heat transfer with solid and permeable fins and found that the permeable fins' average heat transfer rate improves by about 5.63% and average heat transfer coefficient 42.3% as compared. **B.Ramdas Pradip et.al. [3]** studied the thermal systems for many industrials applications with effective emitters such as ribs, fins, baffles etc., which would introduce a new technique called Intensification or Augmentation into the field of engineering.

D.G.Kumbhar et.al. [4] studied on heat transfer augmentation from a horizontal rectangular fin by triangular perforations using ANSYS and concluded that the heat transfer rate increases with perforation as compared to fins of similar dimensions without perforation. The perforation of the fin enhances the heat dissipation rates at the same time decreases the expenditure for fin materials also. **GolnooshMostafavi [5]** investigated the steady-state external natural convection heat transfer from vertically mounted rectangular interrupted finned heat sinks. Results show that adding interruptions enhances the thermal performance of fins and reduces the weight of the fin arrays, which in turn, can lead to lower manufacturing costs. **J.Ajay Paul et.al. [6]** performed a parametric study of extended fins in the optimization of internal combustion engine and found that for high speed vehicles thicker fins provide better efficiency.

N. Nagarani et.al. [7] analyzed the heat transfer rate and efficiency for circular and elliptical annular fins for different environmental conditions. Elliptical fin efficiency is found to be more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice. to solid fins with reduction of cost of the material by 30%. **R.P. Patil et.al. [8]** conducted CFD and experimental analysis of elliptical fins for heat transfer parameters, heat transfer coefficient and tube efficiency by forced convection. At air flow rate of 3.7 m/s the efficiency, increases as heat input increases. **Sable, M.J. et.al. [9]** investigated for natural convection adjacent to a vertical heated plate with a multiple v-type partition plates (fins) in ambient air surrounding. As compared to conventional vertical fins, this v-type partition plate's works not only as extended surface but also as flow tabulator providing better fin array configurations.

KM Sajesh et al. [10] had studied that the heat lost by the body can be increased by increasing the surface area. The increment in surface area is done by creating holes of different sizes on the surface of fins. Increasing the diameter of hole created on the fin brings the overall temperature of the body lower than the lesser diameter model. By creating holes on fins the temperature of fins can be reduced. It also says that the turbulence of air also get increased by creation on holes. This result came by performing a CFD analysis of rectangular fin engine made up with AL 6063 having thermal conductivity of 200W/mK. This CFD is done on steady state and transient state both. This also shows that, the transient temperature of all fins reached to the steady state temperature within 400 seconds of time.**V. Karthikeyan et al. [11]** have founded that heat transfer rate of rectangular fin arrays is analyzed by design with perforated and with extension, analysis is carried out using ANSYS Workbench. In that steady state thermal analysis, temperature variations with respect to distance at which heat flow occur through the fin is analyzed. Heat transfer through fin arrays with rectangular extensions higher than that of fin with other type of fins compared to it. Temperature at the end of fin arrays with rectangular extensions is minimum as compare to fin with extensions, without extension and with perforated. Fin arrays with rectangular extensions provide near about 13 % to 21% more enhancement of heat transfer as compare to other type of fins. This result may vary for forced convection heat transfer. **L. Natrayan et al. [12**] Design of fin plays an important role in heat transfer. There is a scope of improvement in heat transfer of air cooled engine cylinder fin if mounted fin's shape varied from conventional one. Contact time between air flow and fin (time between air inlet and outlet flow through fin) is also important factor in such heat transfer. Wavyfin shaped cylinder block can be used for increasing the heat transfer from the fins by creating turbulence for upcoming air. Improvements in heat transfer can be compare with all the four model of the engine fins geometry by CFD Analysis and its flow characteristics are studied for all the geometries it is found that the curved fins provide better result when compared with all the other geometries.

Pardeep Singh et al. [13] compared the heat transfer performance of fin with same geometry having various extensions and without extensions is in their thermal analysis, temperature variations with respect to distance at which heat flow occur through the fin is analyzed Fin with extensions provide near about 5 % to 13% more enhancement of heat transfer as compare to fin without extensions also the heat transfer through fin with rectangular extensions higher than that of fin with other types of extensions. The temperature at the end of fin with rectangular extensions is lesser as compare to fin with other types of extensions. They also showed that the effectiveness of fin with rectangular extensions is greater than other extensions and choosing the minimum value of ambient fluid temperature provide the greater heat transfer rate enhancement. **P. Sai Chaitanya et al. [14]** had some work on a cylinder fin body is modeled and transient thermal analysis is done by usingPro/Engineer and ANSYS. These fins are used for air cooling systems for two wheelers. In present study, Aluminium alloy 6061is compared with Aluminium Alloy A204. The various parameters (i.e., geometry and thickness of the fin) are considered in the study, By reducing the thickness and also by changing the shape of the fin to circular shape from the conventional geometry i.e. rectangular, the weight of the fin body reduces thereby increasing the heat transfer rate and efficiency of the fin. The results shows, by using circular fin with material Aluminium Alloy 6061 is better since heat transfer rate of the fin is more. By using circular fins the weight of the fin body reduces compared to existing rectangular engine cylinder fin.

Sachin Kumar Gupta et al. [15] had thermal analysis on the fin body by varying materials, geometry and slot sizes. And they concluded now a day's material used for fin body of IC engine is Aluminium alloys. They have replaced older material with Aluminium alloy 6061, Aluminium Alloy C443 and Aluminium Alloy 2014. The shape of the fin remains the same with variable slots sizes. The default thickness of fin is 2.35mm. By slotting the weight of the fin body reduces thereby increasing the heat transfer rate but excess increase in slot sizes leads to decrease in heat transfer. By observing the analysis results they compared fin surface temperature of various sized slotted fins for different materials and founded that the cost of engine decreases due to reduction in the material requirement of cylinder. 75mm slotted fins have maximum heat transfer within different material slotted fin. The minimum surface provided for 75mm for fin surface temperature 75mm slotted fin engine of Aluminium 2014 material have maximum heat transfer As the slots size increase above 75mm heat transfer decreases.

K. Sathishkumar et al. [16] had investigated that the fins with various configurations were modeled using CREO 2.0 and analyses are done by using CFD – Fluent in order to find out the heat transfer rate. It is clear that the results from software and theoretically says that the fins with rectangular notch have greater heat transfer rate compared to that of the fins without holes, fins with holes and V shaped fins. Since the heat dissipation rate is more in rectangular notch so we conclude that the rectangular notch fins are most efficiency and best heat transfer notch among all types of notch. **Ajay Sonkar et al. [17]** had studied that the use of fin/extended surface with extensions, provide efficient heat transfer,temperature of Fin with extensions increases about 2 % to 3% as compare to fin without extensions. Fin with extensions provide near about 4 % to 13% more enhancement of heat transfer as compare to fin without extensions. Heat transfer through fin with trapezoidal extensions higher than that of fin with other types of extensions. By providing extensions in fin there is no improvement in thermal flux. From analysis they have got that the thermal flux decreases with extensions and concluded that using extension in fins surface is having better heat transfer rate as compared to normal fin. The temperature distribution and thermal stresses are calculated using ANSYS. **Singh et al [18].**compared the performance of different profiles of fins using thermal analysis

Computational Fluid Dynamic analysis and Wind tunnel experiments have shown improvements in fin efficiency by changing fin geometry, fin pitch, number of fins, fin material and climate condition. **Abdullah H. M. AlEssa, [19].** studied the augmentation of fin natural convection heat dissipation by square perforations. Comparative thermal tests have been carried out using aluminum heat sinks made with extruded fin, cross-cut rectangular pins, and elliptical shaped pins in low air flow environments. The elliptical pin heat sink was designed to minimize the pressure loss across the heat sink by reducing the vortex effects and to enhance the thermal performance by maintaining large exposed surface area available for heat transfer. The performance of the elliptical pin heat sink was compared with those of extruded straight and crosscut fin heat sinks, all designed for an ASIC chip. **Abdullah H. AlEssa, Ayman M. Maqableh1 and Shatha Ammourah [20].** tried to enhance the natural convection heat transfer from a fin In this study, the enhancement of natural convection heat transfer from a horizontal rectangular fin embedded with rectangular perforations of aspect ratio of two has been examined using finite element technique. The results for perforated fin have been compared with its equivalent solid one. A parametric study for geometrical dimensions and thermal properties of the fin and the perforations was carried out. The study investigated the gain in fin area and of heat transfer coefficients due to perforations. **K. A. Rajput and A. V. Kulkarni [21]** performed a finite element analysis of convective heat transfer augmentation from rectangular fin by circular perforation.

Mirapalli et al [22] provided rectangular and triangular fins on the periphery of engine cylinder. Heat transfer analysis is carried out by placing rectangular and then triangular fins. Analysis is carried out by varying temperatures on the surface of the cylinder from 200 ºC to 600ºC and varying length from 6 cm to 14 cm. Input parameters such as density, heat transfer coefficient, thermal conductivity and thickness of fin are taken and output parameters such as rate of heat flow, heat flow per unit mass, efficiency and effectiveness are determined. Comparisons are presented with rectangular fins. **Jassem et al[23]** investigated the heat transfer by natural convection in a rectangular perforated fin plates. Five fins used in this work first fin non-perforated and others fins perforated by different shapes these fins perforation by differentshapes (circle, square, triangle, and hexagon) but these perforations have the same cross section area. These perforations distributed on 3 columns and 6 rows. Experiments produced through in an experimental facility that was specifically design and constructed for this purpose. **Daund et al [24]** reviewed convection heat transfer through rectangular fins. Various experimental studies have been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer. He also examined the experimental and numerical studies which are done in natural, mixed and forced convection. He found that sets of correlations to give relation between various parameters of heat sink were derived. **Shaikh et al [25]** dealt with performance of various available fins profiles. Widely used fins profile viz. Rectangular, Triangular, Trapezoidal, Circular, Rhombic, and Elliptical Fins. In addition to the normal configuration of fins, to new configurations were designed and created. This includes length of each fins its thickness at the base and number of fins on each model this provided a basis for proper comparison of different fin profiles. The result were tabulated and studied for comparison of different fin profiles. The best performing fin was then selected on the basis of maximum heat dissipation from the circular model this study showed the performance of annular fins of different profiles under similar conditions and to quantify the heat losses and finally compare it with fin profiles on the basis of heat dissipation and thermal stress include. The fin profile was then arranged on the basis of performance.

The details regarding the fin equations and temperature derivations for various types of fins are derived by referring to Fundamentals of heat and mass transfer by **R.C. Sachdeva[26]**. The Nusselt number and Prandtl number and thermal conductivity and viscosity and other required values for the experiment are taken from Heat and mass transfer data book by **C.P. Kothandaraman and S. Subramanyam[27]**

2.2 Comparision of works

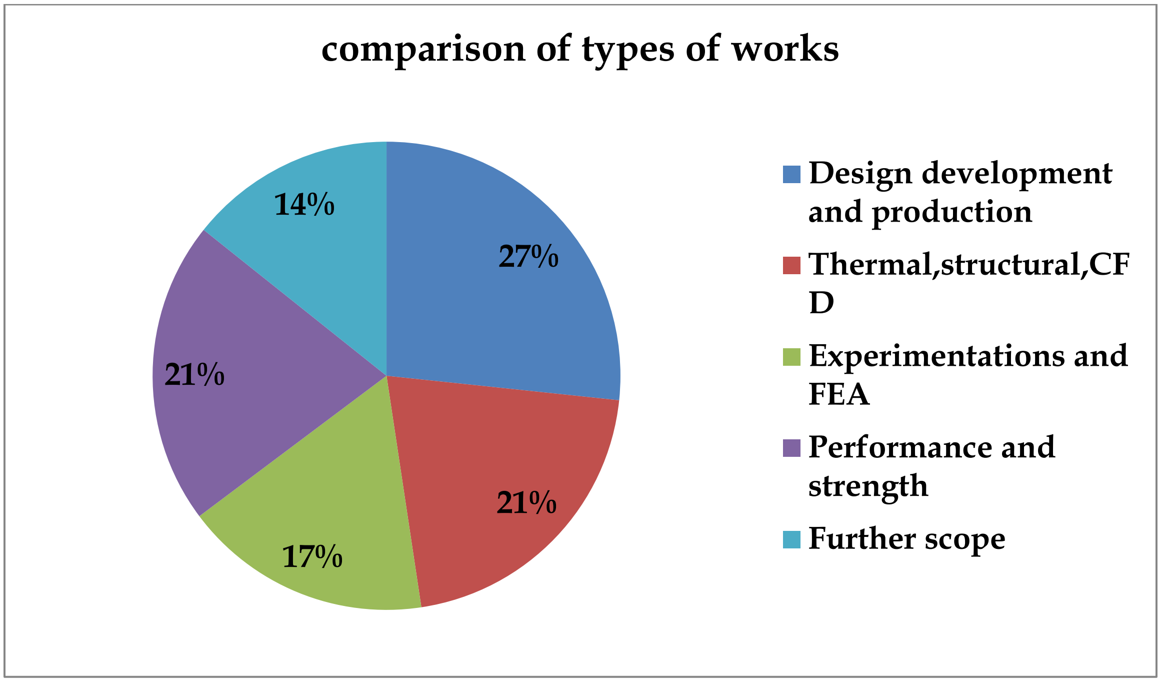


Fig. 2.1 Comparative pie diagram of type of works done on pin fins

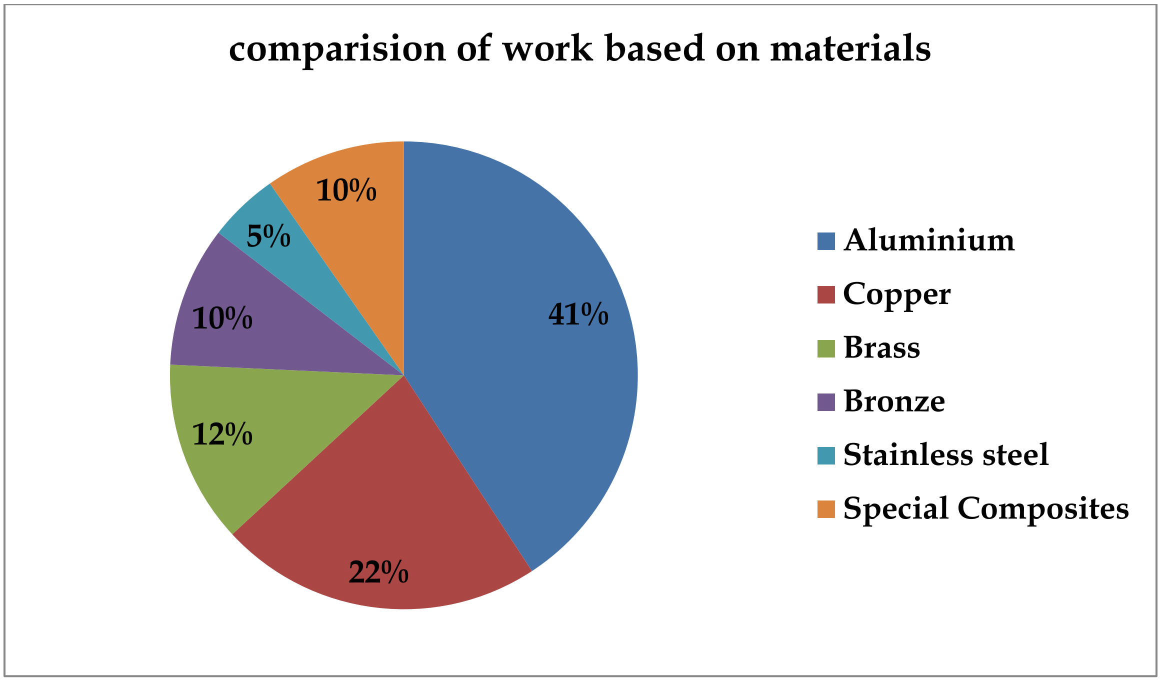


Fig.2.2 Comparative pie diagram on work based on materials used

2.3 Summary of works

The following points are summarized based on the survey conducted

1. Few studies suggested the consideration of new factors for the design of fins which advances the conventional design procedure to reliability based design.
2. Most of the studies compared the results of temperature distribution of various fins by changing the materials in same medium and suggested aluminium and copper as best materials for enhanced heat transfer.
3. Most of the studies varied the geometries of fins and suggested rectangular fin is the best geometry as it has more surface area and some studies have made perforations to increase the heat transfer.
4. Some papers reduced the geometry of the fin in order to reduce the weight so that the efficiency of fin increases and heat transfer rate is increased as the thickness is reduced.
5. Some studies stated that the heat transfer rate of fin depends on environmental conditions and higher velocities sometimes lead to low heat transfer coefficient.
6. Some studies stated that performance of fins can be increased by altering the length of profile, coefficient of thermal conductivity, ambient temperature.
7. Some studies stated that enhancement of heat transfer is directly proportional to nusselts number and better enhancement can be provided for sine wave type fin along the z- axis which shows that the orientation of fin also changes the performance of fin
8. Most of the studies considered air as medium of heat transfer and done experimental and analytical procedures and compared the results with aluminium and copper and brass and some alloys
9. A Few studies were made with fins with different heat loads at its base and combination of fin with mixture of materials for same fin at different lengths.
10. A Few studies were made on perforations with inclinations and extensions with inclinations and in different mediums and different materials such as composites.

CHAPTER III

THEORETICAL ANALYSIS

3.1 Formulation of problem

Consider a circular pin fin of diameter 12 mm and length of 150mm made of aluminum connected to a chip with defined heat load of 63.6 Watts applied to its base which is at constant temperature of 159ºC with help of a heater and thermocouples fitted at different locations where the ambient temperature is 33ºC.

The fin is fixed to the chip which is in form of a cantilever beam where fixed end is supplied heat from heater and the heat input is measured by means of voltmeter and ammeter.

The temperatures at various locations can be measured by thermocouples. This problem was considered for theoretical and experimental analysis to validate the results obtained in ANSYS by changing the geometry and applying different materials.

3.2 Important definitions

1. Heat Transfer

Heat transfer, also referred to simply as heat, is the movement of thermal energy from one thing to another thing of different temperature. These objects could be two solids, a solid and a liquid or gas, or even within a liquid or gas. There are three different ways the heat can transfer: conduction (through direct contact), convection (through fluid movement), or radiation (through electromagnetic waves). Heat transfer occurs when the temperatures of objects are not equal to each other and refers to how this difference is changed to an equilibrium state. Thermodynamics then deals with things that are in the equilibrium state.

2. **Conduction**

   Conduction is the method of transfer of heat within a body or from one body to the other due to the transfer of heat by molecules vibrating at their mean positions. The bodies through which the heat transfer must be in contact with each other. There is no actual movement of matter while transferring heat from one location to the other.

   Conduction occurs usually in solids where molecules in the structure are held together strongly by intermolecular forces of attraction amongst them and so they only vibrate about their mean positions as they receive heat energy and thus pass it to the surrounding molecules by vibrations.

3. **Convection**

   Convection is the mode of heat transfer which occurs mostly in liquids and gases.In this method, heat transfer takes place with the actual motion of matter from one place within the body to the other. Often when we boil water we have seen bubbles and currents develop in the water on careful observation.This is an apt example of the convection process.

4. **Radiation**

   Radiation is a form of heat transfer. It does not require any medium and can be used for transfer of heat in a vacuum as well. This method uses electromagnetic waves which transfer heat from one place to the other. The heat and light from the sun in our solar system reach our planet using radiation only.

5. **Temperature Field**

   The set of temperature values at all points in a given space at a given instant. A temperature field is represented graphically by means of isothermal surfaces, each of which connects all points of the field having the same temperature.

   If the temperature is function of only one coordinate then the field is called one dimensional.

   If the temperature is function of two coordinates and its variation in third coordinate is negligible, it is called two dimensional field.

6. **Thermal conductivity**

   A measure of ability of a material to transfer heat. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is heat energy transferred per unit time per unit surface area divided by the temperature difference between them. It is measured in W/m-k

7. **Fourier law of conduction**

   The law of heat conduction, also known as Fourier's law, states that the rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area, at right angles to that gradient, through which the heat flows

$$\boldsymbol{Q_x = -KA\frac{dT}{dX}}$$

8. **Newton's law of cooling**

   Newton's Law of Cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature (i.e. the temperature of its surroundings).

$$T(t) = T_s + (T_0 - T_s)e^{(-kt)}$$

9. **Stefan-Boltzmann law**

   Stefan-Boltzmann law, statement that the total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature. The law applies only to blackbodies, theoretical surfaces that absorb all incident heat radiation.

$$\mathbf{P = \epsilon\, \sigma\, T^4 A}$$

10. **Heat Transfer coefficient**

    The heat Transfer coefficient or film coefficient or film effectiveness in thermodynamics and in mechanics is the proportionality constant between the heat flux and the thermodynamic force for flow of heat (i.e., the temperature difference, ΔT). It is expressed in W/m^2-k

11. **Natural convection**

    Natural convection, known also as **free convection** is a mechanism, or type of mass and heat transfer, in which the fluid motion is generated only by **density differences** in the fluid occurring due to temperature gradients, not by any external source (like a pump, fan, suction device, etc.).

12. **Forced convection**

    Forced convection is a mechanism, or type of transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.).

13. **Boundary layer**

    The concept of boundary layer as proposed by Prandtl forms the starting point for the simplifications of equations of motion and energy. It has been successfully used in many practical problem. In this concept the flow field over a body is divided into two categories (1) a thin region near the body called boundary layer, where the velocity and temperature gradient is large and (2) the region outside the boundary layer where the velocity and temperature gradient are nearly equal to their free stream value.

    The different boundary layers in a flow are

    1. **Laminar boundary layer**

       A thin layer over the surface of a body immersed in a fluid, in which the fluid velocity relative to the surface increases rapidly with distance from the surface and the flow is laminar.

    2. **Turbulent boundary layer**

       Turbulent boundary layers are significantly more complicated where random, turbulent motion, which for most applications satisfies the non-linear Navier-Stokes equations, may be characterized by Reynolds decomposition, wherein Reynolds-averaging give rise to Reynolds stresses

The layer in which the Reynolds stresses are much larger than the viscous stresses.

3. **Thermal boundary layer**

   The same concept of boundary layer of a flow field in fluid dynamics can be applied to heat and mass transfer. For heat transfer, the boundary layer is known as Thermal Boundary layer, and its thickness can be defined as the distance at which fluid attains 99% of free stream temperature. This layer is called as a thermal boundary layer.

14. Nusselt number

In heat transfer at a boundary (surface) within a fluid, the Nusselt number (Nu) is the ratio of convective to conductive heat transfer (normal to) the boundary. In this context, convection includes both advection and diffusion. Named after Wilhem Nusselt, it is a dimensionless number. The conductive component is measured under the same conditions as heat convection but with a (hypothetically) stagnant (or motionless) fluid

$$\boldsymbol{N_u = CR_e{}^n P_r{}^{1/3}}$$

15. Prandtl number

The prandtl number is a dimensionless number named after german scientist Ludwig Prandtl defined as the ratio of momentum diffusivity to thermal diffusivity

$$\boldsymbol{P_r = P_r \mu / K}$$

16. Grashofs number

The Grashof Number (Gr) is a dimensionless number in fluid dynamics and heat transfer which approximates the ratio of the buoyancy forces to viscous force acting on a fluid. It frequently arises in natural convection and is analogous to the Reynolds number. It is named after Franz Grashof.

$$\mathrm{Gr}_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$ For vertical flat plates

$$\mathrm{Gr}_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}$$ For pipes

$$\mathrm{Gr}_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}$$ For bluff bodies

17. Pecelt number

The Peclet number is a dimensionless number used in calculations involving convective heat transfer. It is the ratio of the thermal energy convected to the fluid to the thermal energy conducted within the fluid. The Peclet number is the product of the Reynolds number and the Prandtl number.

$$\mathrm{Pe}_L = \frac{Lu}{\alpha} = \mathrm{Re}_L\,\mathrm{Pr}.$$

18. Reynolds number

A dimensionless number used in fluid mechanics to indicate whether fluid flow past a body or in a duct is steady or turbulent.

Reynolds number is the ratio of the inertia to the viscous forces acting on a fluid.

$$\mathbf{R_e = V_a\, d_f / V}$$

3.3 Specifications of fin

1. Diameter of fin : 12mm
2. Material of fin : Aluminum
3. Length of fin : 150mm
4. Thermal conductivity of material : 110.7 W/m-k
5. Number of thermocouples : 6
6. Dimensions of duct : 150 mm x 100 mm

3.4 Assumptions made

7. Steady state conduction with no heat generation in the fin
8. Thickness is small compared to length and width, i.e. one-dimensional conduction in x-direction only
9. Thermal conductivity of fin material is constant
10. Isotropic (i.e. const. k in all directions) and homogeneous (i.e. const. density) material
11. Uniform heat transfer coefficient over the entire length of fin and the base wall
12. Negligible radiation effect
13. The fin base temperature was constant for all type of materials

3.5 Material and medium properties

Fin material	=	**Aluminium fin**
1. Thermal conductivity	=	110.7 W/m k
2. Density	=	2770 kg/m^3
3. Specific heat	=	875 J/kg K ^{o}C
4. Temperature	=	27 ^{o}C

Medium	=	**Air**
1. Temperature	=	57.75 ^{o}C
2. Kinematic viscosity	=	18.97 x 10^{-6}
3. Prandtl number	=	0.696
4. Velocity	=	1.8132 m/s
5. Reynolds number	=	29710.068
6. Nusselt number	=	78.1328
7. Convective heat transfer coefficient	=	38.915 W/m^2 k

3.6 Calculations and results

Temperature table from experiment at steady state

Table 3.1 Experimental Data

Voltmeter Reading volts	Ammeter Reading amps	Manometer reading h_1 cm	Manometer reading h_2 cm	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC	T_6 ºC
120	0.53	127	82	159	140	118	113	100	32

1. Velocity of air at orifice,

$$V_o = C_d \sqrt{\frac{2gh(\rho_m - \rho_a)}{\rho_a} \quad . \quad \frac{1}{1-\beta}}$$

$$V_o = C_d \sqrt{\frac{2 * \ 9.81 * 4.5 * \ 10^{-3}(13.6 * 1000 - 1.17)}{1.17} \quad . \quad \frac{1}{0.5263}}$$

$$\rho_m = density\ of\ manometric\ fluid = 13.6 * \ 10^3 \frac{kg}{m^2}$$

$$\rho_a = density\ of\ air = \ 1.7 \frac{kg}{m^3}$$

2. Velocity of air in duct, V_a can be obtained by applying continuity equation.
   V_a × Cross sectional area of duct = V_o × cross sectional area of orifice

$$V_a = \frac{velocity\ ar\ orifice * cross\ sectional\ area\ of\ orifice}{cross\ sectional\ ara\ of\ duct}$$

$$V_a = \frac{V_o * \frac{\pi {d_o}^2}{4}}{W * B}$$

$$V_a = \frac{86.574 * \frac{\pi(20 * 10^{-3})^2}{4}}{0.15 * 0.100}$$

$$V_a = 1.8132\, m/s$$

3. Reynolds number, Re of air flow

$R_e = V_a\, d_f / V$

$$R_e = \frac{1.8132 * 12 * 10^{-3}}{21.09 * 10^{-6}}$$

$$R_e = 1031.69$$

$$for\ R_e\ 40\ to\ 4000\ \ c = 0.683\ n = 0.466$$

4. Prandtl number Pr = 0.692
5. Nusselt number Nu

$$N_u = CR_e{}^{n}P_r{}^{1/3} = 0.683 * 1031.69^{0.466} * 0.692^{1/3}$$

$$N_u = 15.326$$

6. Heat transfer coefficient can be calculated by using the correlation

$$h = N_u\, K / d_f$$

$$h = 15.326 * \frac{0.03047}{12} * 10^{-3}$$

$$= 38.915\, w/\, m^2K$$

$$m = \sqrt{\frac{hp}{KA}}$$

$$m = \sqrt{\frac{38.915 * \ \pi * 12 * \ 10^{-3}}{110 * \frac{\pi}{4} * (12 * 10^{-3})^2}}$$

$$m = 10.8593$$

7. Using the equation estimate the temperature T_o using T_1 at $x = x_1$

$$\frac{T - \ T_\infty}{T_o - T_\infty} = \ \frac{cosh[m(L - x)]}{cosh(mL)}$$

$$T \ = 32 + \frac{(159 - 32)cosh[10.8593 * (-150 - 0.045)]}{cosh \ 10.8593 * 0.15}$$

$$T \ = 114.69$$

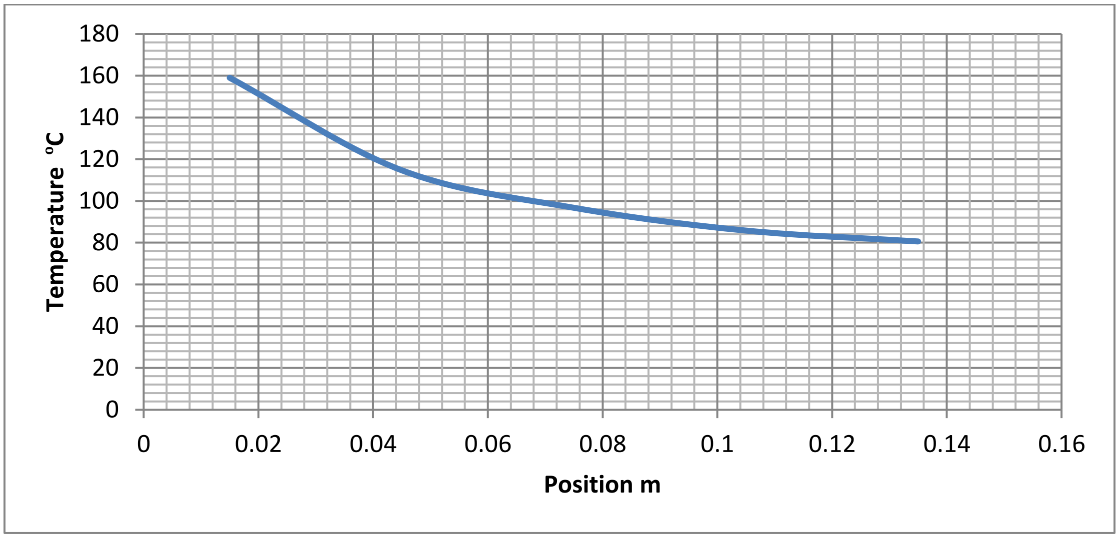
8. Using T_o , estimate the other temperature values T_2, T_3, T_4, T_5 and compare with the temperatures recorded by thermocouples
9.

Table 3.2 Tabular form of Temperature and Position (Theoretical)

Position m	Temperature ºC
0.015	159
0.045	114.69
0.075	96.736
0.105	85.818
0.135	20.61

3.7 Graphs

Graph 3.1 Temperature Vs Position



CHAPTER IV

EXPERIMENTAL ANALYISS

4.1 Experimental statement

Consider a circular pin fin of diameter 12 mm and length of 150mm made of aluminum connected to a chip with defined heat load of 63.6 Watts applied to its base which is at constant temperature of 159ºC with help of a heater and thermocouples fitted at different locations where the ambient temperature is 33ºC.

The fin is fixed to the chip which is in form of a cantilever beam where fixed end is supplied heat from heater and the heat input is measured by means of voltmeter and ammeter.

The temperatures at various locations can be measured by thermocouples. This problem was considered for theoretical and experimental analysis to validate the results obtained in ANSYS by changing the geometry and applying different materials.

4.2 Experimental setup

The experimental setup consists of a fin whose base is fixed to a heater which is supplied heat with help of electrical input and the input is measured by means of a voltmeter and ammeter. The fin is placed in a rectangular duct whose one end is fixed with a blower which blows the air through the duct and the other end is free to atmosphere, the air supply can be regulated by means of a valve fitted to tube connected to blower and the tube is fitted with a differential manometer containing mercury whose height is measured to calculate the velocity of air and the fin is equipped with thermocouples fitted at various locations to measure the temperature along the length of fin.

4.2.1 Fin

The fin is made of aluminium whose thermal conductivity is W/m-k and is fitted to the heater. The fin is also equipped with thermocouples at various distances to measure the temperature along the length of fin.

4.2.2 Rectangular duct

Process duct work conveys large volumes of hot, dusty air from processing equipment to mills, bag houses to other process equipment. Process duct work may be round or rectangular. Although round duct work costs more to fabricate than rectangular duct work, it requires fewer stiffeners and is favored in many applications over rectangular ductwork.The air in process duct work may be at ambient conditions or may operate at up to 900 °F (482 °C). Process ductwork varies in size from 2 ft diameter to 20 ft diameter or to perhaps 20 ft by 40 ft rectangular.

Fig. 4.1 rectangular duct

Fig. 4.2 voltmeter

4.2.3 Digital voltmeter

A voltmeter is an instrument used for measuring electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.A voltmeter in a circuit diagram is represented by the letter V in a circle. Voltmeters are made in a wide range of styles. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a multimeter, are standard test instruments used in electrical and electronics work.

4.2.4 Digital ammeter

An ammeter (from Ampere Meter) is a measuring instrument used to measure the current in a circuit. Digital ammeter designs use a shunt resistor to produce a calibrated voltage proportional to the current flowing. This voltage is then measured by a digital voltmeter, through use of an analog to digital converter (ADC) The digital display is calibrated to display the current through the shunt. Such instruments are often calibrated to indicate the RMS value for a sine wave only, but many designs will indicate true RMS within limitations of the wave crest factor.

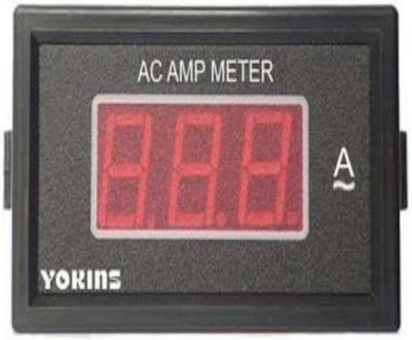


Fig. 4.3 ammeter

Fig. 4.4 dimmerstat

4.2.5 Dimmerstat

Dimmerstat is registered trademark of AE for continuously variable voltage auto-transformer. It is the most effective device for step less, break less & continuous control of AC voltage & therefore for various parameters, dependent on AC voltage. The basic Dimmerstat is meant for operation from a nominal input voltage of 240V AC & can give output voltage anywhere between 0 to 240V or 0 to 270VAC by simple transformer action. Three such Dimmerstat connected electrically in star and mechanically in tandem, become suitable for operation from a nominal input voltage of 415V 3Ph AC and can give output anywhere between 0 to 415V or 0 to 470V.

4.2.5 Thrermocouple

The thermocouple is a temperature measuring device. It uses for measuring the temperature at one particular point. In other words, it is a type of sensor used for measuring the temperature in the form of an electric current or the EMF. The thermocouple consists two wires of different metals which are welded together at the ends. The welded portion was creating the junction where the temperature is used to be measured. The variation in temperature of the wire induces the voltages.

4.2.6 Blower fan

A wheel with vanes on a rotating shaft in a case or chamber used to create a blast of air for a forge or a current for draft and ventilation called also fanner. Centrifugal fans use the kinetic energy of the impellers to increase the volume of the air stream, which in turn moves against the resistance caused by ducts, dampers and other components. The centrifugal fan is one of the most widely used fans. Centrifugal fans are by far the most prevalent type of fan used in the HVAC industry today. They are often cheaper than axial fans and simpler in construction.

Fig. 4.5 blower fan

Fig 4.6 temperature indicator

4.2.7 Digital temperature indicator

Since modern temperature indicators are based on digital electronics, it is necessary to transform temperature into an electric signal by means of temperature sensors. Due to the fact that there are different physical measuring principles depending on the sensor, diverse temperature indicators will be required. Pt100 resistance sensors can get changed with temperature and resistance. Temperature indicators should determine the current resistance. For doing this temperature indicators allow a constant current to flow. By means of the voltage drop, the sensor can calculate resistance. Thermo-elements are also used to measure temperature by converting the temperature difference into a continuous voltage creating a voltage which is shown as temperature.

4.2.8 Differential manometer

A differential manometer is a device that measures the difference in pressure between two places. Differential manometers can range from devices simple enough to be built at home to complex digital equipment. Standard manometers are used to measure the pressure in a container by comparing it to normal atmospheric pressure. Differential manometers are also used to compare the pressure of two different containers. They reveal both which container has greater pressure and how large the difference between the two is. Differential manometers have a wide range of uses in different disciplines. One example is that they can be used to measure the flow dynamics of a gas by comparing the pressure at different points in the pipe

Fig. 4.7 U tube manometer

4.3 Specifications

Length of fin (L) = 150mm

Diameter of fin (d_f) = 12mm

Thermal conductivity of material (K) = 110.7 W/m^2-k

Diameter of orifice (d_o) = 20mm

Width of duct (w) = 150mm

Breadth of duct (b) = 100mm

Coefficient of discharge (C_d) = 0.62

Density of manometric fluid (ƿ) = 13600 kg/m^3

4.4 Assumptions made

1. Steady state conduction with no heat generation in the fin
2. Thickness is small compared to length and width, i.e. one-dimensional conduction in x-direction only
3. Thermal conductivity of fin material is constant
4. Isotropic (i.e. const. k in all directions) and homogeneous (i.e. const. density) material
5. Uniform heat transfer coefficient over the entire length of fin and the base wall
6. Negligible radiation effect
7. The fin base temperature was constant for all type of materials

4.5 Procedure

1. Step the power input to the heater to desired level through the dimmerstat (VI)
2. Switch on the blower and set the air flow rate to desired value
3. Allow the system to attain steady state
4. At steady state record the temperatures on the surface (T_1, T_2, T_3, T_4, T_5) and the ambient temperature T_6
5. Note down the difference in two levels of limbs of manometers
6. Repeat the experiment by varying the air flow and keeping the power input to heater constant and varying power input and keeping the air flow constant to obtain the readings for various heat loads and air velocities

4.6 Tabulation

Table 4.1 tabulation

Voltmeter Reading volts	Ammeter Reading amps	Manometer reading h_1 cm	Manometer reading h_2 cm	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC	T_6 ºC
120	0.53	127	82	145	129	109	104	92	33
120	0.53	127	82	151	133	113	108	95	33
120	0.53	127	82	157	138	116	111	98	33
120	0.53	127	82	159	140	118	113	100	33

4.7 Calculations and results

10. Velocity of air at orifice,

$$V_o = C_d \sqrt{\frac{2gh(\rho_m - \rho_a)}{\rho_a} \quad . \quad \frac{1}{1-\beta}}$$

$$V_o = C_d \sqrt{\frac{2 * \ 9.81 * 4.5 * \ 10^{-3}(13.6 * 1000 - 1.17)}{1.17} \quad . \quad \frac{1}{0.5263}}$$

$$\rho_m = density\ of\ manometric\ fluid = 13.6 * \ 10^3 \frac{kg}{m^2}$$

$$\rho_a = density\ of\ air = \ 1.7 \ \frac{kg}{m^3}$$

11. Velocity of air in duct, V_a can be obtained by applying continuity equation.

    V_a × Cross sectional area of duct = V_o × cross sectional area of orifice

$$V_a = \frac{velocity\ ar\ orifice * cross\ sectional\ area\ of\ orifice}{cross\ sectional\ ara\ of\ duct}$$

$$V_a = \frac{V_o * \frac{\pi {d_o}^2}{4}}{W * B}$$

$$V_a = \frac{86.574 * \frac{\pi(20 * 10^{-3})^2}{4}}{0.15 * 0.100}$$

$$V_a = 1.8132\ m/s$$

12. Reynolds number, Re of air flow

$$R_e = V_a\ d_f / V$$

$$R_e = \frac{1.8132 * 12 * 10^{-3}}{21.09 * 10^{-6}}$$

$$R_e = 1031.69$$

$$for\ R_e\ 40\ to\ 4000\ \ c = 0.683\ n = 0.466$$

13. Prandtl number Pr = 0.692
14. Nusselt number Nu

$$N_u = C{R_e}^n {P_r}^{1/3} = 0.683 * 1031.69^{0.466} * 0.692^{1/3}$$

$$N_u = 15.326$$

15. Heat transfer coefficient can be calculated by using the correlation

$$h = N_u\ K / d_f$$

$$h = 15.326 * \frac{0.03047}{12} * 10^{-3}$$

$$= 38.915\, w/\,m^2K$$

$$m = \sqrt{\frac{hp}{KA}}$$

$$m = \sqrt{\frac{38.915 * \pi * 12 * 10^{-3}}{110 * \frac{\pi}{4} * (12 * 10^{-3})^2}}$$

$$m = 10.8593$$

16. Using the equation estimate the temperature T_o using T_1 at $x = x_1$

$$\frac{T - T_\infty}{T_o - T_\infty} = \frac{cosh[m(L-x)]}{cosh(mL)}$$

$$T = 32 + \frac{(159-32)cosh[10.8593 * (-150 - 0.045)]}{cosh\, 10.8593 * 0.15}$$

$$T = 114.69$$

17. Using T_o, estimate the other temperature values T_2, T_3, T_4, T_5 and compare with the temperatures recorded by thermocouples.

18. Effectiveness of fin $= \frac{\tanh(\,mL)}{\sqrt{\frac{hA}{kP}}}$

$$\frac{\tanh 10.8593 * 0.15}{\sqrt{\frac{38.915 * \frac{\pi}{4} * (12 * 10^{-3}\,)^2}{110 * \pi * 12 * 10^{-3}}}}$$

$$= 28.421$$

19. Efficiency of fin $= \frac{\tanh(\,mL)}{mL}$

$$\frac{\tanh(\,10.8593 * 0.15)}{10.8593 * 10.15} = 0.5684$$

4.8 Graphs

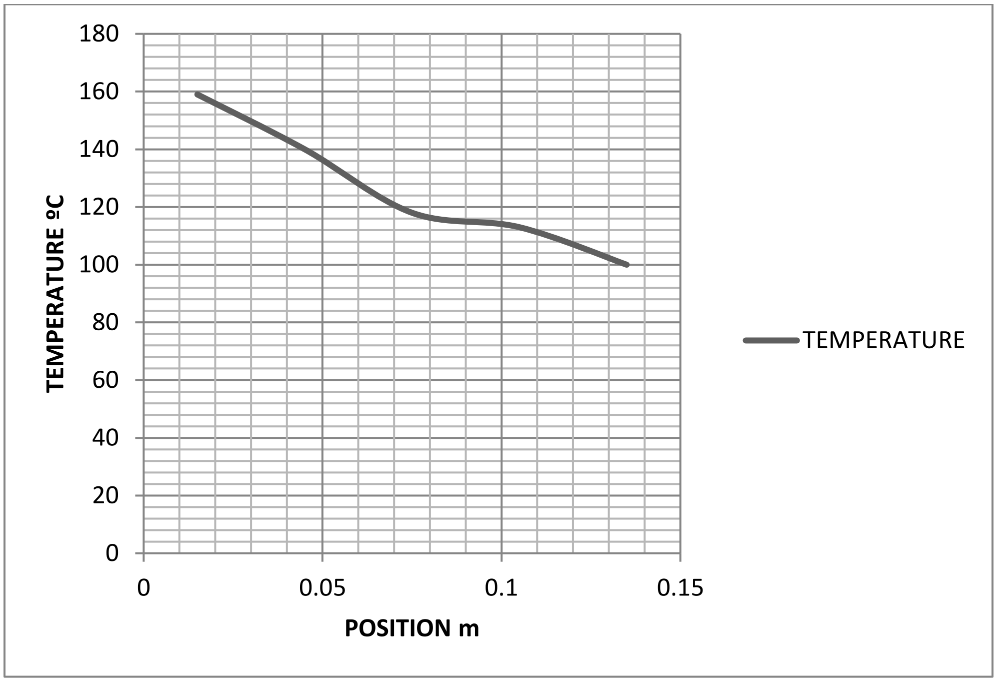


Fig 4.8 Temperature Vs Position

CHAPTER V

MODELING AND FEA

5.1 Introduction to finite element method

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is also referred to as finite element analysis (FEA). It subdivides a large problem into smaller, simpler parts. The simple equations that model these finite elements are then assembled into a large system of equations that models the entire problem. FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

The sub-division of a whole domain into simpler parts has several advantages:

- Accurate representation of complex geometry
- Inclusion of dissimilar metal properties
- Easy representation of total solution
- Capture of local effects

Most often it is not possible to ascertain the behavior of complex continuous system without some form of approximations. For simple members like uniform beams, plates etc., classical solutions can be sought by forming differential or integral equations through structures like machine tool frames, pressure vessels, automobile bodies, ships, air craft structures, domes etc., need some approximate treatment to arrive at their behavior, be it static deformation, dynamic properties or heat conducting property. Indeed these are continuous systems with their mass and electricity being continuously distributed.

The classical differential equation solution approach leads to intractability. To overcome this, engineers and mathematicians have from time to time proposed complex structures, which are defined using a finite number of well-defined components. Such systems are then regarded as discrete systems.

5.2 Historical background

The method originated from the need to solve complex elasticity and structural density problems in civil and aeronautical engineering. Its development can be traced back to work by A. Hrennikoff and R. Courant. In china, in the later 1950s and early 1960s, based on the computations of dam constructions, K. Feng proposed a systematic numerical method for solving partial differential equations. The method was called finite difference method based on variation principle, which was another independent invention of finite element method. Although the approaches used by these pioneers are different, they share one essential characteristic: mesh discretization of a continuous domain into set of discrete sub-domains, usually called elements.

Hrennikoff's work discritizes the domain by using a lattice analogy while Courant's approach divides the domain into finite triangular sub regions to solve second order elliptical partial differentiation equations (PDEs) that arise from the problem of torsion of a cylinder. Courant's contribution was evolutionary, drawing on a large body of earlier results for PDEs developed by Rayleigh, Ritz, and Galerkin.

The finite element method obtained its real impetus in the 1960s and 1970s by the developments of J. H. Argyris with the co-workers at the University of Stuttgart, R. W. Clough with the co-workers at UC Berkeley, O. C. Zienkiewicz with the co-workers Ernest Hinton, Bruce Irons and others at the university of Swansea, Philippe G. Ciarlet at the University of Paris 6 and Richard Gallagher with co-workers at Cornell University.

5.3 Need for finite element method

To predict the behavior of stricter the designer adopts three tools such as analytical, experimental and numerical methods. The analytical method is used for the regular sections of known geometric entities or primitives where the component geometry is expressed mathematically. The solution obtained through the analytical method is exact and takes less time. This method cannot be used for irregular sections and the shapes that require very complex mathematic equations. On the other hand the experimental method is used for finding the unknown parameters of interest. But the experimentation requires the testing equipment and a specimen for each behavior of requirement. This in turn, requires a high initial investment to procure the equipment and to prepare the specimens.

The solution obtained is exact by the time consumed to find the results and during the preparation of specimens also. There are many numerical schemes such as finite difference methods, Finite element method, Boundary element and volume method, Finite strip and volume method and Boundary Integral methods etc., are used to estimate the approximate solutions of acceptably tolerance.

5.4 The process of finite element method

A typical work out of the method involves (1) dividing the domain of problem into a collection of sub-domains, with each sub-domain represented by a set of element equations to the original problem, followed by (2) symmetrically recombining all sets of element equations into a global system of equations for final calculations. The global system of equations has the known solution techniques, and can be calculated from the initial values of the original problem to obtain a numerical answer.

In the first step above, the element equations are simple equations that locally approximate the original complex equations to be studied, where the original equations are often partial differential equations (PDE). To explain the approximation in the process, FEM is commonly introduced as a special case of Galerkin method. The process, in the mathematical language, is to construct an integral of the inner product of residual and the weight functions and set the integral to zero. In simple terms, it is a procedure that minimizes the error of approximation by fitting the trial function into the PDE. The residual is error caused by the trial function into the PDE. The residual is the error caused by trial functions, and the weight functions are polynomial approximation functions that project the residuals. The process eliminates all the spatial derivates from the PDE, thus approximating the PDE locally with

- A set of algebraic equations for steady state problems and
- A set of ordinary differential equations for transient problems.

These equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equations sets that rise in the steady state problems are solved using numerical linear algebraic methods, while ordinary differential equation sets that rise in the transient problems are solved by the numerical integration using standard techniques such as Euler method and Runge-Kutta method.

In step (2) above, a global system of equations is generated from the element equations through the transformation of coordinates from the sub-domains local nodes to the global domain nodes. This spatial transformation includes approximate orientation adjustments as applied in relation to the reference condition system. The process is often carried out by FEM software using co-ordinate data generated by sub-domains.

5.5 Field and boundary conditions

The field variables such as displacements, strains and stresses must satisfy the governing conditions, which can be mathematically expressed in the form of differential equations.

For structure mechanic problems the boundary conditions may be kinematic i.e., where the displacements (and slopes i.e., derivative of displacement) may be prescribed. Initial values are given to problems where time is involved. The specified temperature or heat flow/heat flux or convections may be specified in thermal analysis.

5.6 Steps involved in finite element modelling

The steady state thermal analysis is used to determine temperature, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary with time. A steady state thermal analysis calculates the effects of steady thermal loads on a system or component. In this method the structure is assumed to be build of numerous connected tiny elements. From this comes the name “Finite Element Method“. Extremely complex structures can also be simulated by proper arrangement of these elements. The most commonly used elements are beams, solids, plates, prismatic shapes etc. The points interconnecting the elements are called nodes. The broad steps in the finite element method when it is applied to thermal analysis are as follows:

1. Divide the continuum into a finite number of sub regions of simple geometry such as line segments, triangles, quadrilaterals. (Square and rectangular elements are subsets of quadrilateral), tetrahedrons and hexahedrons (cubes) etc
2. Nodes are assigned to location in the element at which unknown function, such as temperature is to be determined. Nodes are often placed at corners of elements, but additional nodes can be placed internally or along the element boundaries
3. A shape function is assumed within each element so that temperature at desired nodes can be found
4. Satisfy the temperature distribution and convection and heat flow relations within a typical element
5. Determine the thermal nodal loads for typical element which may involve initial temperature, heat flow and convections
6. Develop equilibrium equations for nodes of the discretized continuum in terms of element contributions
7. Solve the equilibrium for the nodal elements with given heat flow and convection.
8. Calculate the temperature and heat flux at selected points within the element.

5.7 Applications of finite element method

Since early 1960s there has been much progress in the method. The method requires a large number of computations requiring a fast computer. Infact digital computer advances have been responsible for expanding usage of finite element method. A rigorous mathematical basis to the finite element method was provided in 1973 with the publication by Strang and fix. The Finite element method was initially developed to solve structural steel problems. Its use, of late, has been rapidly extended to various fields. The method has since been generalized for the numerical modeling of physical systems in a wide variety of engineering disciplines, e.g., electromagnetism, heat transfer, fluid dynamics.

NASA sponsored the original version of NASTRAN, and UC Berkeley made the finite element program SAP IV widely available. In Norway the ship classification society Det Norske Veritas (now DNV GL) developed Sesam in 1969 for use in analysis of ships.

5.8 3D Modeling of pin fin

The 3D modeling of pin fin is performed in SOLIDWORKS modeling software.

5.8.1 Introductions to solid works

SOLIDWORKS is a solid modeling computer aided design (CAD) and computer aided engineering (CAE) computer program that runs on Microsoft windows. SOLIDWORKS is published by DASSAULT SYSTEMS.

SOLIDWORKS uses sketch entities and tools to facilitate the creation of parts. While sketch entities have specific geometries (line, rectangle, parallelogram, slot, polygon, circle, arc, ellipse, parabola, spline, etc.), some of the sketch tools (fillet, chamfer, offset, convert entities, intersection curves, trim, extend, split, jog line, constructive geometry, mirror, stretch, move, rotate, scale, copy, pattern, etc.) are used to modify the shapes of sketch entities. Entities are grouped to define the boundary or profile, which are closed regions needed for creating extruded or revolved parts. SOLIDWRKS sketch entities and tools can be accessed by clicking the tools bar.

Sketch entities include line, rectangle (2-opposite vertices, centre, 2-opposite vertices, 3-point corner,3-point centre), parallelogram, slot (straight, centre-point straight, 3-arc, center-point arc), polygon, circle (centre-1-point,3-points on perimeter), arc(center-2-point, tangent, 3-point arc), ellipse(full, partial), parabola, and spline.

Sketch tools include fillet, chamfer, offset, convert entities, intersection curves, trim, extend, split entities, jog line, construction geometry, make path, mirror (straight, dynamic), stretch entities, move entities, rotate entities, scale entities, copy entities, and pattern (linear, circular).

5.8.2 Steps involved in modeling

The modeling is done by following three steps

a. Creation of body

The body is created by the sketch entities and feature entities with the available dimensions of the fin. A sketch of front view of fin is generated and is extruded to required depth or thickness. Another sketch is developed to provide perforations for Fin. Extruded cut feature of this sketch creates a hole in the body. Linear pattern of extruded cut feature operation creates the required number of holes. The part is saved in standard format of '.SLDPRT' for the assembly operation.

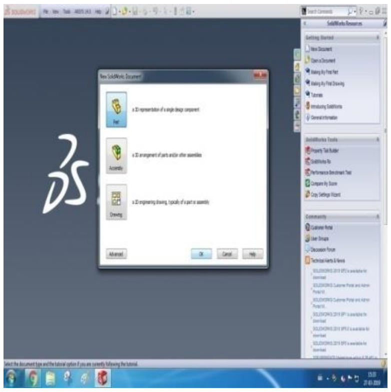


Fig. 5.1 Part module in solid works

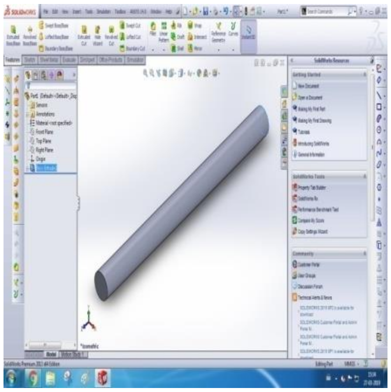
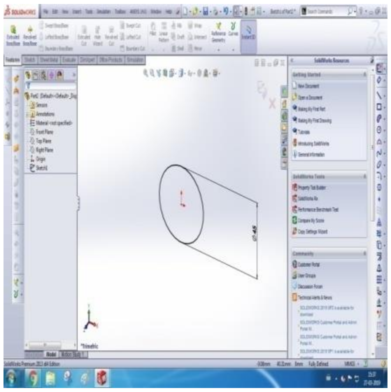


Fig. 5.2 Extruded fin in solid works

b. Creation of Chip

The body is created by sketch entities band feature entities with the available dimensions of chip. A sketch of front view of the chip is generated and is extruded to required depth or thickness. The part is saved in standard format of '.SLDPRT' for the assembly operation



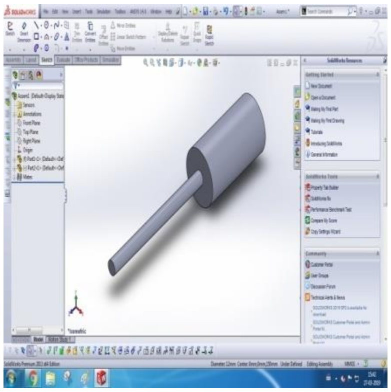


Fig. 5.3 Chip Modeling in solid works Fig.5.4 Assembly off body and chip

c. Assembling the body and chip

The assembly of the pin fin was prepared in the assembly file of SOLIDWORKS. The two part files are imported into the assembly file. The body and the chip are joined together by the use of mate option three mating are given for the complete assembly. The mating can be given in many ways. Here the surface area of whole body and matching surface area of the chip are selected. The assembled pin fin is as shown in the figure. It is saved in the '.igs ' format to be used in the ANSYS WORKBENCH for the analysis work.

5.9 Analysis

Analysis of the fin is done in ANSYS MECHANICAL WORKBENCH software considering the designing conditions and material properties of aluminuim, copper, brass, bronze, stainless steel, polymers etc.,

5.10 History of ansys

ANSYS, Inc. is an American computer aided engineering software developer headquartered south of Pittsburgh in Cecil Township, Pennsylvania, United States. ANSYS publishes engineering analysis software across a range of disciplines including finite element analysis, structural analysis, computational fluid dynamics, explicit and implicit methods, and heat transfer.

The company was founded in 1970 by John A. Swanson as *Swanson Analysis Systems, Inc* (SASI). Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static(stationary), dynamic (moving) and thermal (heat transfer) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold to TA associates. The new owners took SASI's leading software, called ANSYS, as their flagship product and designated ANSYS, Inc. as the new company name.

5.11 Introduction to ansys mechanical

ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, non-linear and dynamic studies. This computer simulation product provides finite element to model behavior, and supports material models and equation solvers for wide range of mechanical design problems. ANSYS Mechanical also include thermal analysis and coupled physics, capabilities, involving acoustics, piezoelectric, thermal-structural and thermoelectric analysis.

This type of analysis involves is typically used for design and optimization of a system far too complex to be analyzed by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as Physics and Chemistry Departments.

ANSYS provides a cost-effective way to explore the performance of the products or process in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in level of the risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effects of design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

5.12 Steps involved in the analysis of the fin

1. Save the 3d solid assembly of fin created using SOLIDWORKS in “.igs” format
2. Steady state thermal analysis module is selected from the Analysis system toolbox menu of ANSYS WORKBENCH 15.0, so as to perform a steady state thermal analysis on the pin fin for determination of temperature distribution

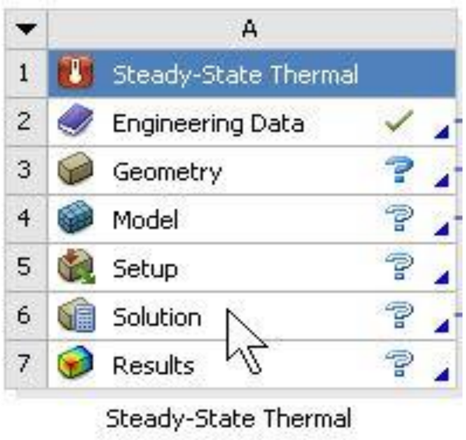
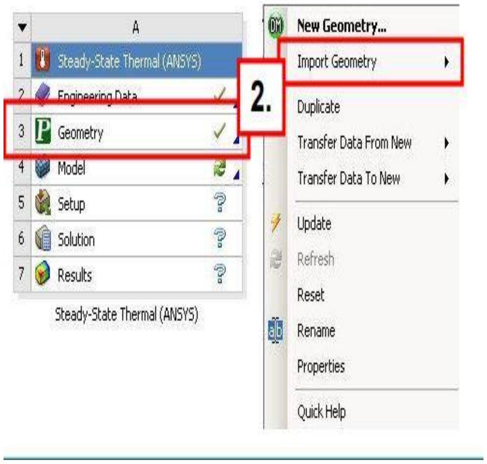


Fig. 5.5 Analysis System Tool Box

3. The Steady state thermal module is placed on the project schematic window of WORKBENCH. All the material properties of the materials required for the analysis are entered in engineering data section of steady state thermal module
4. The ‘.igs’ file is imported into the Geometry (Design Modular) section of Steady state thermal module, and the 3D solid assembly is generated in order to work under ANSYS environment. The 3D solid’s surface is divided into the sections for facilitating the loading points during analysis



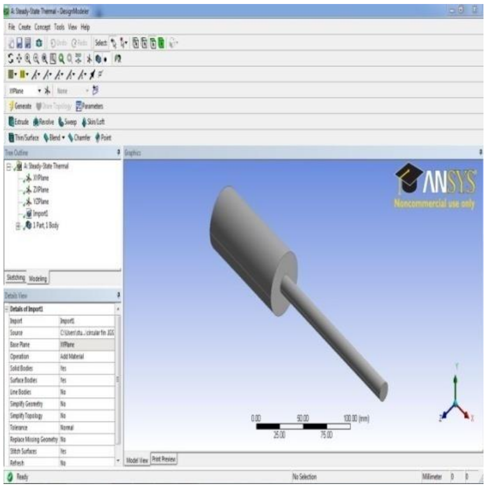
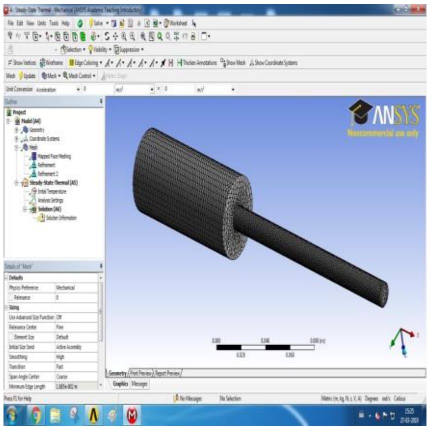


Fig. 5.6 Importing geometry

Fig. 5.7 Generating solid works model

5. The process of FEA is done in the MECHANICAL MODEL window. The window is opened below.
6. The materials are assigned in the geometry sections of mechanical model window
7. Contact regions are given as the 3D solid assembly consists of a fin body and chip. A solid-solid bonded contact was given at the region as the bond strength of fin and chip
8. Meshing of the 3D solid assembly is performed with a hexagonal-sweep method with a size of 20mm for the fin and tetragonal method with a size of 20mm for the solid



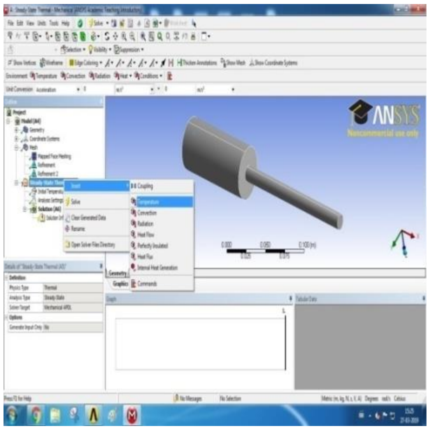


Fig. 5.8 Meshing in ANSYS

Fig. 5.9 Inserting Temperature

9. The load setup is given to the model as below
   - **a.** An Initial value of temperature is given.
   - **b.** Convection is applied to the surfaces of fin
   - **c.** Other possible thermal loads include heat flux, heat flow, heat generation and radiation

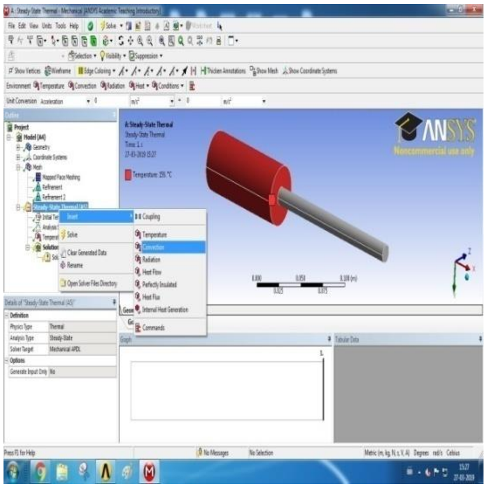


Fig. 5.10 Inserting convection

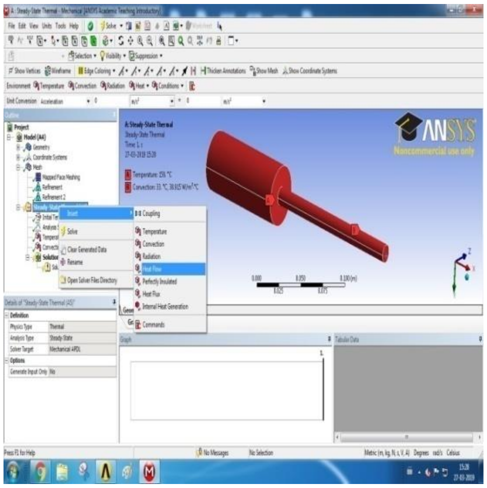


Fig. 5.11 Inserting Heat Flow

10. The solver module is used to obtain the solution for the given boundary conditions to the model. The required temperature distribution is evaluated for given loading conditions

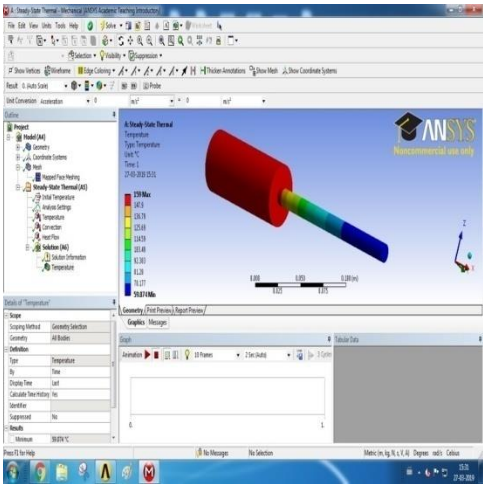


Fig. 5.12 Temperature distribution in ANSYS

11. Results obtained in the FEA analysis using ANSYS are noted for comparison purpose

12. This process is repeated for all the cases of varying geometry and varying loads with different materials and corresponding temperature distributions are plotted.

5.13 Geometry of fin

Table 5.1 Geometry of fin

Fin configuration	Volume	Surface area	Dimensions	Height
Circular	1.696×10^-5 m^3	5.88×10^-3 m^2	D=0.012 m	0.15 m
Rectangular	1.696×10^-5 m^3	6.98×10^-3 m^2	l=0.015 m, b=0.0075m	0.15 m
Triangular	1.696×10^-5 m^3	7.498×10^3m^2	S=0.01616 m	0.15 m

5.13.1 Types of perforations

1. Solid with no perforation
2. Solid with circular perforation
3. Solid with rectangular perforation
4. Solid with elliptical perforation
5. Solid with pentagonal perforation

5.13.2 Dimensions of perforation

Table 5.2 Dimensions of perforations

Perforation	Dimensions	No. of perforations	Spacing of each perforation
Circular	3 mm	4 holes	30 mm
Rectangular	3 mm (l=3mm,b=1.5mm)	4 holes	30 mm
Elliptical	3 mm (a=3mm,b=1.5mm)	4 holes	30 mm
Pentagonal	3 mm(inscribed in circle r=3)	4 holes	30 mm

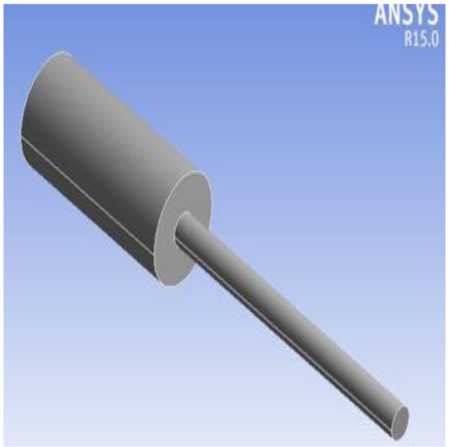


Fig.5.13 Solid with no perforation

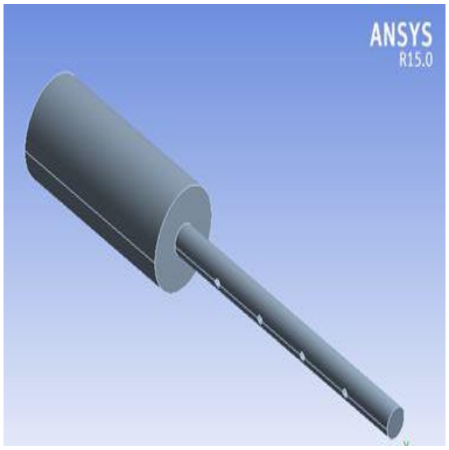


Fig.5.14 Solid with circular perforation

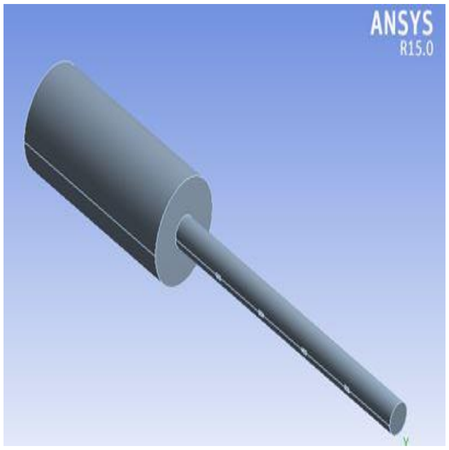


Fig.5.15 Solid with rectangular perforation

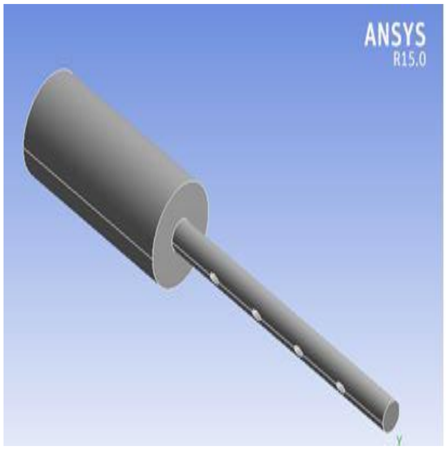


Fig.5.16 Solid with elliptical perforation

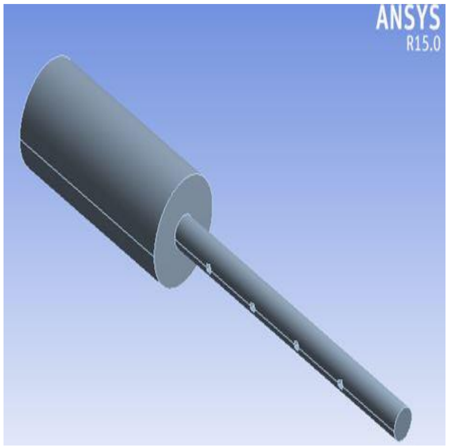


Fig.5.17 Solid with polygonal perforation

CHAPTER VI

RESULTS AND DISCUSSIONS

6.1 Theoretical analysis of fins

The theoretical analysis of fin is done for Aluminium fin of 12 mm diameter and length of 150 mm acted upon by a heat load of 63.6 watts at base and the ambient temperature was 33 ºC and the base of fin is at constant temperature of 159ºC.

The theoretical analysis of fin is done by using the correlations of fins and the resulting temperatures are obtained are compared with those obtained by experimental analysis.

6.1.1 Temperature distribution table

Table 6.1 Temperatures theoretical and experimental values

Position m	Theoretical Temperature ºC	Experimental Temperature ºC
0.015	159	159
0.045	114.69	140
0.075	96.736	118
0.105	85.818	113
0.135	80.61	100

It is observed that the temperature readings obtained in theoretical and experimental has vast difference and these should be solved by finite element analysis to obtain the accurate result

6.1.2 Temperature distribution graph

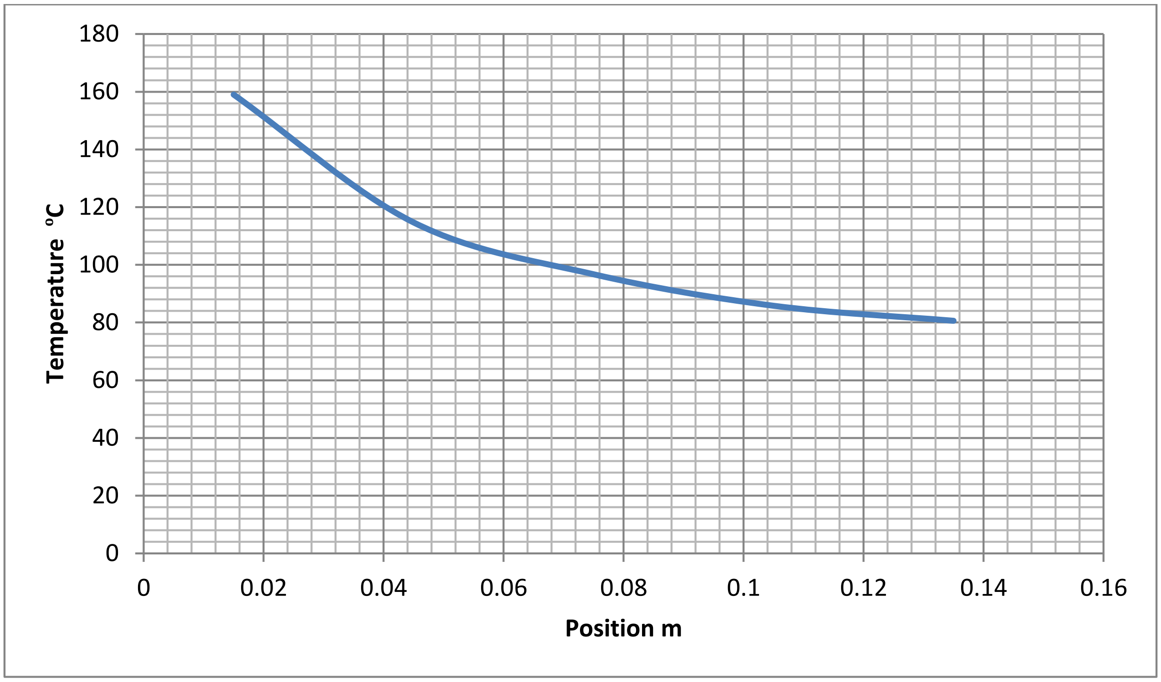


Fig. 6.1 Temperature vs Position (Theoretical)

6.2 Experimental analysis

The Experimental analysis of fin is done for Aluminium fin of 12 mm diameter and length of 150 mm acted upon by a heat load of 63.6 watts at base and the ambient temperature was 33 ºC.

The various temperature readings are obtained by using thermocouples at various locations and heat input is supplied by heater and the corresponding readings of voltmeter and ammeter and temperature are taken by using Digital instruments and the values are tabulated

The readings are taken until the steady state condition is reached

The experimental analysis was done at ANIL NEEERUKONDA INSTITUTE OF TECHNOLOGY COLLEGE in Heat transfer lab of MECHANICAL ENGINEERING DEPARTMENT.

6.2.1 Tabulation of experimental data

Table 6.2 Experimental Data

Voltmeter Reading volts	Ammeter Reading amps	Manometer reading h_1 cm	Manometer reading h_2 cm	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC	T_6 ºC
120	0.53	127	82	145	129	109	104	92	33
120	0.53	127	82	151	133	113	108	95	33
120	0.53	127	82	157	138	116	111	98	33
120	0.53	127	82	159	140	118	113	100	33

6.2.2 Temperature distribution

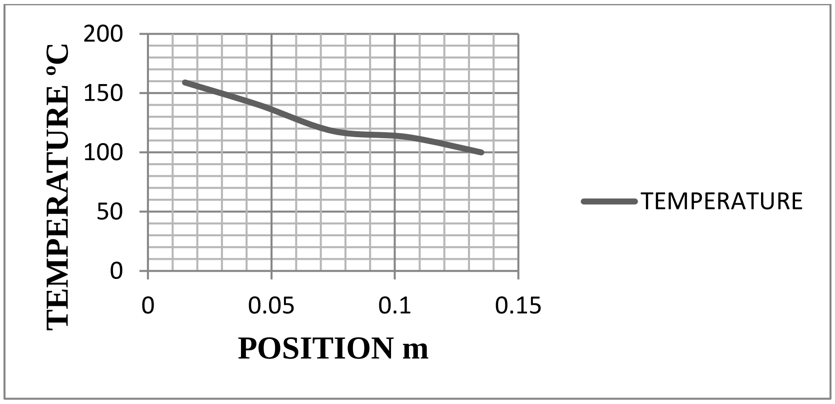


Fig.6.2 Temperature vs Position(Experimental)

6.3 Finite element results tabulation

The tabulation consists of the various temperatures at respective positions for pin fin for different materials in different mediums and different type of perforations. Each and every type of fins temperature is tabulated.

6.3.1 Plane solid with no perforations in air medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	146	126	112	101	93.74
	copper	159	152	140	131	126	122.37
	stainless steel	159	116	70	49.5	40.6	35.77
	brass	159	141	114	96.3	85.4	78.96
	silver	159	152	141	133	127	124.2
TRIANGULAR	Aluminium	159	147.3	129.7	121.1	94.54	89.115
	copper	159	152.1	141.01	131.2	120.8	118.82
	stainless steel	159	138.3	107.1	76.03	44.92	34.6464
	brass	159	142	116.5	91.08	65.61	57.119
	silver	159	152.4	142.5	132.6	122.7	120.77
RECTANGULAR	Aluminium	159	140.95	138.02	126.4	111.21	100.58
	copper	159	151.02	148.9	128.62	122.91	117.68
	stainless steel	159	137.92	119.4	91.2	51.98	34.51
	brass	159	138.22	121.48	119.2	91.8	73.305
	silver	159	140.22	137.2	131.2	122.9	119.74

6.3.2 Plane solid with no perforation in hydrogen medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	142.2	116.9	91.6	66.36	57.94
	copper	159	148.4	138.2	126.38	101.22	88.028
	stainless steel	159	138.2	107.21	75.84	44.65	39.02
	brass	159	149.8	131.3	103.7	76.04	48.382
	silver	159	147.6	130.4	113.3	96.04	90.482
TRIANGULAR	Aluminium	159	141.6	115.4	89.24	63.08	54.36
	copper	159	146.01	126.6	107.2	87.7	83.48
	stainless steel	159	138.01	106.6	75.56	43.71	37.48
	brass	159	138.8	108.63	78.49	48.18	38.08
	silver	159	146.52	122.22	108.94	90.07	85.94

RECTANGULAR	Aluminium	159	138.1	106.6	75.22	64.78	64.294
	copper	159	148.7	128.2	117.9	97.39	82.099
	stainless steel	159	138.01	106.4	74.9	43.36	33.049
	brass	159	145.22	117.6	85.44	53.46	45.175
	silver	159	138.5	128.3	107.9	97.62	84.631

6.3.3 Plane solid with no perforation in argon medium

FIN	MATERIAL	T_b °C	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C
CIRCULAR	Aluminium	159	138.07	133.02	129.08	124.59	122.93
	copper	159	157.5	153.2	148.8	144.5	141.54
	stainless steel	159	138.42	119.44	96.42	51.34	39.499
	brass	159	158.48	149.25	143.24	126.44	109.85
	silver	159	159.92	151.23	144.24	143.21	142.6
TRIANGULAR	Aluminium	159	152.9	143.7	134.5	125.3	122.5
	copper	159	155.9	151.2	146.2	141.8	141.11
	stainless steel	159	140.32	122.96	111.84	90.48	84.434
	brass	159	147.6	130.4	113.3	96.19	90.486
	silver	159	156.1	151.7	147.3	143.2	142.14
RECTANGULAR	Aluminium	159	145.6	134.6	132.02	131.7	130.26
	copper	159	152.7	149.3	148.02	142.07	140.49
	stainless steel	159	138.02	127.5	95.95	64.12	44.164
	brass	159	140.09	131.02	128.4	111.8	108.6
	silver	159	158.09	152.3	150.9	145.48	141.6

6.3.4 Circular perforation in air medium

FIN	MATERIAL	T_b °C	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C
CIRCULAR	Aluminium	159	141.31	119.56	101.27	89.908	83.243
	copper	159	148.84	136.44	125.47	118.29	114.01
	stainless steel	159	102.95	60.437	42.53	36.22	34.088
	brass	159	134.01	109.754	88.829	76.263	69.148
	silver	159	148.98	137.64	127.7	120.23	116.1

TRIANGULAR	Aluminium	159	146.43	129.39	109.37	93.505	87.129
	copper	159	151.56	137.97	127.71	121.11	117.24
	stainless steel	159	116.75	67.231	43.356	36.807	34.427
	brass	159	142.69	111.67	91.49	79.366	72.687
	silver	159	152.46	138.97	129.28	122.85	119.24
RECTANGULAR	Aluminium	159	141.31	119.56	101.27	89.908	83.243
	copper	159	148.84	136.44	125.47	118.29	114.01
	stainless steel	159	102.95	60.437	42.53	36.22	34.088
	brass	159	134.01	109.37	88.829	76.263	69.148
	silver	159	148.98	137.64	127.07	120.23	116.1

6.3.5 Circular perforation in hydrogen medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	115.76	86.669	68.833	58.627	55.021
	copper	159	131.4	110.29	95.77	87.506	84.24
	stainless steel	159	61.217	38.442	34.098	33.209	33.062
	brass	159	107.71	75.637	58.096	49.535	46.258
	silver	159	132.67	111.91	97.912	89.851	86.69
TRIANGULAR	Aluminium	159	135.56	97.009	73.371	60.02	53.014
	copper	159	144.91	117.48	99.204	87.891	81.456
	stainless steel	159	95.32	44.001	34.937	33.344	33.044
	brass	159	131.57	86.588	62.785	50.832	44.819
	silver	159	145.36	119.01	101.26	90.261	83.986
RECTANGULAR	Aluminium	159	135.93	94.768	70.749	54.474	50.953
	copper	159	143.84	115.41	96.305	84.597	77.807
	stainless steel	159	92.221	42.747	34.549	33.196	33.028
	brass	159	118.39	84.464	60.857	48.917	43.051
	silver	159	139.57	117.17	98.571	86.893	80.21

6.3.6 Circular perforation in argon medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	145.71	135.96	128.75	124.59	123.06
	copper	159	152.76	147.85	144.33	142.18	141.42
	stainless steel	159	103.56	71.54	56.73	46.22	45.179
	brass	159	140.89	127.52	117.87	112.43	110.45
	silver	159	152.9	148.48	145.52	143.18	142.42
TRIANGULAR	Aluminium	159	152.03	140	130.68	124.56	121
	copper	159	156.01	149.77	145.11	142.04	140.21
	stainless steel	159	130.55	85.366	61.655	49.645	43.824
	brass	159	150.33	133.05	120.64	112.63	108.02
	silver	159	130.55	85.308	61.495	45.586	43.824
RECTANGULAR	Aluminium	159	152.36	138.62	128.52	121.6	117.92
	copper	159	155.77	148.95	143.21	140.41	138.46
	stainless steel	159	129.47	83.587	59.593	46.46	42.159
	brass	159	149.8	131.4	116.22	109.94	104.46
	silver	159	155.9	149.41	144.07	141.18	139.63

6.3.7 Rectangular perforation air medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	157.181	135.98	119.39	109.83	106.02
	copper	159	158.45	147.2	138.41	133.09	131.04
	stainless steel	159	149.44	81.995	51.637	40.822	37.65
	brass	159	156.32	128.58	107.76	95.911	91.355
	silver	159	158.33	147.48	139.6	134.49	132.54
TRIANGULAR	Aluminium	159	129.54	108.54	94.54	86.68	83.523
	copper	159	142.64	129.74	122.22	116.08	114.54
	stainless steel	159	76.904	47.54	38.96	34.83	33.113
	brass	159	122	97.082	81.6	72.705	69.409

TRIANGULAR	silver	159	143.21	131.64	123.91	118.006	116.34
RECTANGULAR	Aluminium	159	129.96	110.3	95.205	87.021	84.231
	copper	159	143.81	131.07	122.2	116.88	114.48
	stainless steel	159	80.452	49.605	38.705	35.139	34.173
	brass	159	124.75	98.824	82.593	73.381	70.043
	silver	159	144.52	132.54	123.98	118.6	116.91

6.3.8 Rectangular perforation in hydrogen medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	154.97	115.82	89.069	74.036	68.623
	copper	159	156.91	133.04	114.83	104.46	100.38
	stainless steel	159	139.09	58.31	38.069	34.003	33.313
	brass	159	152.74	106.5	76.81	61.955	56.657
	silver	159	157.75	133.49	116.89	106.66	102.74
TRIANGULAR	Aluminium	159	109.93	80.143	63.89	53.692	50.839
	copper	159	127.1	103.61	89.63	80.944	78.081
	stainless steel	159	55.23	36.52	35.54	33.106	33.029
	brass	159	100.14	68.039	54.55	45.667	43.812
	silver	159	128.27	106.21	91.23	83.512	80.492
RECTANGULAR	Aluminium	159	113.6	82.112	64.054	54.42	51.041
	copper	159	129.2	105.79	90.695	81.096	78.752
	stainless steel	159	57.991	43.387	33.701	33.122	33.033
	brass	159	104.33	71.577	54.747	46.521	43.498
	silver	159	130.09	107.56	92.921	84.376	81.169

6.3.9 Rectangular perforation in argon medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	145.63	136.07	129.24	125.81	123.59
	copper	159	152.81	148.52	144.49	142.44	141.72
	stainless steel	159	101.81	71.19	55.973	45.55	45.538
	brass	159	148.65	127.38	118.38	113.9	111.08

CIRCULAR	silver	159	154.25	148.68	145.54	143.34	142.72
TRIANGULAR	Aluminium	159	144.11	133.42	124.71	119.92	118.52
	copper	159	151.69	145.81	141.49	139.47	138.6
	stainless steel	159	99.19	69.647	54.00	44.99	42.286
	brass	159	138.6	123.7	115.07	107	104.73
	silver	159	152.24	146.53	142.96	140.57	139.76
RECTANGULAR	Aluminium	159	145.52	133.84	125.54	120.64	118.71
	copper	159	152.33	146.54	142.43	139.9	138.92
	stainless steel	159	103.441	70.71	53.284	45.42	42.579
	brass	159	140.27	124.73	114.13	107.82	105.37
	silver	159	152.7	147.27	143.39	140.98	140.07

6.3.10 Elliptical perforaation in air medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	134.96	113.78	99.947	91.428	88.002
	copper	159	145.36	133.69	125.19	120.14	117.92
	stainless steel	159	86.44	56.738	40.392	37.775	34.538
	brass	159	127.84	103.37	86.5	77.254	73.51
	silver	159	146.66	135	127.07	121.97	119.9
TRIANGULAR	Aluminium	159	146.26	117.21	97.059	84.19	76.573
	copper	159	150.52	128.72	113.29	101.68	96.967
	stainless steel	159	134.21	82.744	52.076	40.046	34.2
	brass	159	140.40	98.143	72.525	57.72	49.271
	silver	159	150.77	126.97	115.25	105.58	99.604
RECTANGULAR	Aluminium	159	134.96	113.78	99.947	91.248	88.022
	copper	159	145.36	133.69	125.19	120.14	117.92
	stainless steel	159	86.44	56.738	40.392	37.775	34.538
	brass	159	127.84	103.07	86.5	77.254	73.51
	silver	159	146.66	135	127.07	121.97	119.9

6.3.11 Elliptical perforation in hydrogen medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	117.24	86.166	67.494	57.493	53.688
	copper	159	132.65	109.6	94.826	85.925	82.4
	stainless steel	159	63.377	38.351	34.004	33.189	33.05
	brass	159	109.21	75.583	57.487	48.457	45.294
	silver	159	133.46	111.41	96.77	88.346	84.842
TRIANGULAR	Aluminium	159	139.68	96.39	71.61	56.548	50.659
	copper	159	144.11	108.68	86.256	72.849	65.054
	stainless steel	159	94.894	37.814	33.536	33.087	33.005
	brass	159	131.11	78.061	54.049	42.213	38.216
	silver	159	144.68	110.07	88.23	75.06	67.032
RECTANGULAR	Aluminium	159	124.48	94.321	68.33	54.589	47.469
	copper	159	137.4	114.39	93.164	80.466	73.714
	stainless steel	159	65.399	42.375	34.351	33.814	33.015
	brass	159	115.03	83.808	58.781	46.809	41.095
	silver	159	136.17	115.66	95.311	82.733	75.717

6.3.12 Elliptical perforation in argon medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	145.67	135.57	127.53	123.60	121.65
	copper	159	152.41	147.34	143.64	141.41	140.58
	stainless steel	159	101.58	70.499	54.54	46.522	44.277
	brass	159	140.02	126.11	116.04	110.94	108
	silver	159	152.83	147.54	144.61	142.68	141.68
TRIANGULAR	Aluminium	159	152.43	138.89	127.08	121.34	116.93
	copper	159	155.37	145.74	137.75	133.23	130.78
	stainless steel	159	130.45	71.744	53.008	41.411	37.677
	brass	159	149.43	125.25	108.41	97.652	91.109
	silver	159	155.57	145.33	138.898	134.47	132.35

RECTANGULAR	Aluminium	159	146.76	137.39	125.95	118.26	113.81
	copper	159	153.72	148.18	142.28	138.41	135.98
	stainless steel	159	116.2	81.891	57.544	45.855	40.322
	brass	159	144.52	129.83	115.1	105.49	99.823
	silver	159	154.07	148.78	143.25	139.53	137.26

6.3.13 Pentagonal perforation in air medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	139.72	117.08	107.99	93.747	89.285
	copper	159	148.45	136.08	127.28	121.76	118.94
	stainless steel	159	96.783	56.287	41.982	36.477	34.675
	brass	159	135.53	107.44	90.311	79.622	74.705
	silver	159	149.04	137.28	128.91	123.55	120.89
TRIANGULAR	Aluminium	159	145.46	133.23	124.84	119.68	117.52
	copper	159	152.32	146.23	141.95	139.34	138.22
	stainless steel	159	104.49	69.695	52.874	44.189	41.956
	brass	159	140.666	124.4	113.29	106.72	104.01
	silver	159	152.69	147	142.95	140.43	139.4
RECTANGULAR	Aluminium	159	152.45	138.41	128.09	121.8	117.27
	copper	159	155.84	148.81	143.65	140.19	138.07
	stainless steel	159	130.49	82.623	59.077	47.48	41.835
	brass	159	150	131.08	117.5	108.75	103.75
	silver	159	156.05	149.44	144.5	141.24	139.26

6.3.14 Pentagonal perforation in hydrogen medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	124.9	91.414	71.195	59.821	54.573
	copper	159	137.27	113.72	97.808	88.186	83.647
	stainless steel	159	72.567	40.067	34.45	33.278	33.058
	brass	159	117.53	81.023	60.593	50.3	45.934

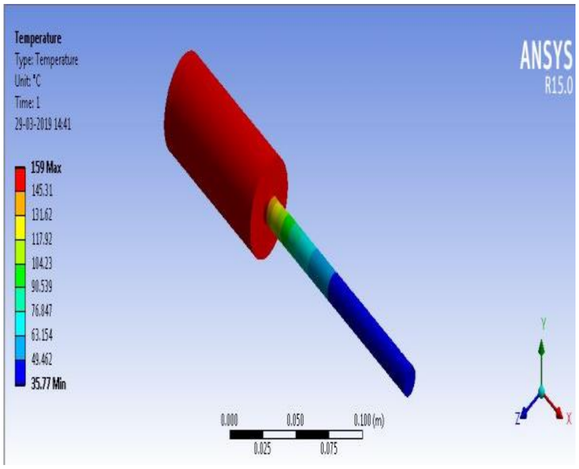
CIRCULAR	silver	159	138.17	115.64	100.03	90.565	86.096
TRIANGULAR	Aluminium	159	145.46	133.32	124.84	119.689	117.52
	copper	159	152.32	146.33	141.95	139.34	138.22
	stainless steel	159	104.49	69.695	52.874	44.189	41.956
	brass	159	140.66	124.4	113.79	106.72	104.01
	silver	159	152.69	147.0	142.95	140.43	139.4
RECTANGULAR	Aluminium	159	136.47	95.032	70.577	57.062	49.491
	copper	159	144.47	115.25	95.86	83.895	77.035
	stainless steel	159	94.375	42.708	34.563	33.241	33.025
	brass	159	131.46	83.737	60.366	48.519	42.705
	silver	159	144.99	116.38	97.44	86.099	79.4350

6.3.15 Pentagonal perforation in argon medium

FIN	MATERIAL	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC
CIRCULAR	Aluminium	159	149.49	138.41	130.34	125.17	122.62
	copper	159	154.44	149.05	145.03	142.49	141.72
	stainless steel	159	116.82	79.2	59.2	49.187	44.58
	brass	159	145.84	130.37	120.06	113.22	109.93
	silver	159	154.72	149.55	145.83	143.41	142.21
TRIANGULAR	Aluminium	159	145.37	133.33	124.81	113.685	117.53
	copper	159	152.45	146.29	141.93	139.29	138.18
	stainless steel	159	104.2	70.033	52.707	44.841	41.958
	brass	159	140.5	124.24	113.34	106.67	104.01
	silver	159	152.75	147.03	142.96	140.06	139.41
RECTANGULAR	Aluminium	159	152.5	138.45	128.18	121.36	117.27
	copper	159	155.86	148.88	143.66	140.19	138.07
	stainless steel	159	129.99	82.813	59.288	47.461	41.835
	brass	159	141.44	131.04	117.59	108.86	103.71
	silver	159	156	149.46	144.56	141.23	139.26

6.4 Finite element analysis solved models

Fig. 6.1-6.25	Air medium	Fig. 6.126-6.150	Argon medium
Fig. 6.26-6.50	hydrogen medium	Fig. 6.151-6.175	Air medium
Fig. 6.51-6.75	Argon medium	Fig. 6.176-6.200	hydrogen medium
Fig. 6.76-6.100	Air medium	Fig. 6.201-6.225	Argon medium
Fig. 6.101-6.125	hydrogen medium		



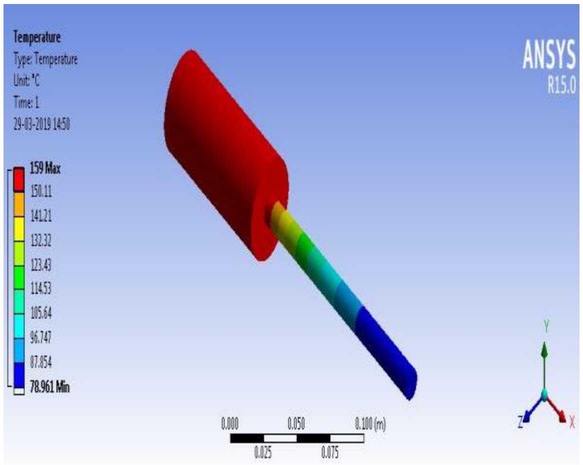
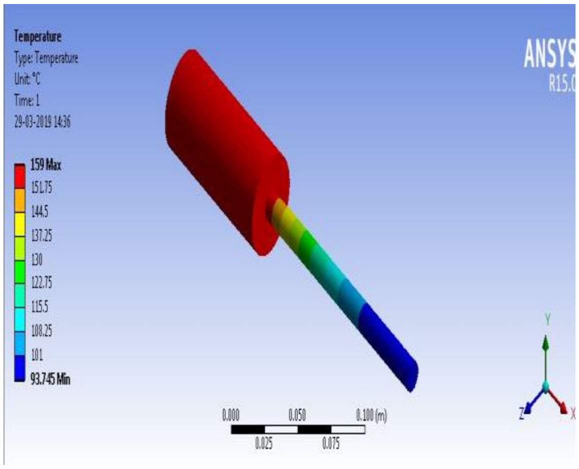


Fig.6.1 Stainless steel circular fin

Fig.6.3 Brass circular fin



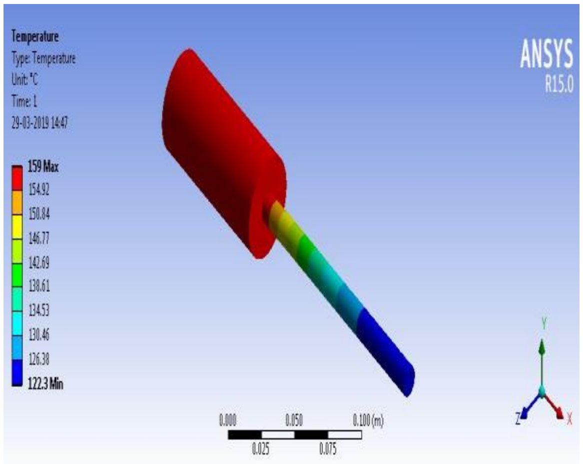


Fig.6.2 Aluminium circular fin

Fig.6.4 Copper circular fin

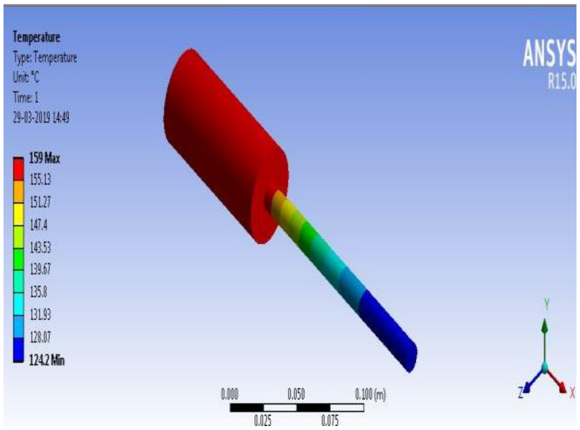


Fig.6.5 Silver circular fin

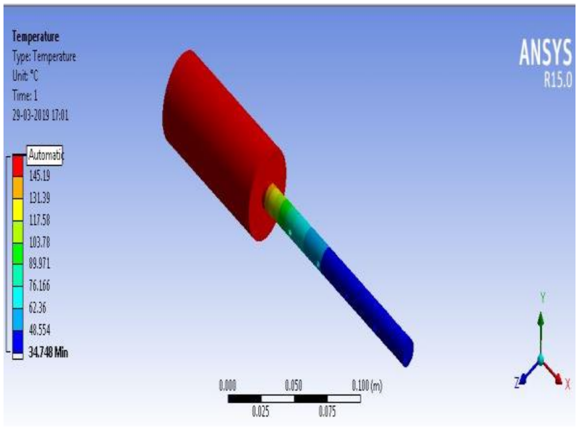


Fig.6.6 Stainless steel circular fin circular holes

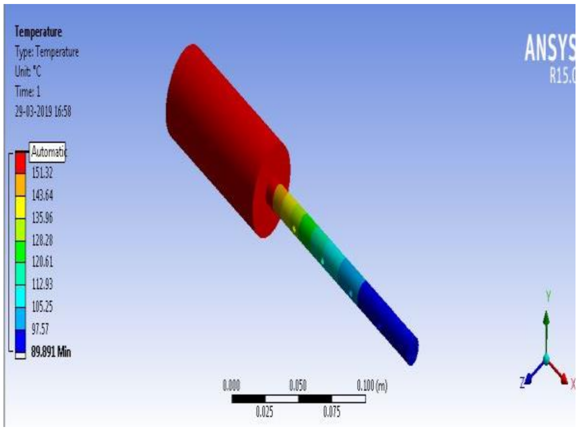


Fig.6.7 Aluminium circular fin circular holes

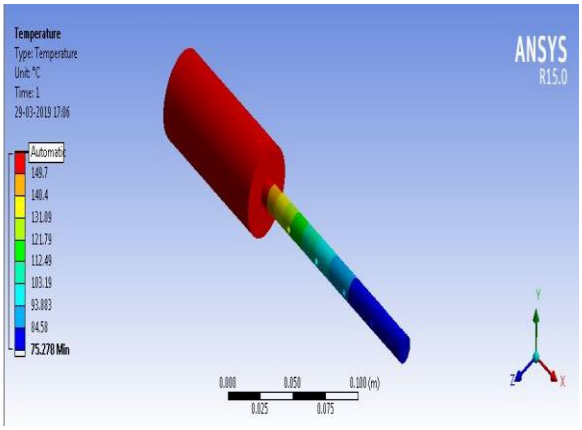


Fig.6.8 Brass circular fin circular holes

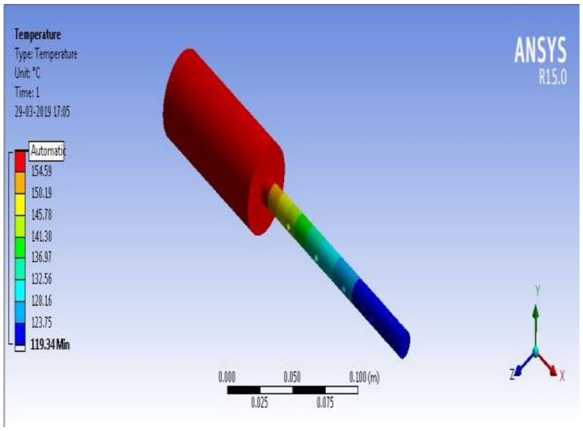


Fig.6.9 Copper circular fin circular holes

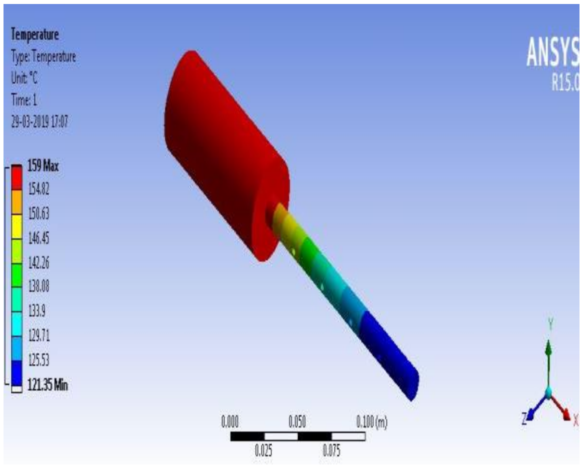


Fig.6.10 Silver circular fin circular holes

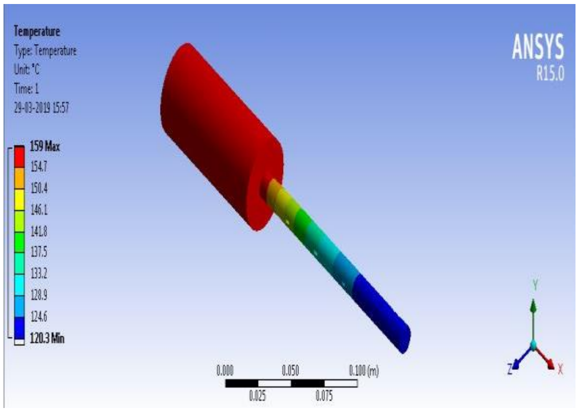


Fig.6.11 Stainless steel circular fin rectangular holes

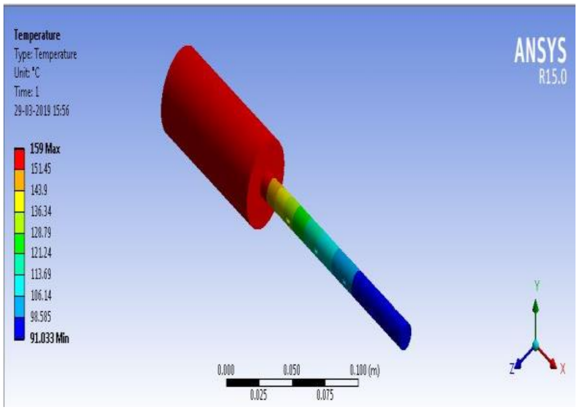


Fig.6.12 Aluminium circular fin rectangular holes

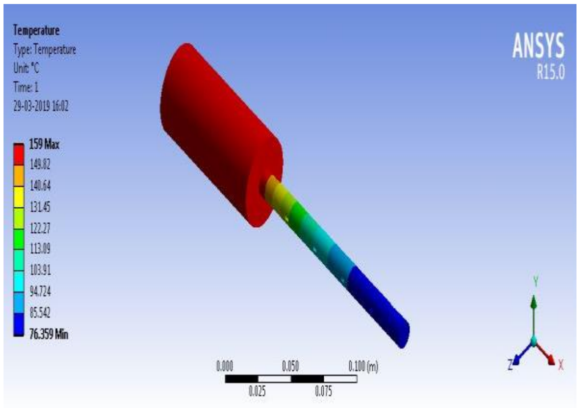


Fig.6.13 Brass circular fin rectangular holes

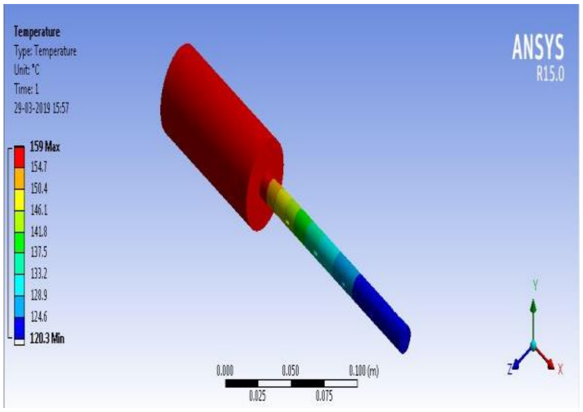


Fig.6.14 Copper circular fin rectangular holes

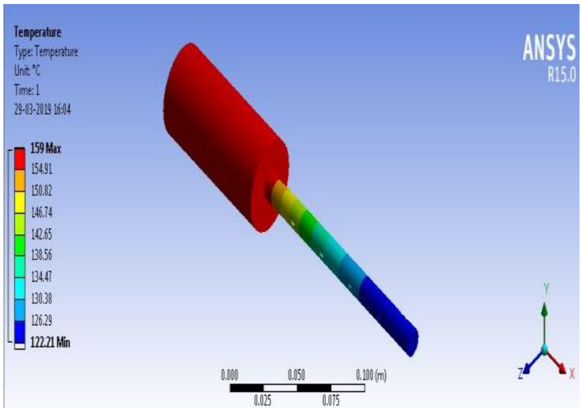


Fig.6.15 silver circular fin rectangular holes

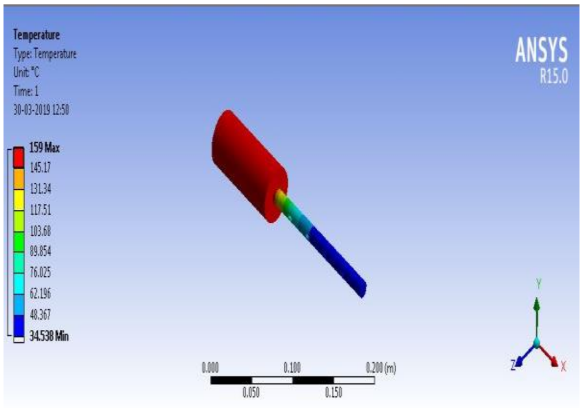


Fig.6.16 Stainless steel circular fin elliptical hole

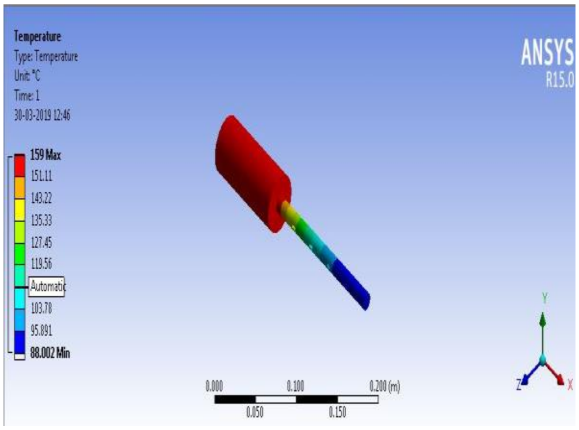


Fig.6.17 aluminium circular fin elliptical hole

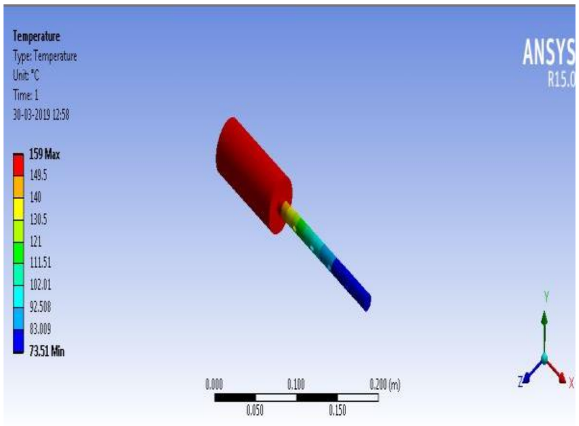


Fig.6.18 Brass circular fin elliptical hole

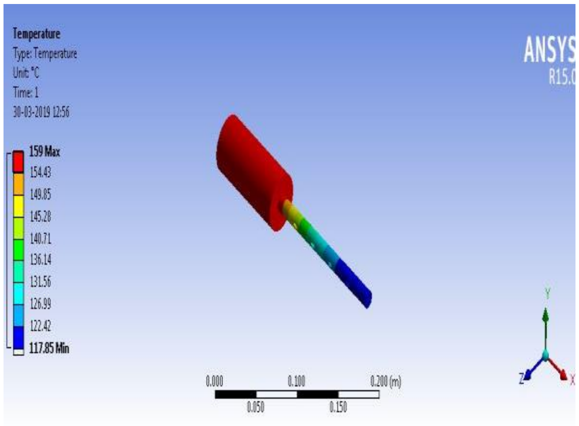


Fig.6.19 copper circular fin elliptical hole

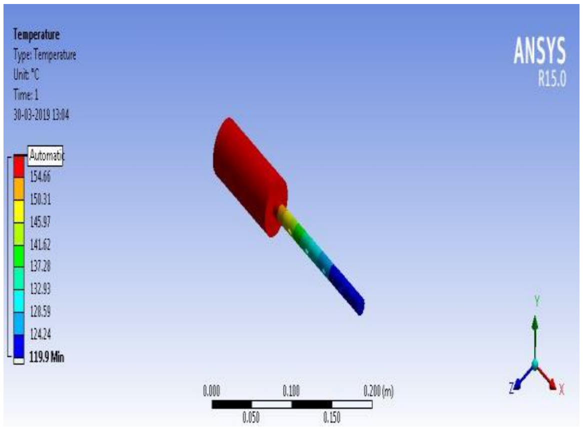


Fig.6.20 Silver circular fin elliptical hole

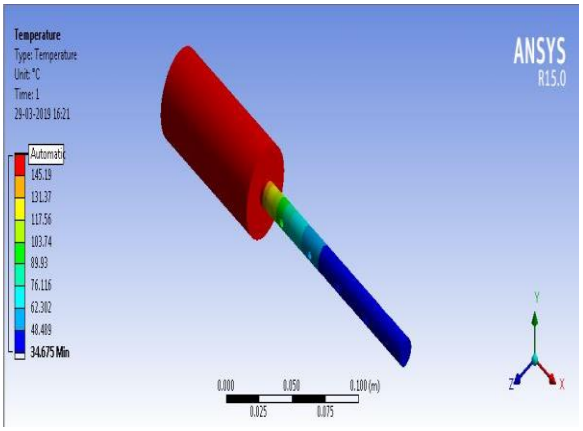


Fig.6.21 stainless steel circular fin pentagonal hole

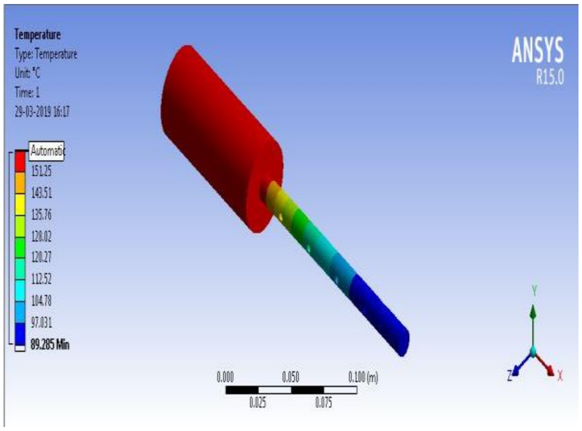


Fig.6.22 Aluminium circular fin pentagonal hole

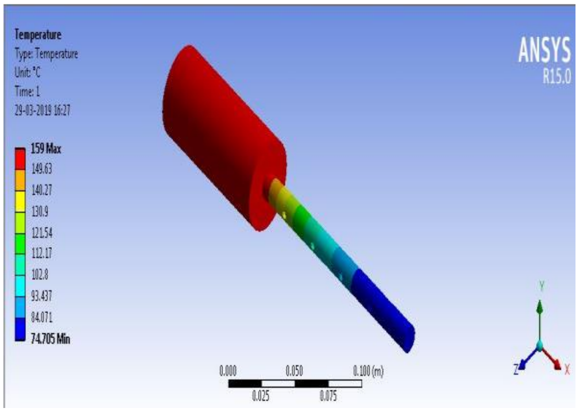


Fig.6.23 Brass circular fin pentagonal hole

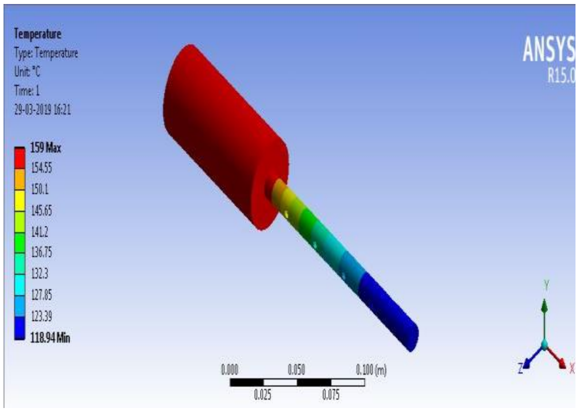


Fig.6.24 Copper circular fin pentagonal hole

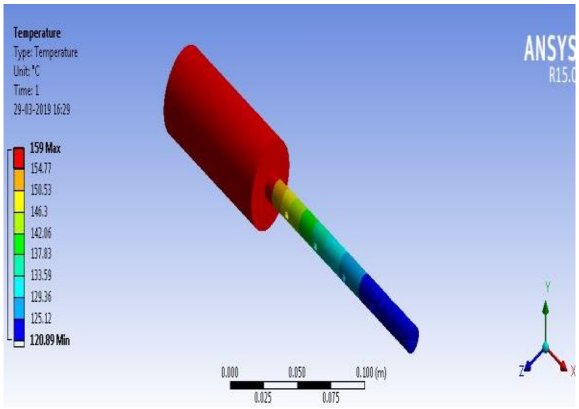


Fig.6.25 silver circular fin pentagonal hole

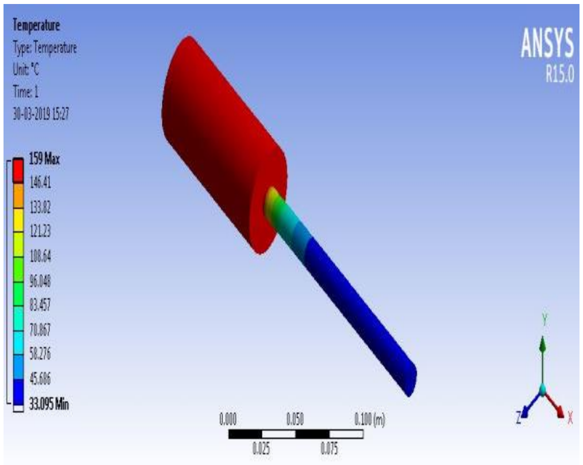


Fig.6.26 Stainless steel circular fin

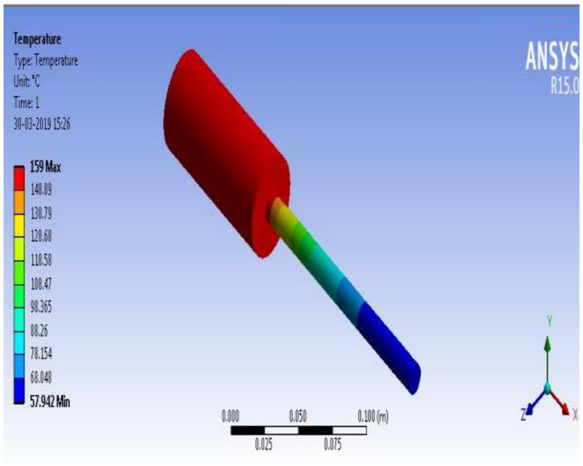


Fig.6.27 Aluminium circular fin

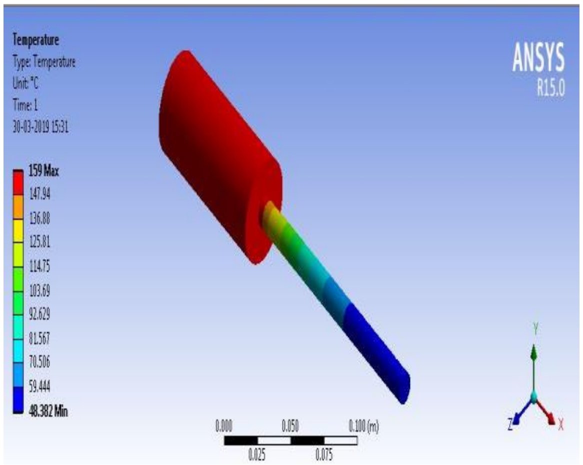


Fig.6.28 Brass circular fin

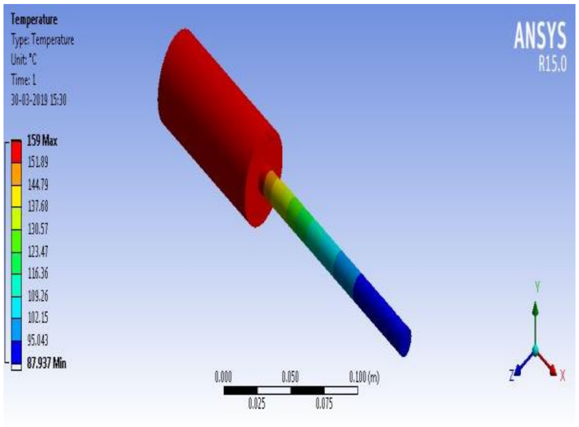


Fig.6.29 Copper circular fin

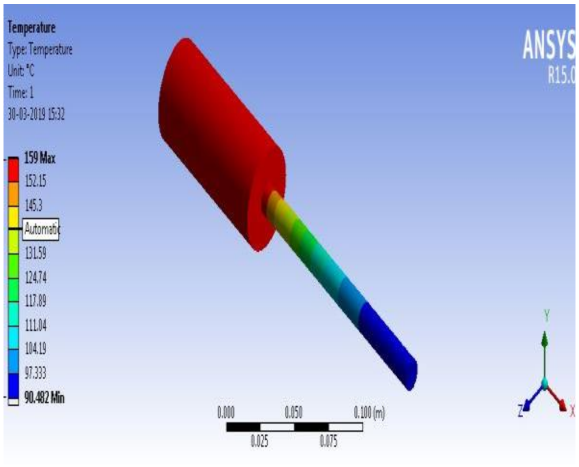


Fig.6.30 Silver circular fin

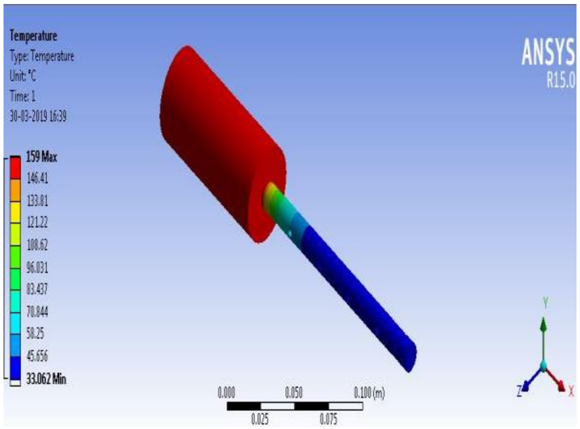


Fig.6.31 stainless steel circular fin circular hole

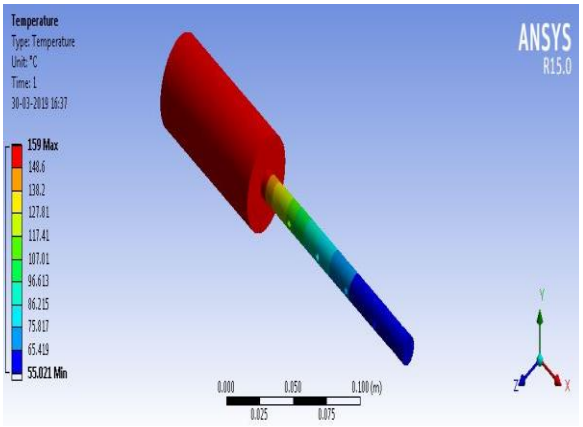


Fig.6.32 aluminium circular fin circular hole

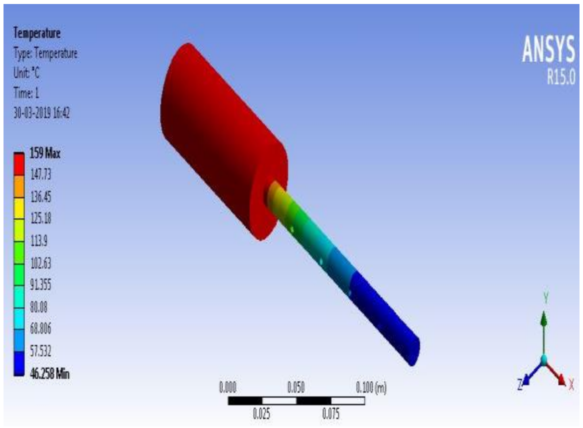


Fig.6.33 Brass circular fin circular hole

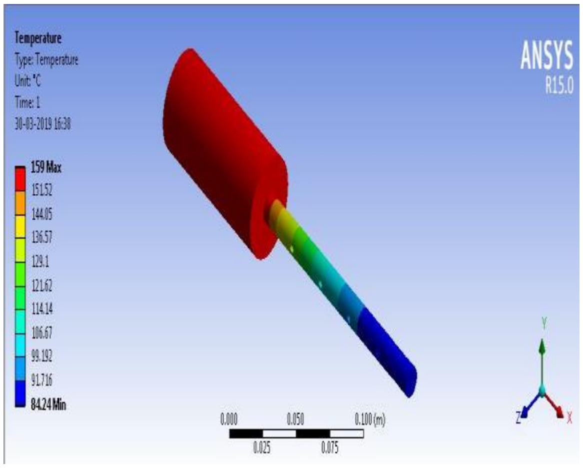


Fig.6.34 Copper circular fin circular hole

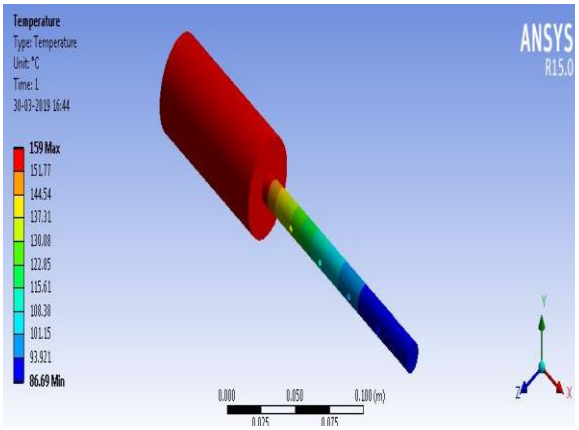


Fig.6.35 Silver circular fin circular hole

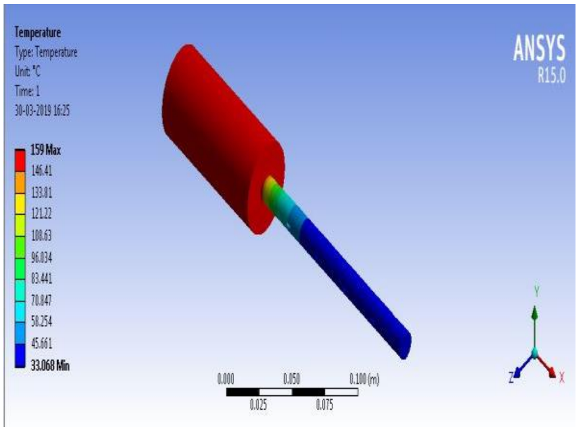


Fig.6.36 stainless stell circular fin rectangular hole

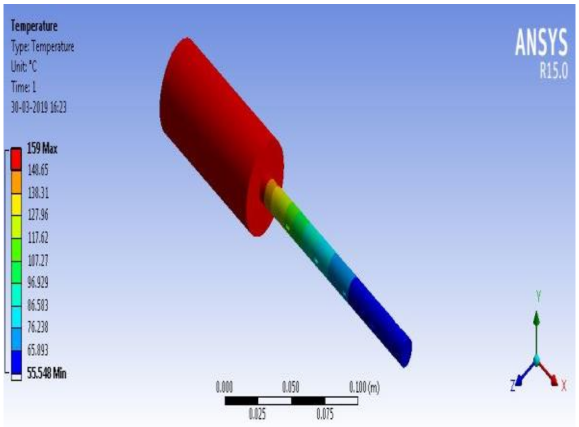


Fig.6.37 Aluminium circular fin rectangular hole

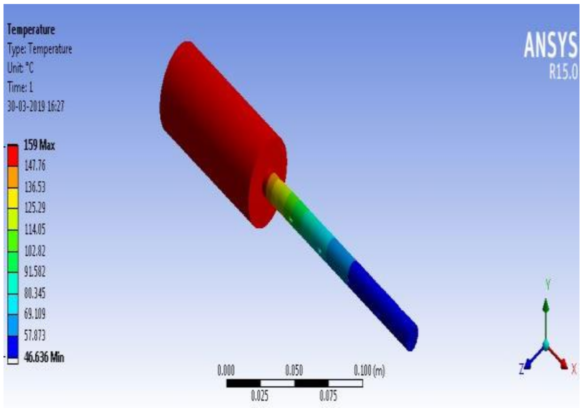


Fig.6.38 Brass circular fin rectangular hole

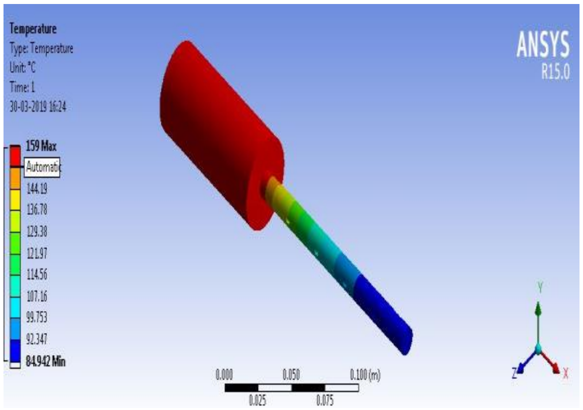


Fig.6.39 Copper circular fin rectangular hole

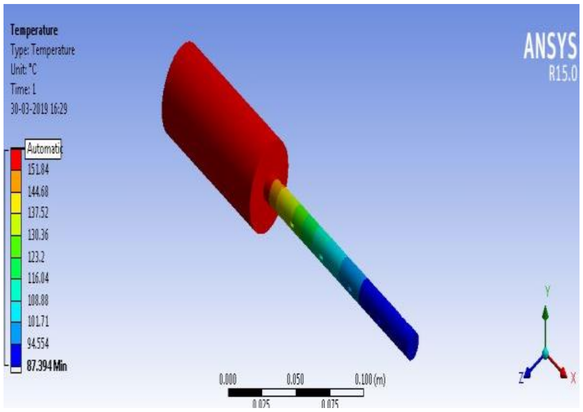


Fig.6.40 Silver circular fin rectangular hole

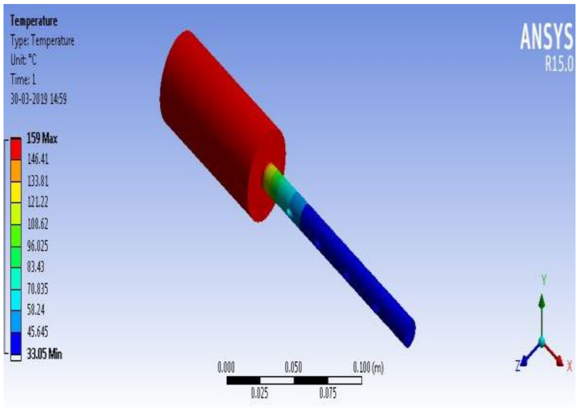


Fig.6.41 stainless steel circular fin elliptical hole

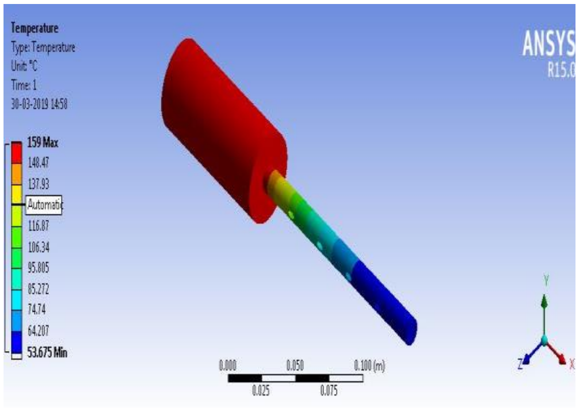


Fig.6.42 Aluminium circular fin elliptical hole

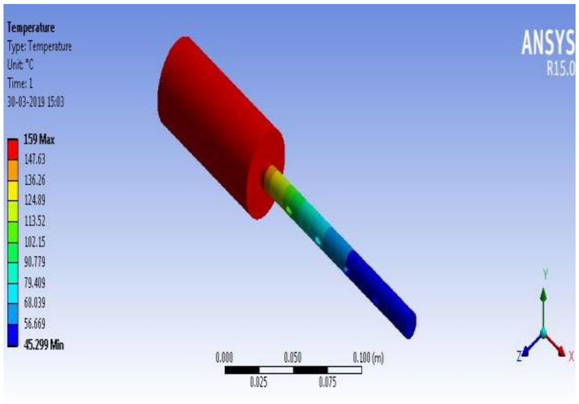


Fig.6.43 Brass circular fin elliptical hole

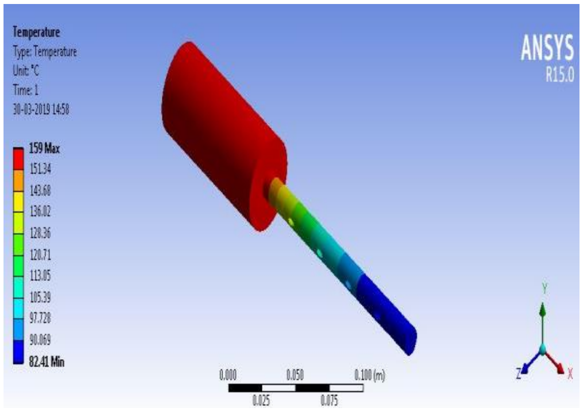


Fig.6.44 copper circular fin elliptical hole

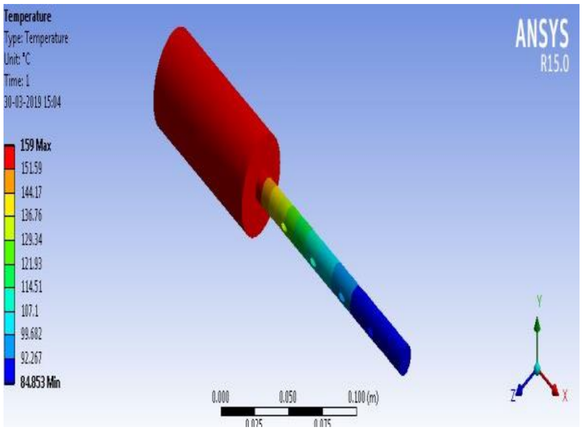


Fig.6.45 Silver circular fin elliptical hole

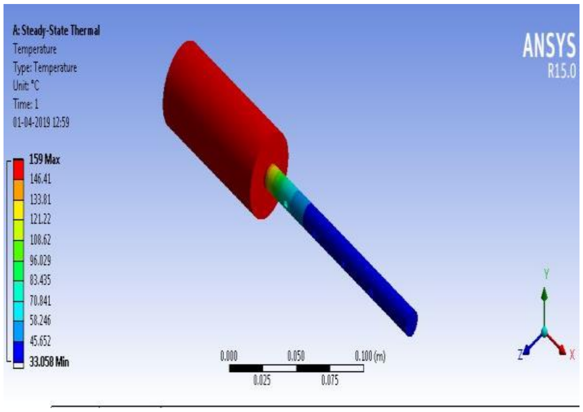


Fig.6.46 stainless steel circular fin pentagonal hole

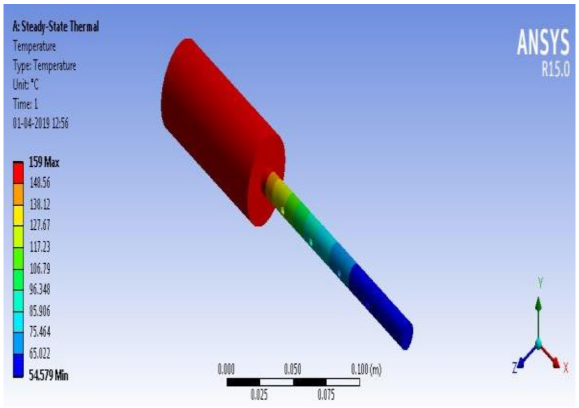


Fig.6.47 Aluminium circular fin pentagonal hole

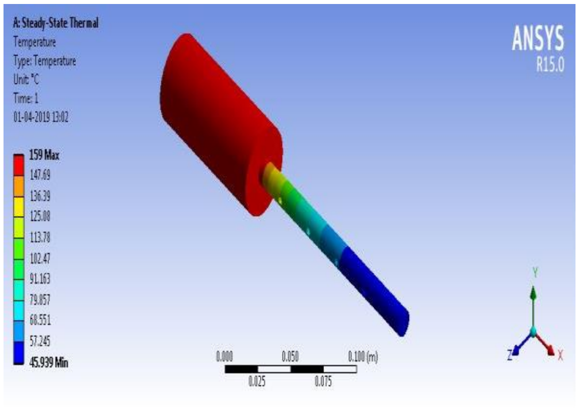


Fig.6.48 Brass circular fin pentagonal hole

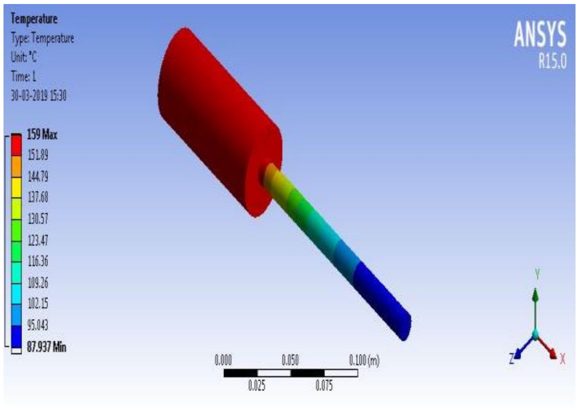


Fig.6.49 Copper circular fin pentagonal hole

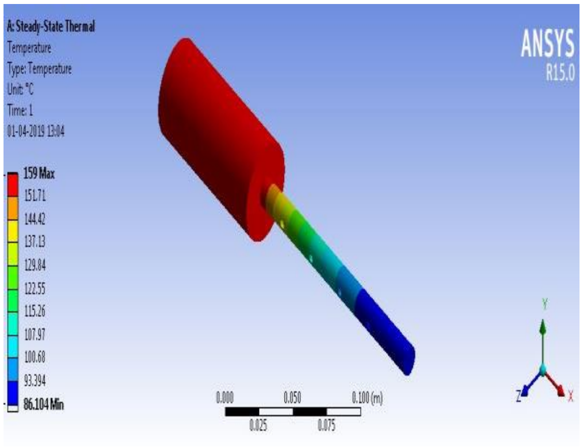


Fig.6.50 Silver circular fin pentagonal hole

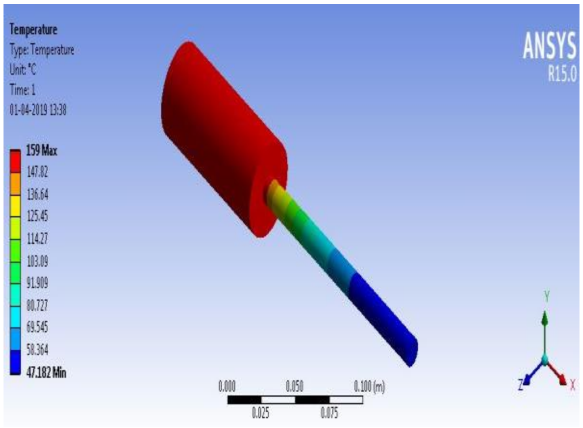


Fig.6.51 stainless steel circular fin

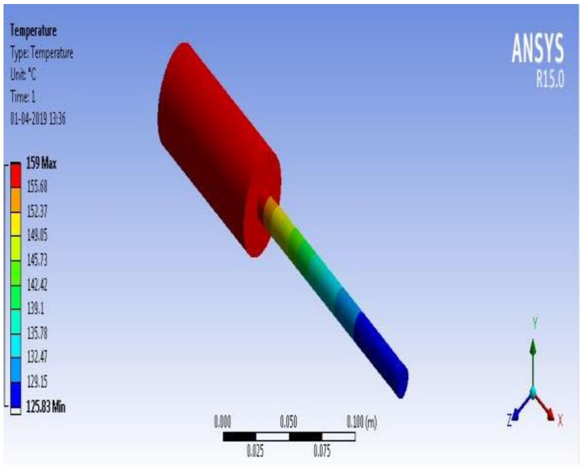


Fig.6.52 aluminium circular fin

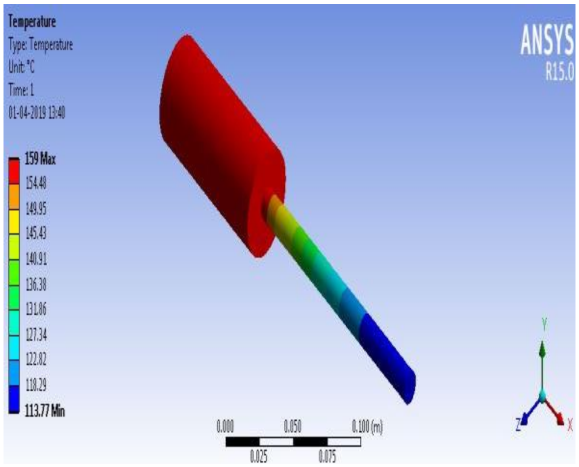


Fig.6.53 Brass circular fin

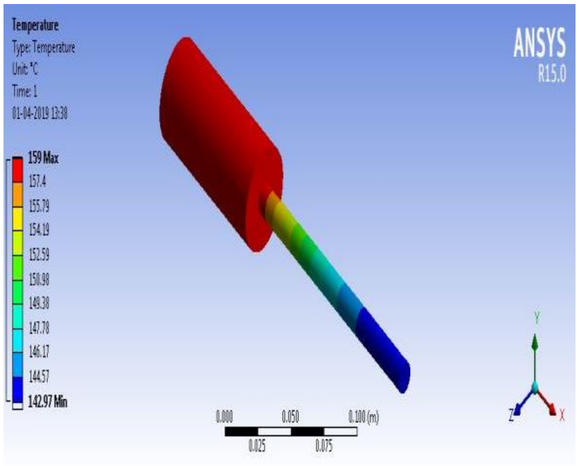


Fig.6.54 Copper circular fin

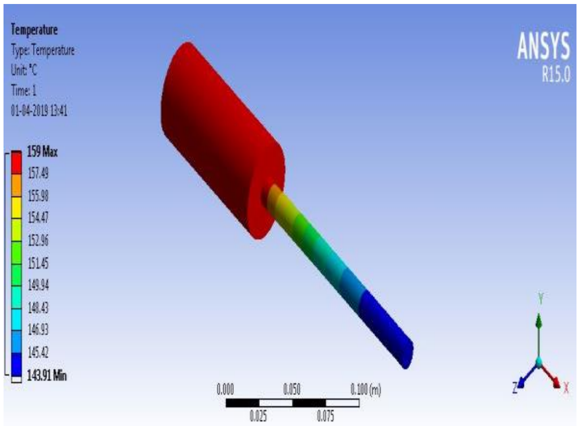


Fig.6.55 Silver circular fin

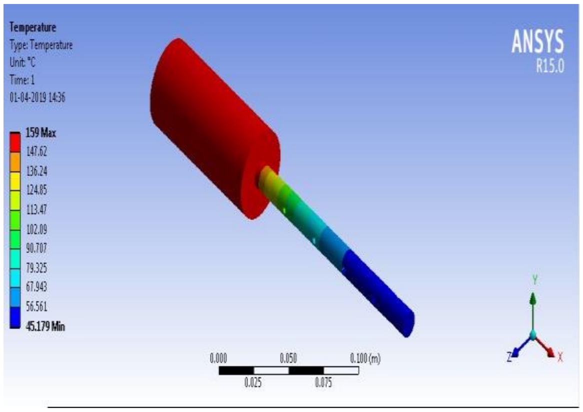


Fig.6.56 stainless steel circular fin circular hole

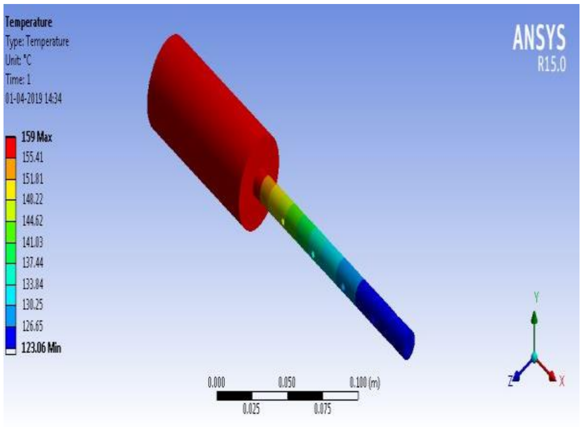


Fig.6.57 Aluminium, circular fin circular hole

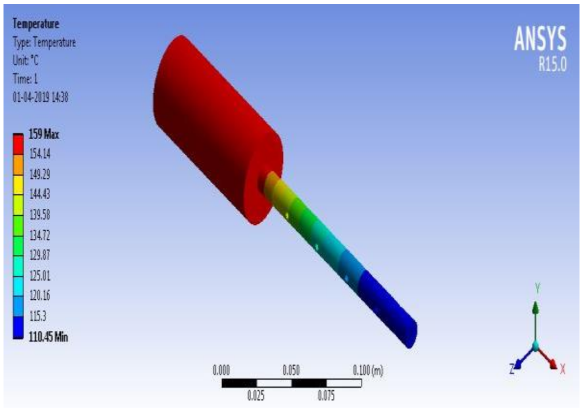


Fig.6.58 Brass circular fin circular hole

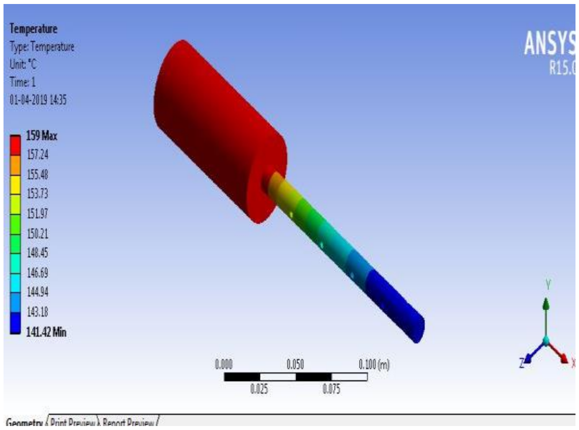


Fig.6.59 Copper circular fin circular hole

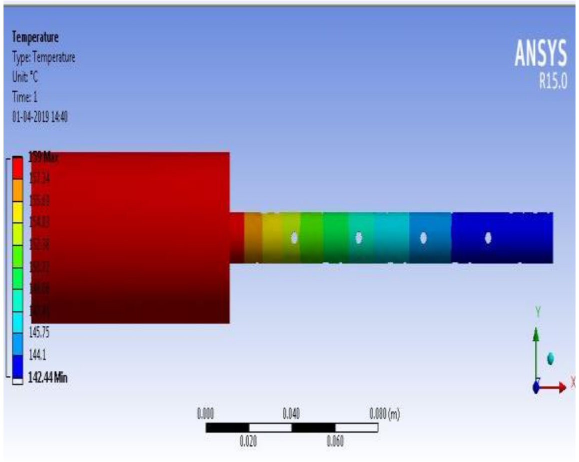


Fig.6.60 Silver circular fin circular hole

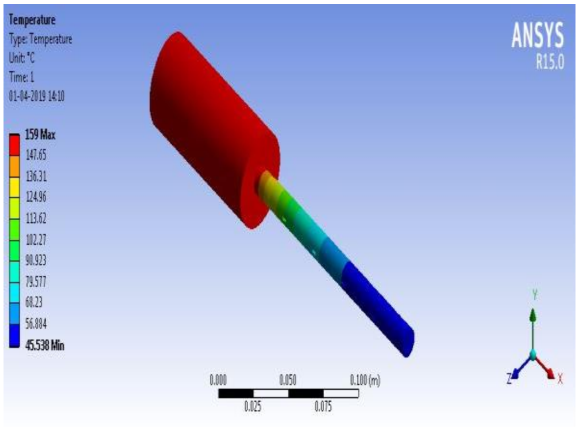


Fig.6.61 stainless steel circular fin rectangular hole

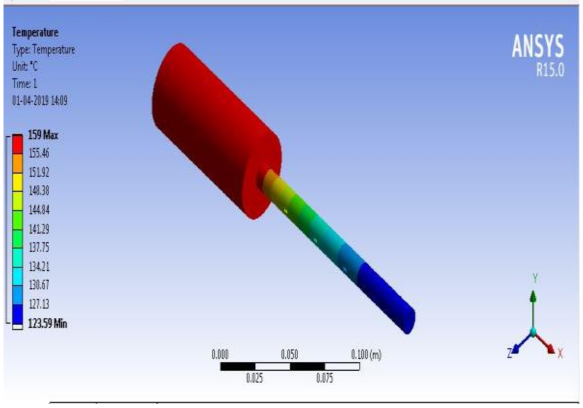


Fig.6.62 aluminium circular fin rectangular hole

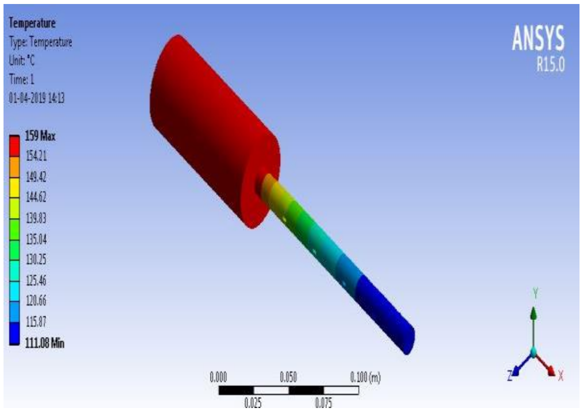


Fig.6.63 brass circular fin rectangular hole

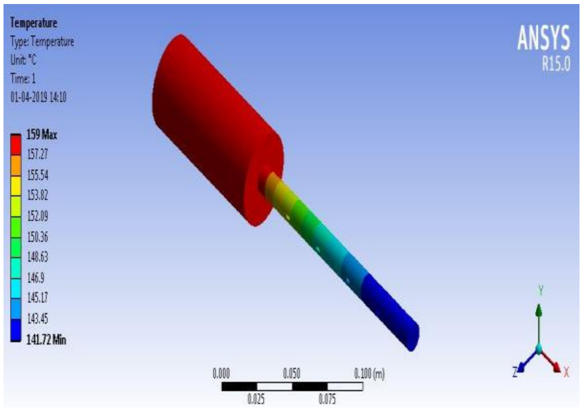


Fig.6.64 Copper circular fin rectangular hole

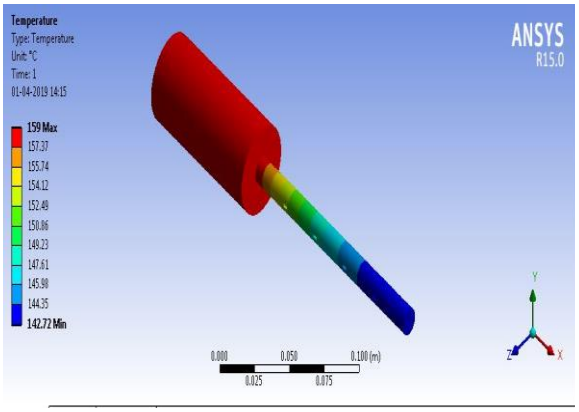


Fig.6.65 silver circular fin rectangular hole

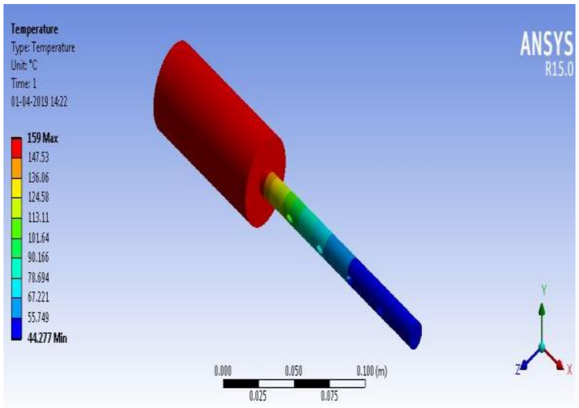


Fig.6.66 stainless steel circular fin elliptical hole

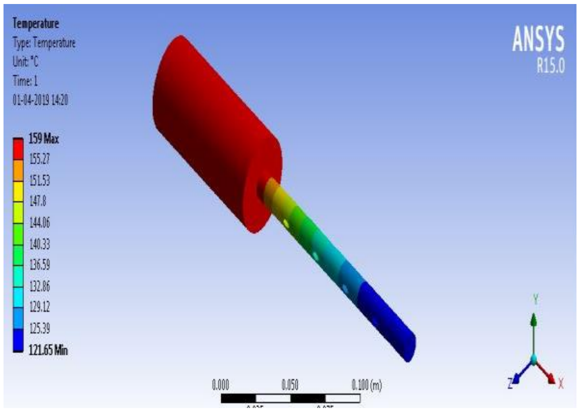


Fig.6.67 aluminium circular fin elliptical hole

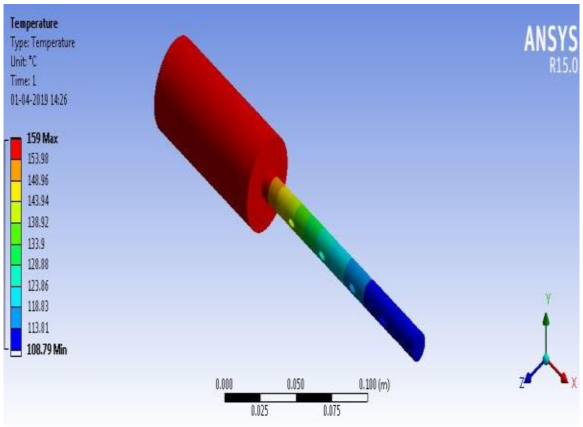


Fig.6.68 brass circular fin elliptical hole

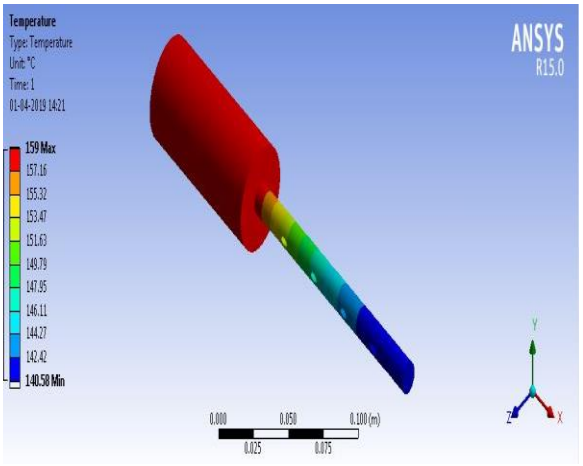


Fig.6.69 copper circular fin elliptical hole

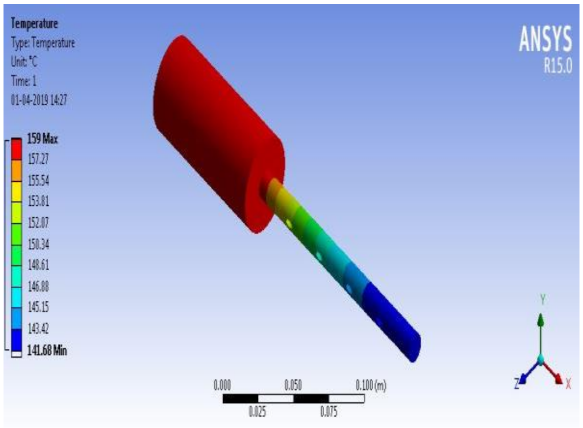


Fig.6.70 Silver circular fin elliptical hole

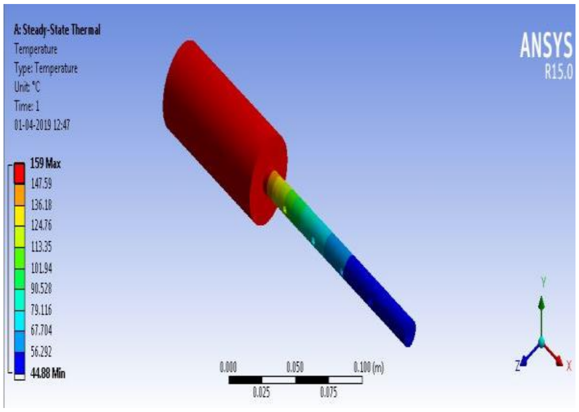


Fig.6.71 Stainless steel circular fin pentagonal hole

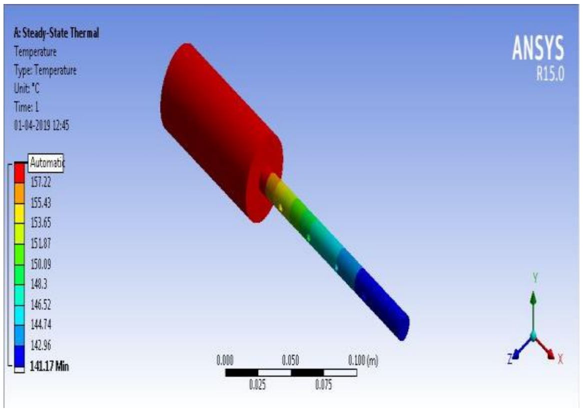


Fig.6.74 copper circular fin pentagonal hole

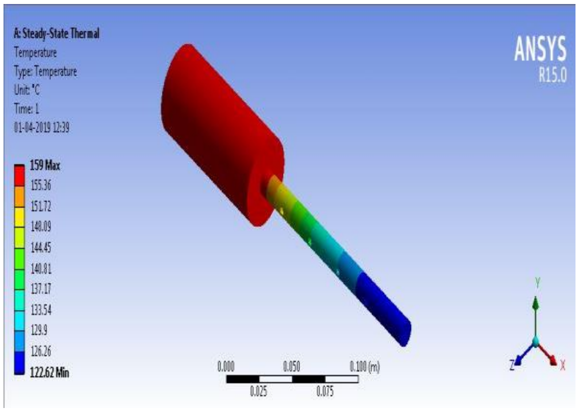


Fig.6.72 aluminium circular fin pentagonal hole

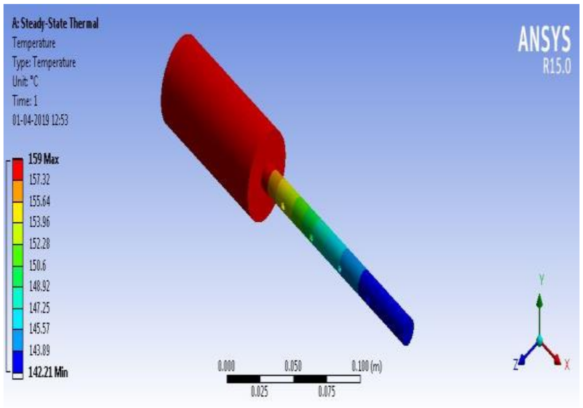


Fig.6.75 Silver circular fin pentagonal hole

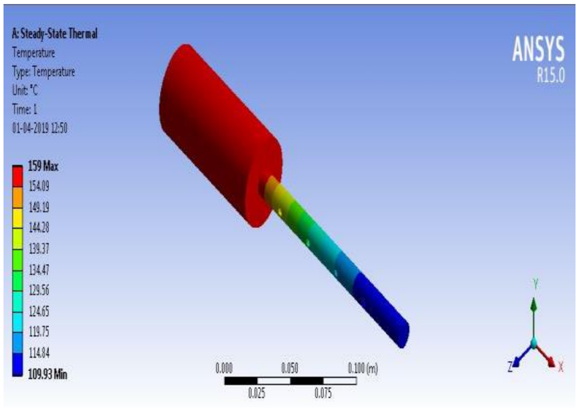


Fig.6.73 brass circular fin pentagonal hole

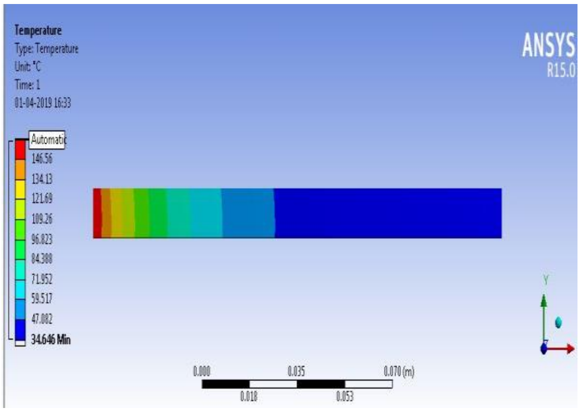


Fig.6.76 Stainless steel triangular fin

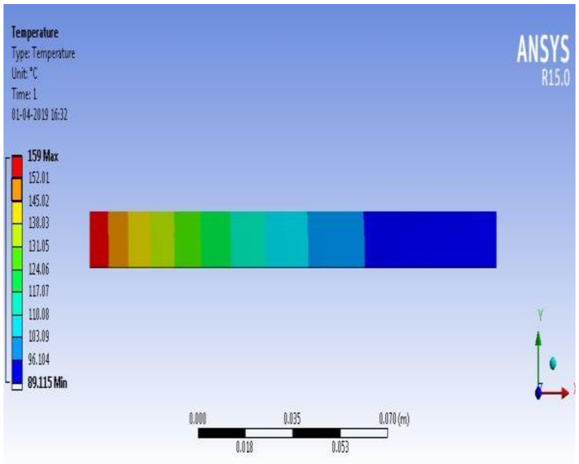


Fig.6.77 Aluminium triangular fin

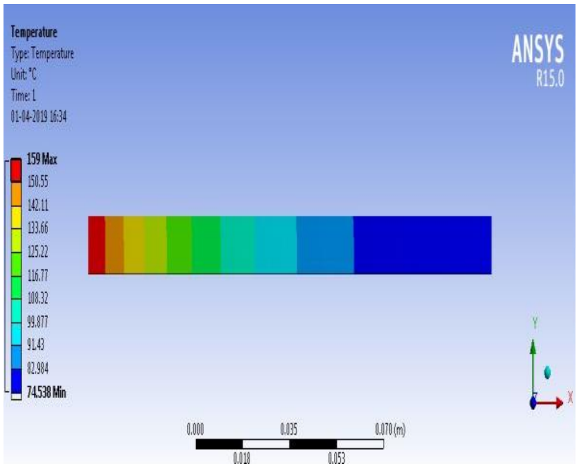


Fig.6.78 Brass triangular fin

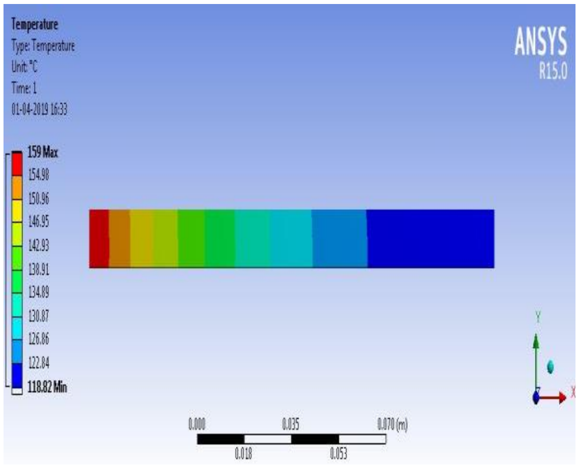


Fig.6.79 Copper triangular fin

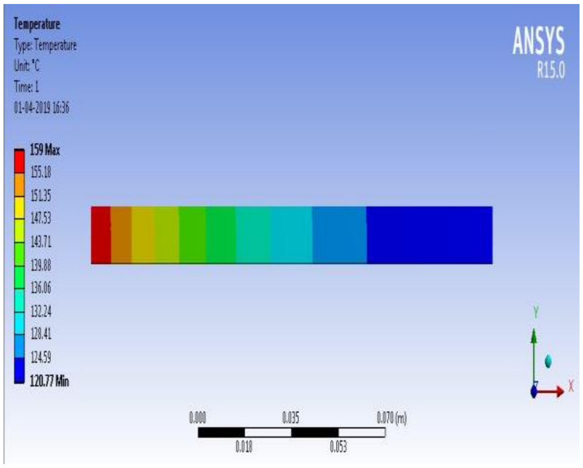


Fig.6.80 Silver triangular fin

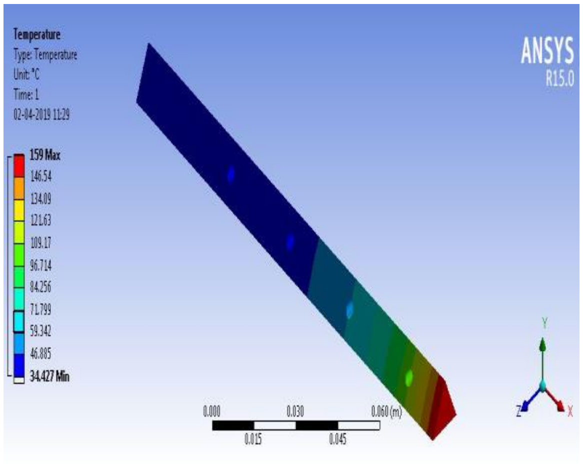


fig.6.81 SS triangular fin circular hole

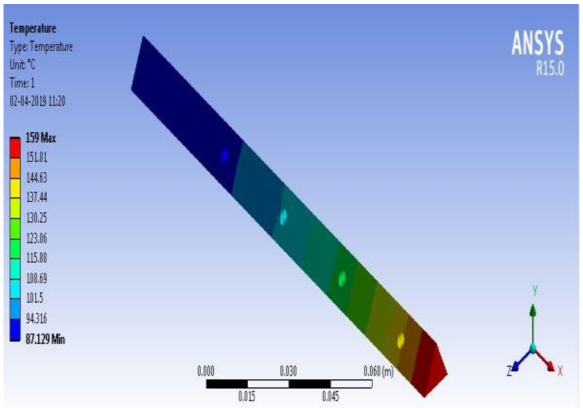


Fig.6.82aluminium triangular fin circular hole

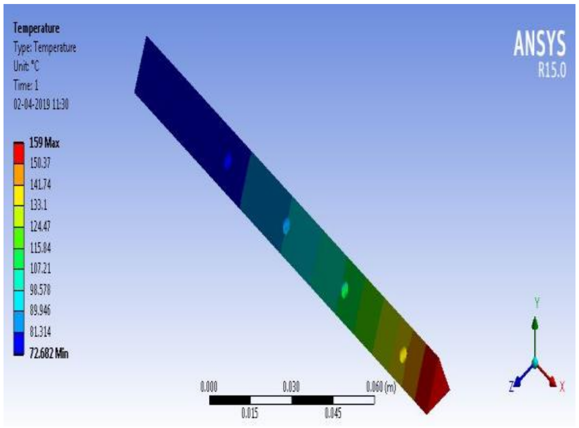


Fig.6.83 brass triangular fin circular hole

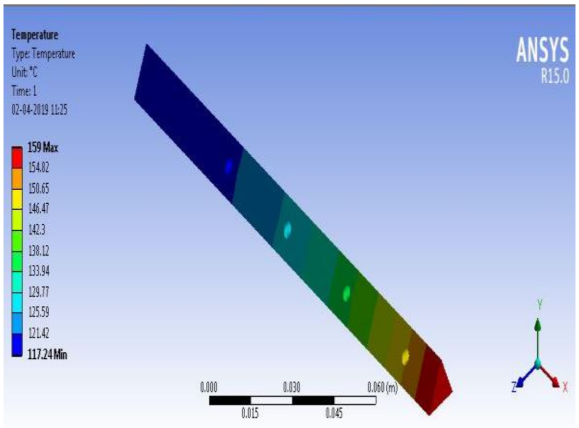


Fig.6.84 Copper triangular fin circular hole

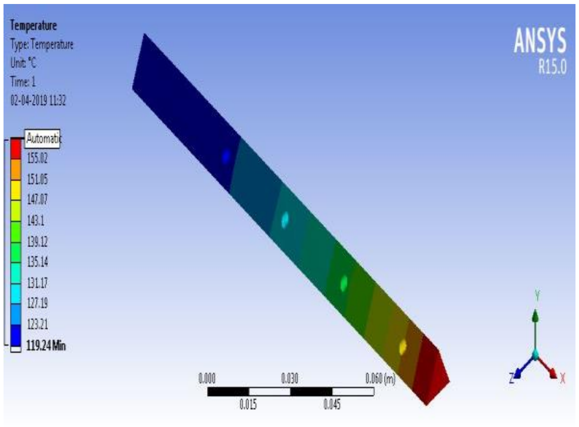


Fig.6.85 Silver triangular fin circular hole

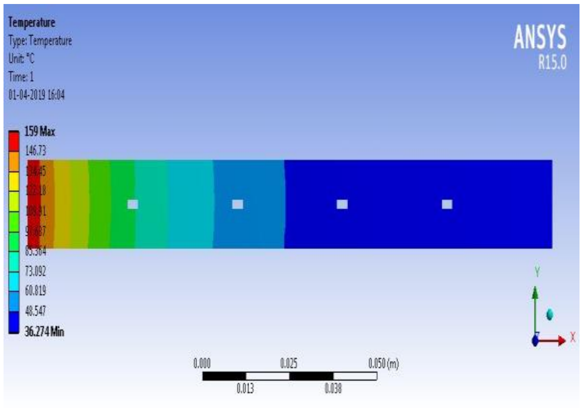


Fig.6.86 SS triangular fin rectangular hole

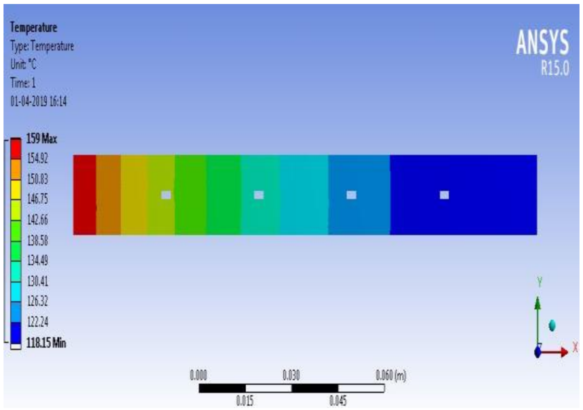


Fig.6.87 Aluminium triangular fin rectangular hole

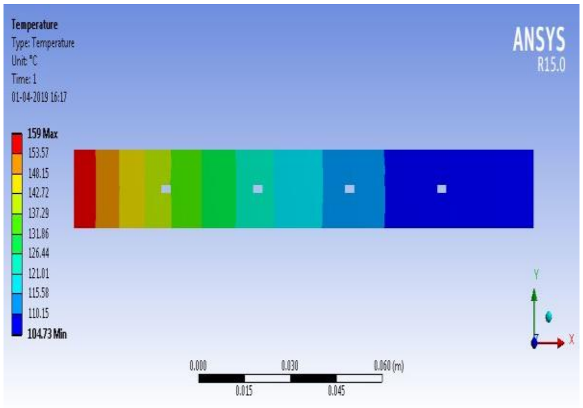


Fig.6.88 Brass triangular fin rectangular hole

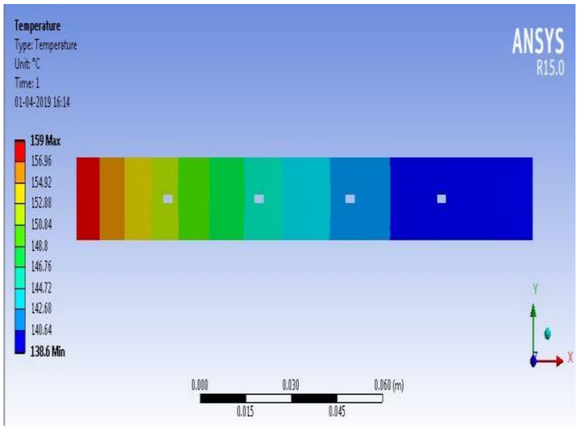


Fig.6.89 Copper triangular fin rectangular hole

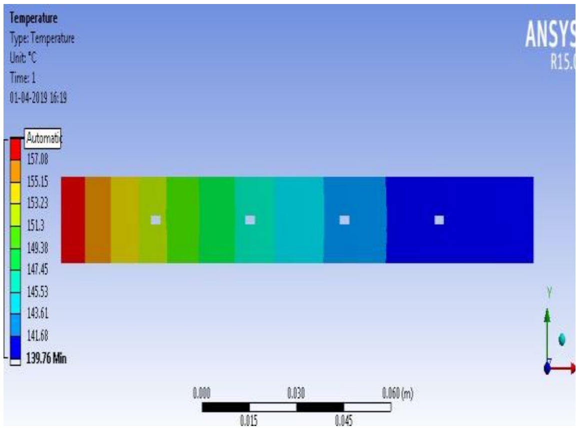


Fig.6.90 Silver triangular fin rectangular hole

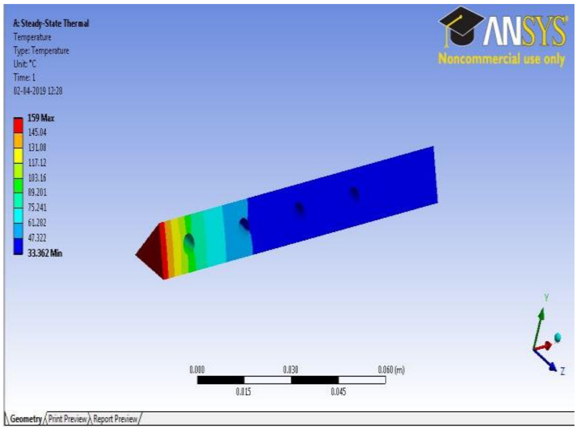


Fig.6.91 SS triangular fin elliptical hole

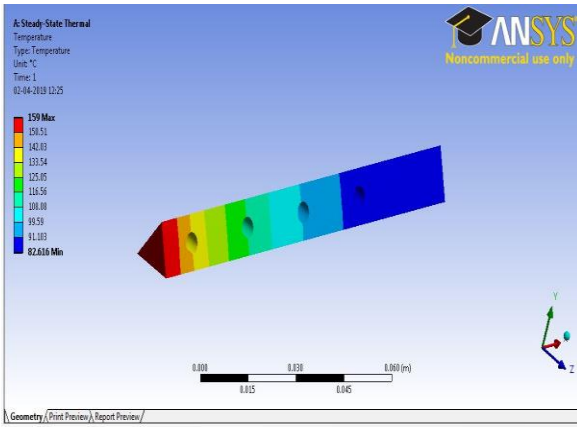


Fig.6.92 aluminium triangular fin elliptical hole

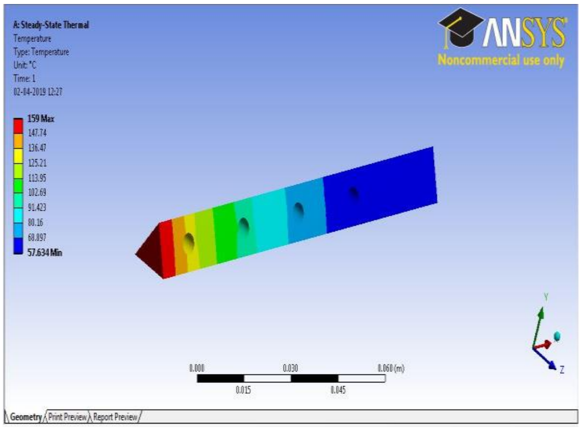


Fig.6.93 Brass triangular fin elliptical hole

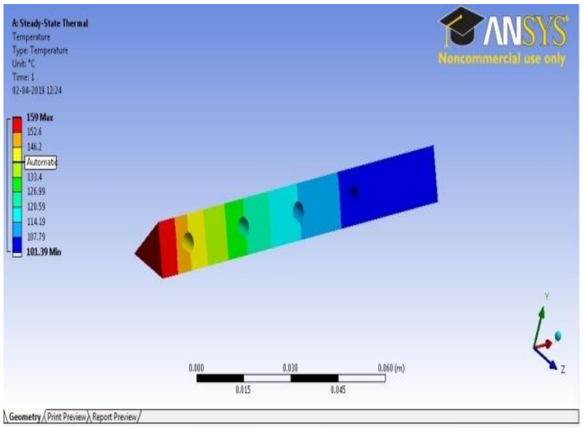


Fig.6.94 Copper triangular elliptical hole

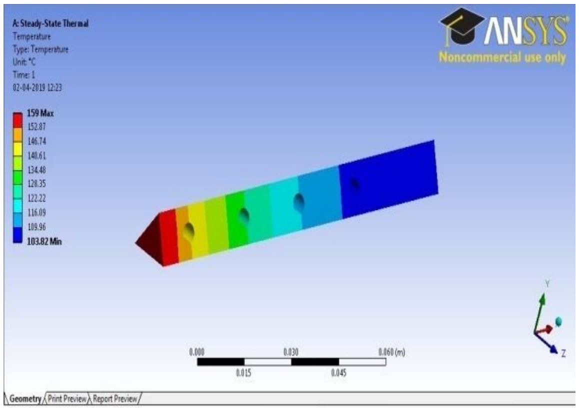


Fig.6.95 Silver triangular fin elliptical hole

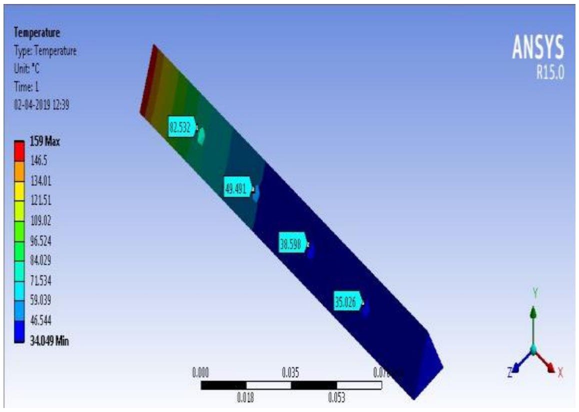


Fig.6.96 SS triangular fin pentagonal hole

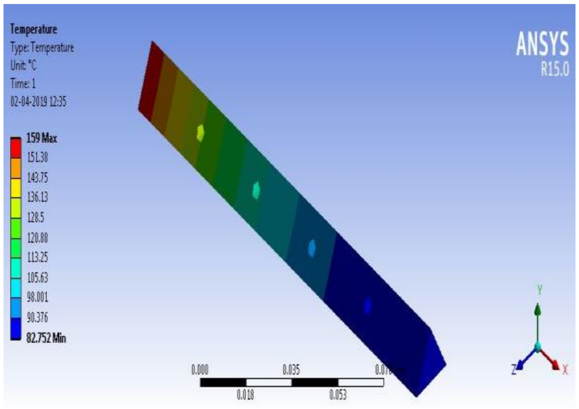


Fig.6.97 Aluminium triangular fin pentagonal hole

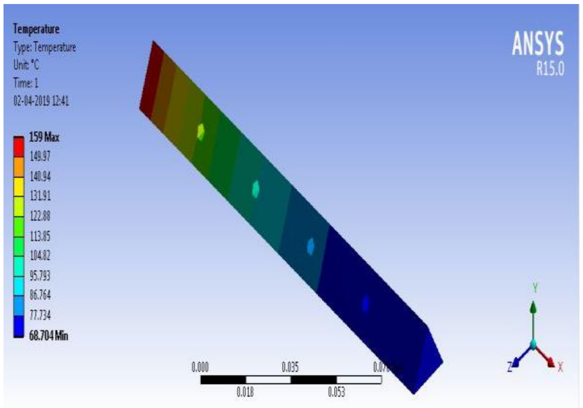


Fig.6.98 Brass triangular fin pentagonal hole

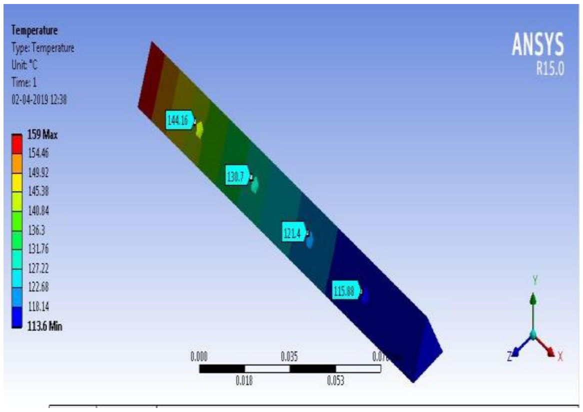


Fig.6.99 Copper triangular fin pentagonal hole

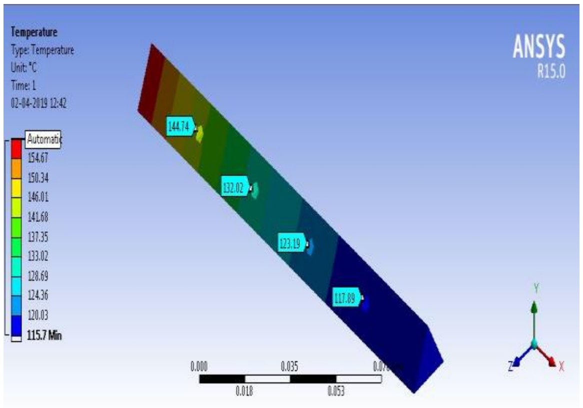


Fig.6.100 Silver triangular fin pentagonal hole

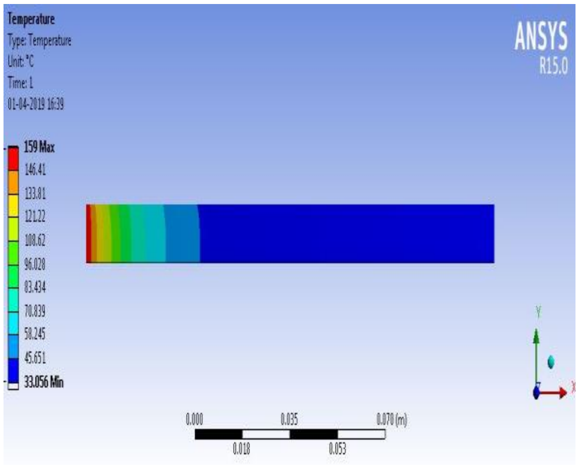


Fig.6.101 SS triangular fin

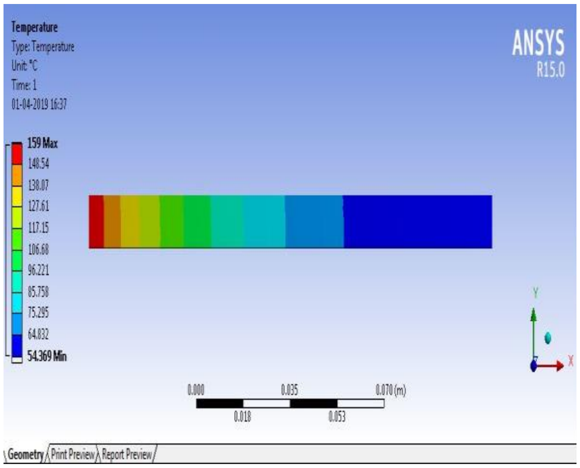


Fig.6.102 aluminium triangular fin

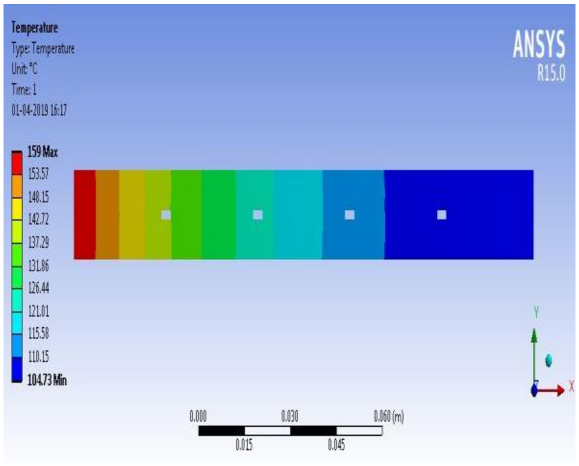


Fig.6.103 Brass triangular fin

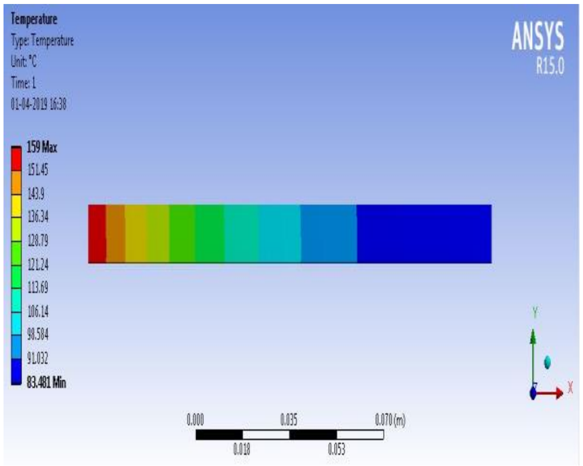


Fig.6.104 Copper triangular fin

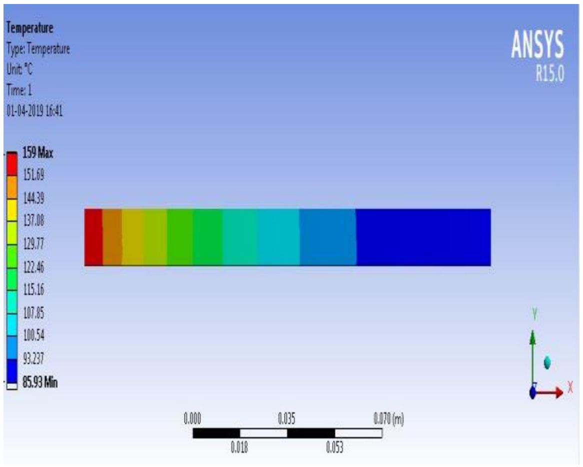


Fig.6.105 Silver triangular fin

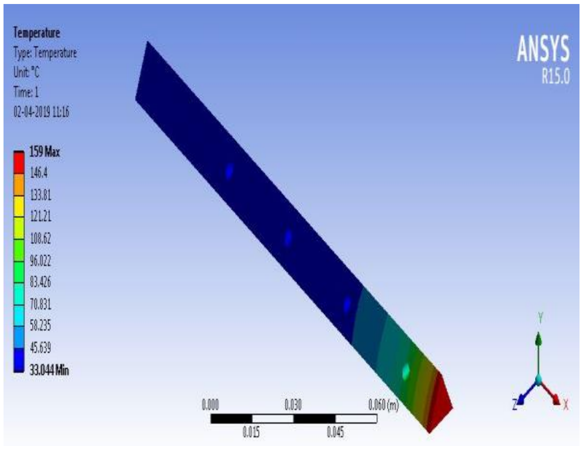


Fig.6.106 SS triangular fin circular hole

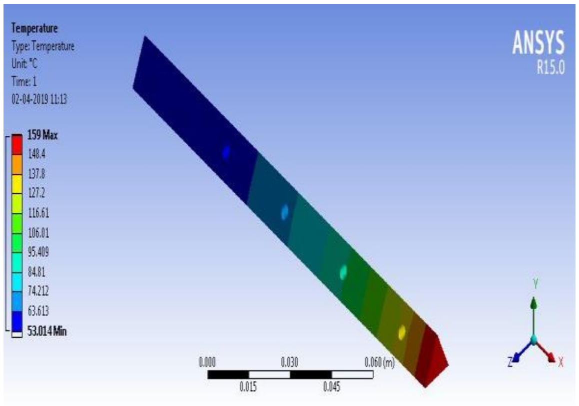


Fig.6.107 Aluminium triangular fin circular hole

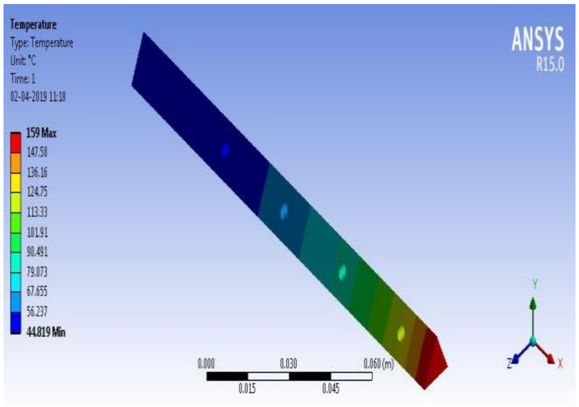


Fig.6.108 Brass triangular fin circular hole

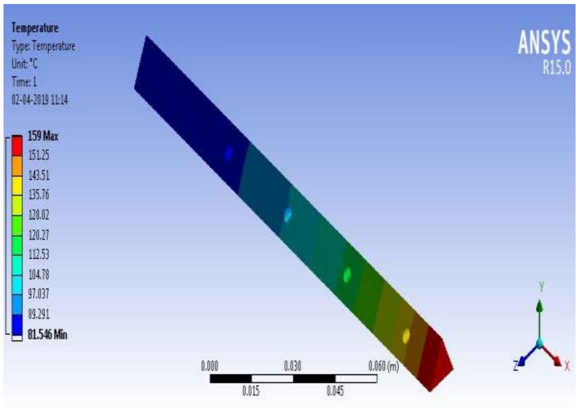


Fig.6.109 Copper triangular fin circular hole

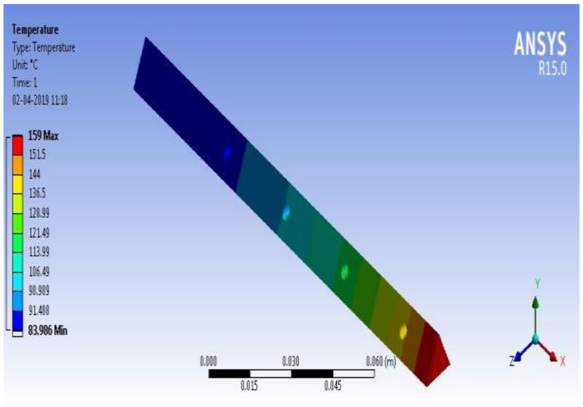


Fig.6.110 Silver triangular fin circular hole

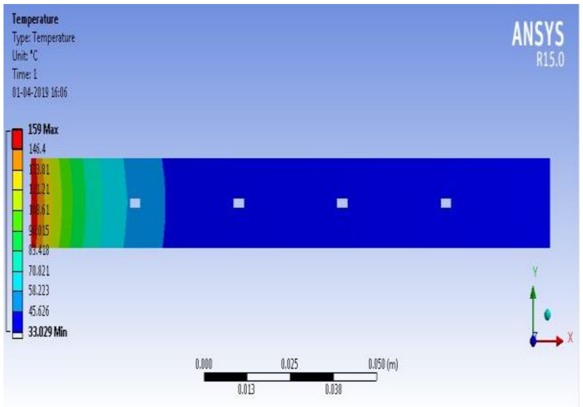


Fig.6.111 SS triangular fin rectangular hole

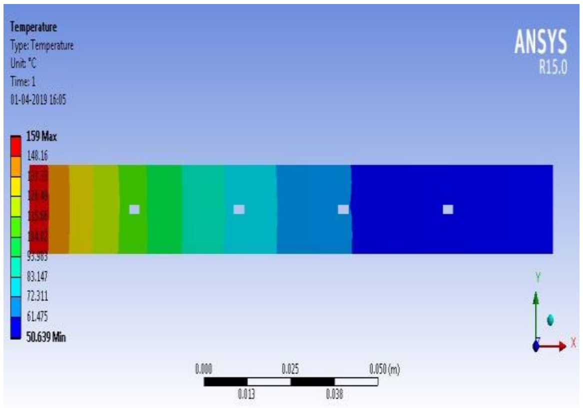


Fig.6.112 aluminium triangular fin rectangular hole

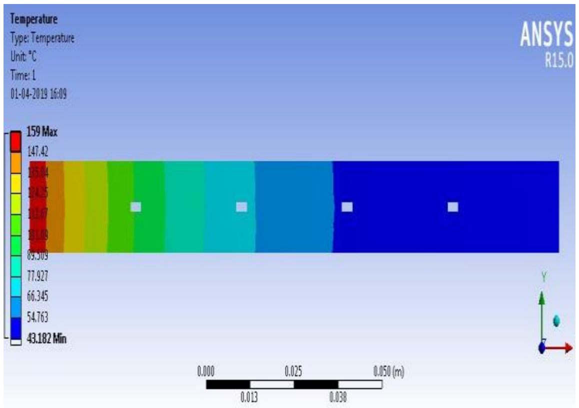


Fig.6.113 brass triangular fin rectangular hole

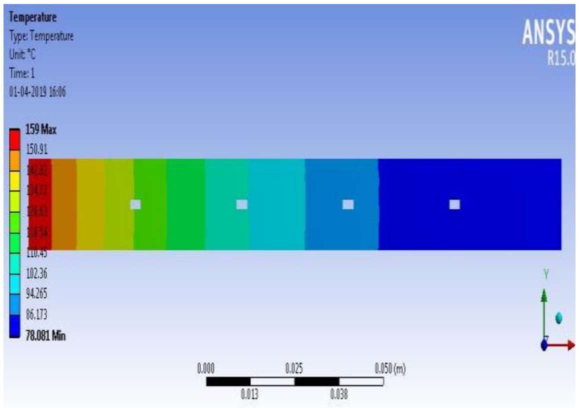


Fig.6.114 Copper triangular fin rectangular hole

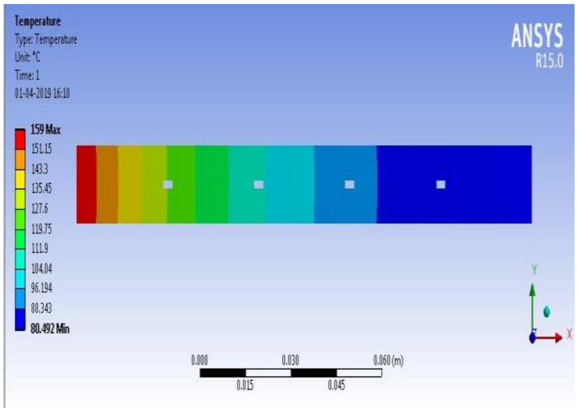


Fig.6.115 Silver triangular fin rectangular hole

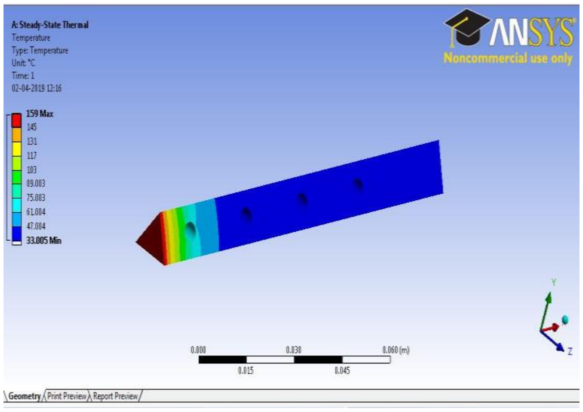


Fig.6.116 SS triangular fin elliptical hole

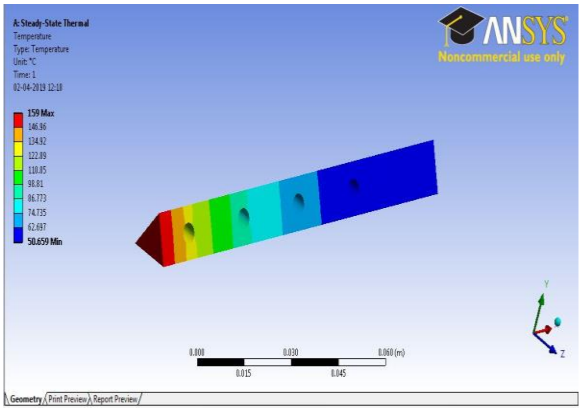


Fig.6.117 aluminium triangular fin elliptical hole

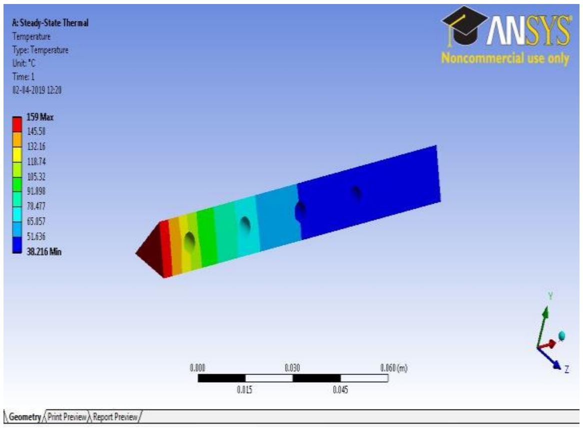


Fig.6.118 brass triangular fin elliptical hole

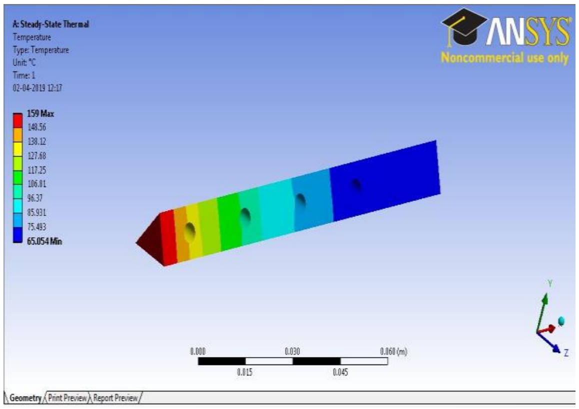


Fig.6.119 Copper triangular fin elliptical hole

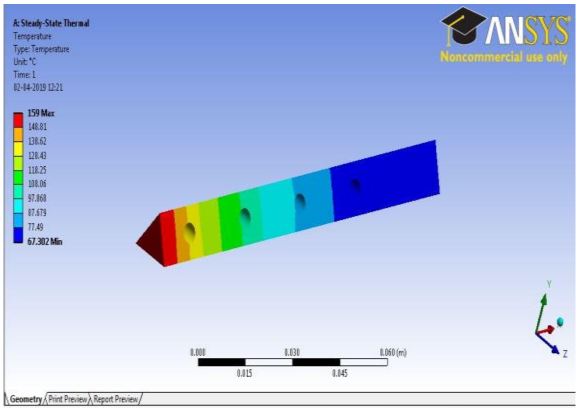


Fig.6.120 silver triangular fin elliptical hole

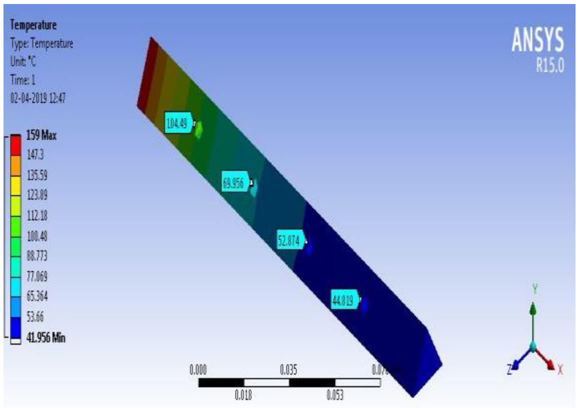


Fig.6.121 SS triangular fin pentagonal hole

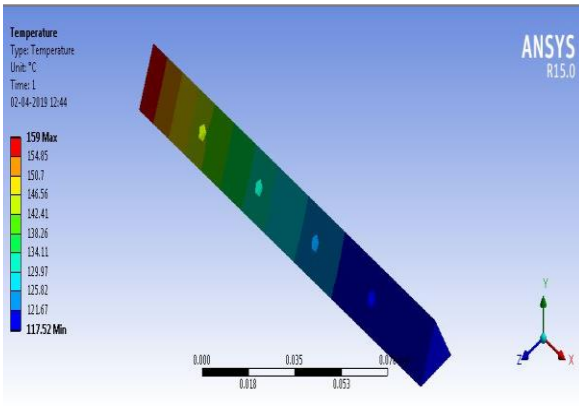


Fig.6.122 aluminium triangular fin pentagonal hole

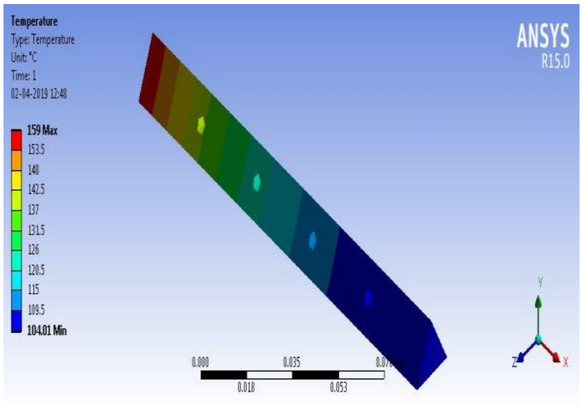


Fig.6.123 brass triangular fin pentagonal hole

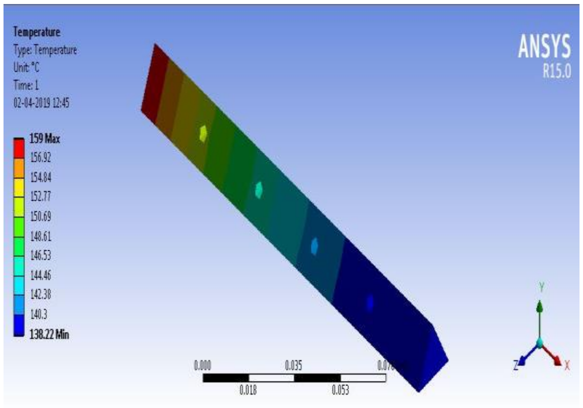


Fig.6.124 copper triangular fin pentagonal hole

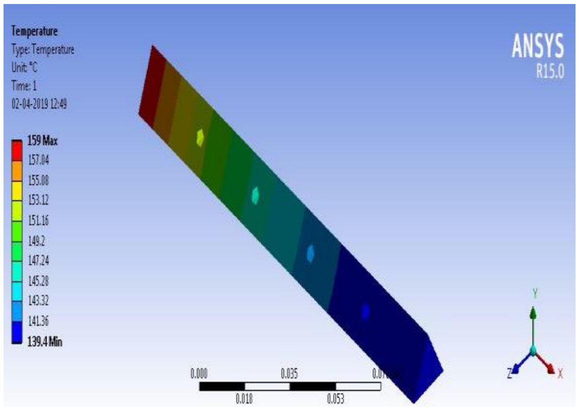


fig.6.125 silver triangular fin pentagonal hole

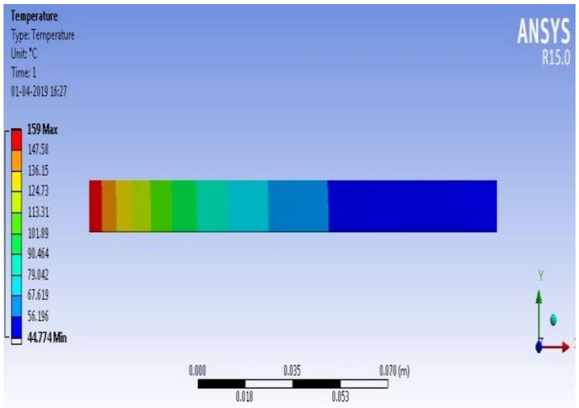


Fig.6.126 SS triangular fin

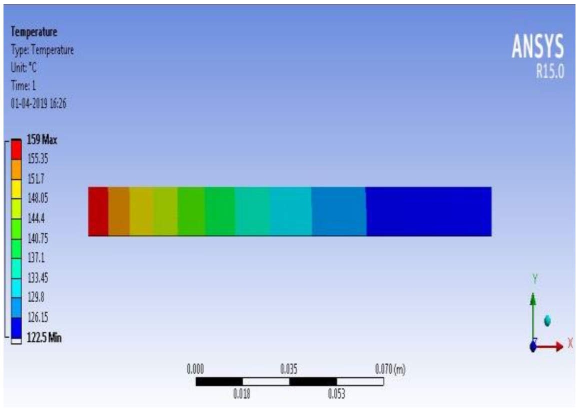


Fig.6.127 Aluminium triangular fin

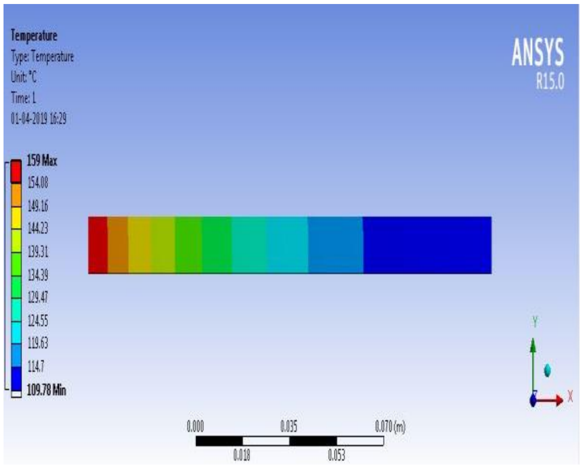


Fig.6.128 Brass triangular fin

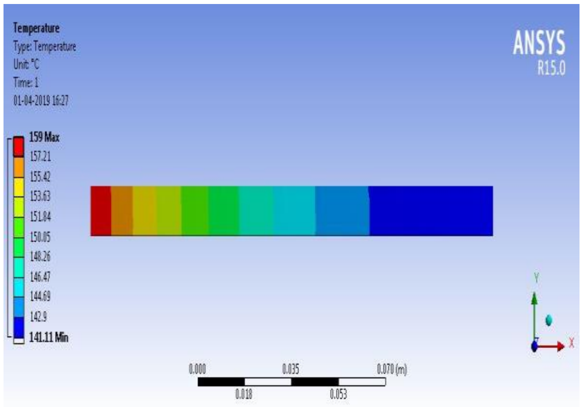


Fig.6.129 Copper triangular fin

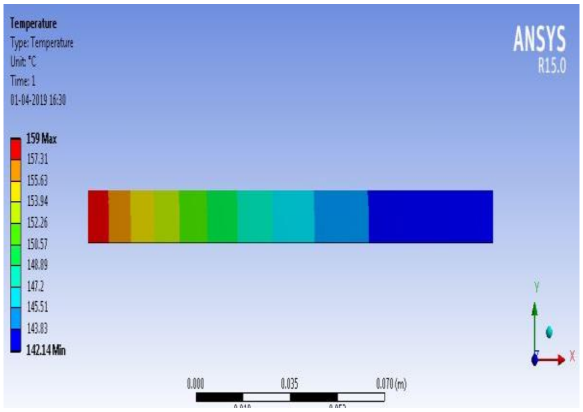


Fig.6.130 Silver triangular fin

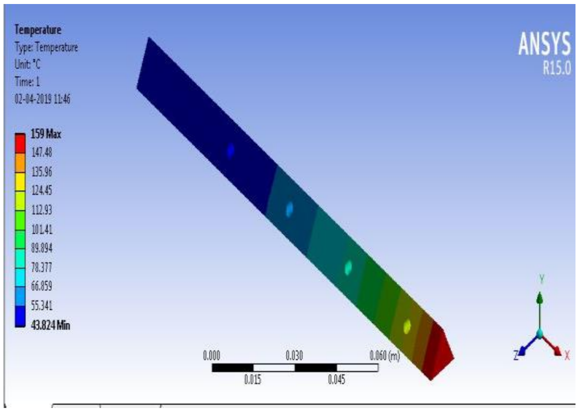


Fig.6.131 SS triangular fin circular hole

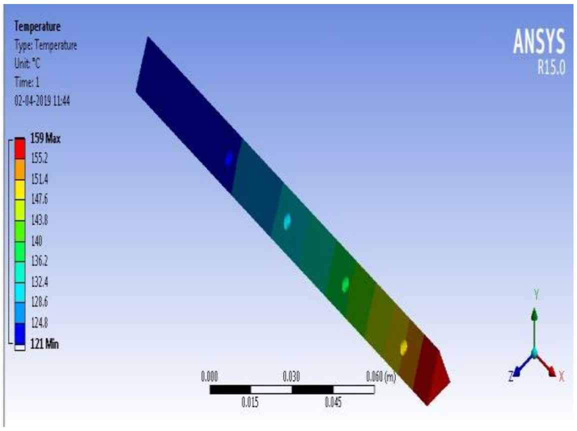


Fig.6.132 Aluminium triangular fin circular hole

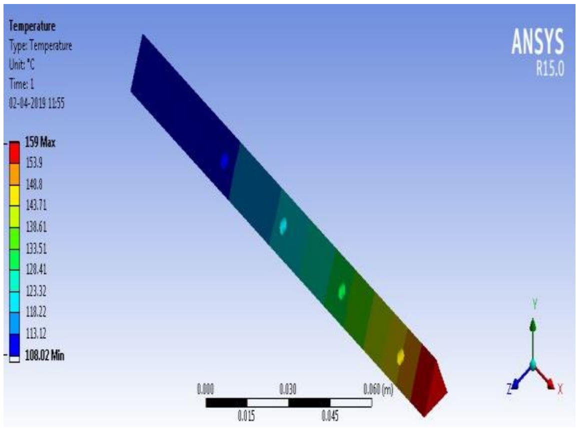


Fig.6.133 brass triangular fin circular hole

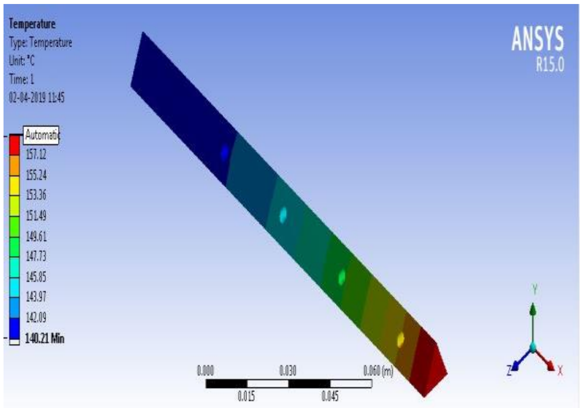


Fig.6.134 copper triangular fin circular hole

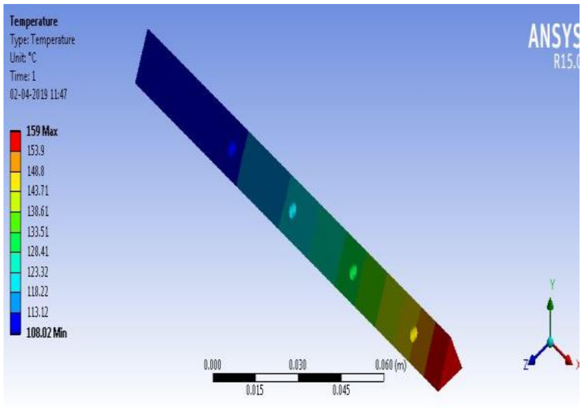


Fig.6.135 silver triangular fin circular hole

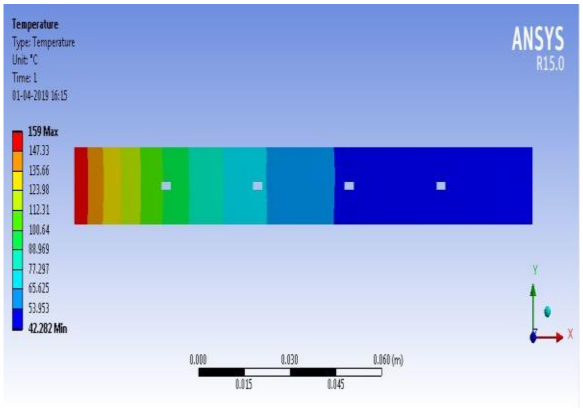


Fig.6.136 SS triangular fin rectangular hole

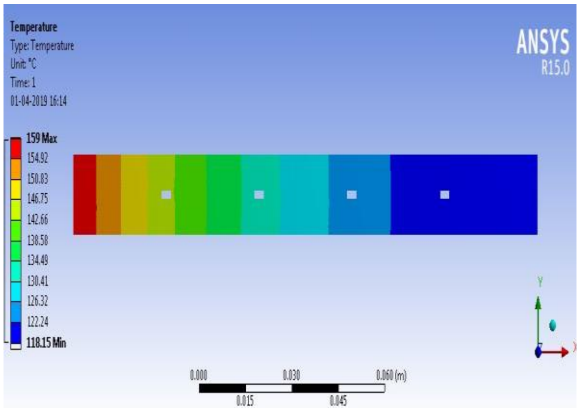


Fig.6.137 aluminium triangular fin rectangular hole

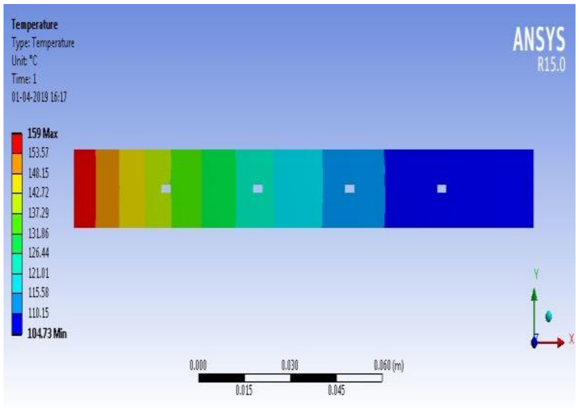


Fig.6.138 brass triangular fin rectangular hole

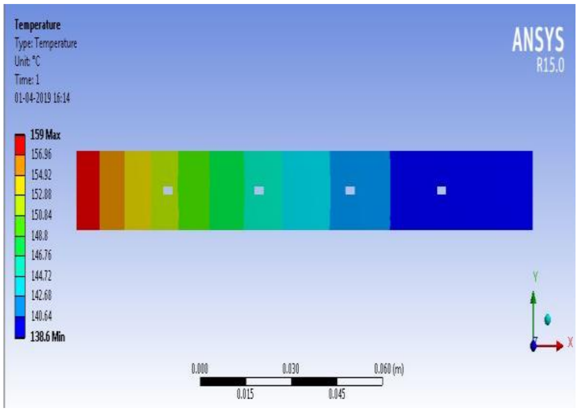


Fig.6.139 copper triangular fin rectangular hole

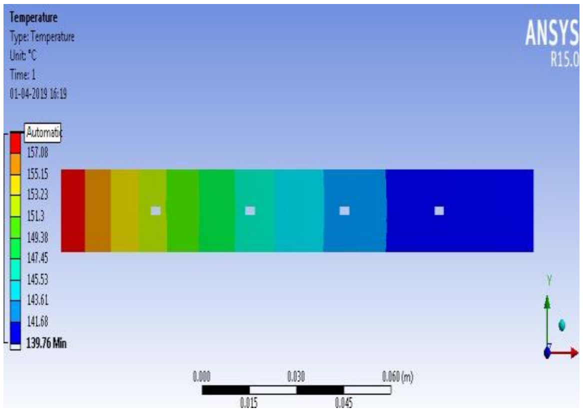


Fig.6.140 silver triangular fin rectangular hole

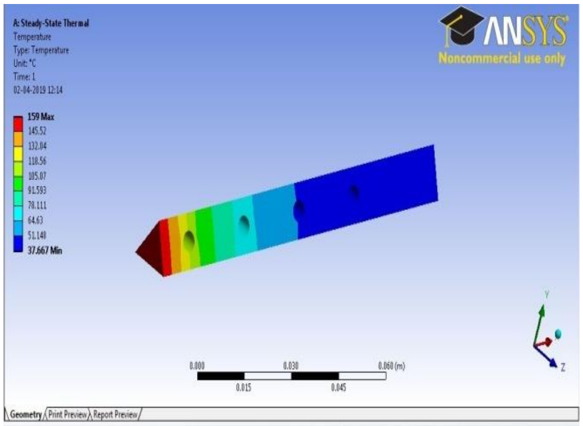


Fig.6.141 SS triangular fin elliptical hole

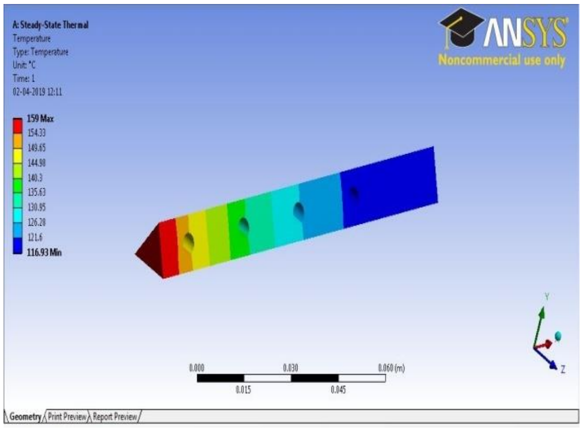


Fig.6.142 aluminium triangular fin elliptical hole

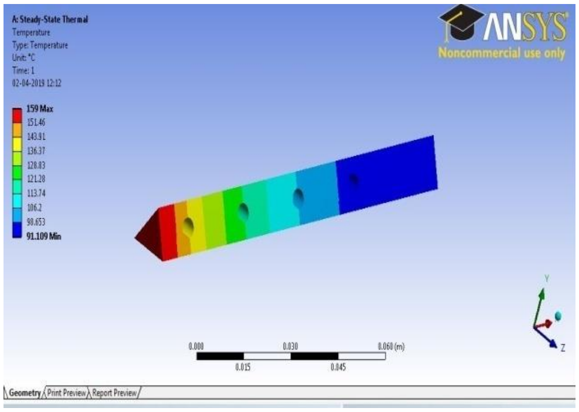


Fig.6.143 brass triangular fin elliptical hole

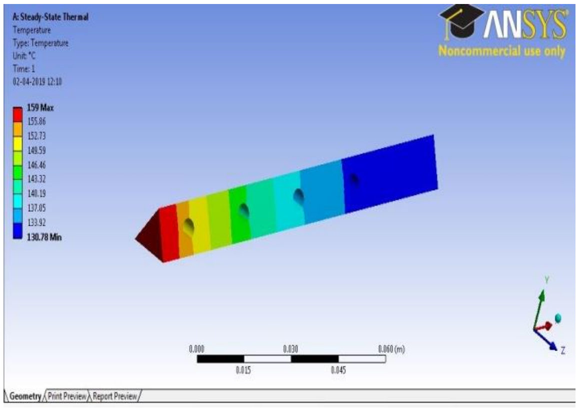


Fig.6.144 copper triangular fin elliptical hole

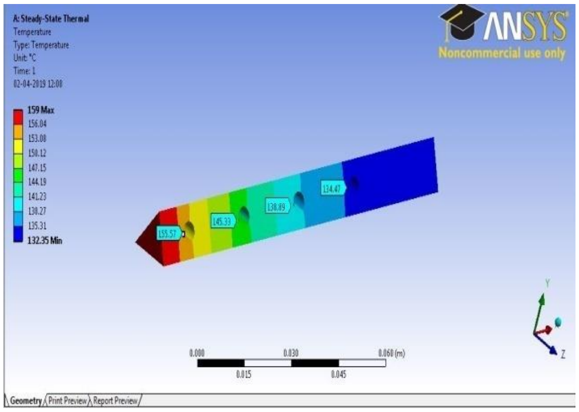


Fig.6.145 silver triangular fin elliptical hole

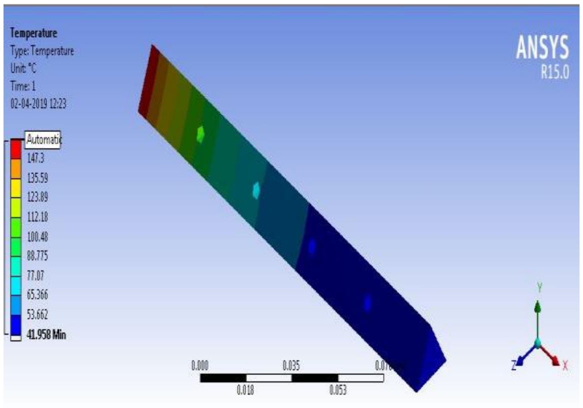


Fig.6.146 SS triangular fin pentagonal hole

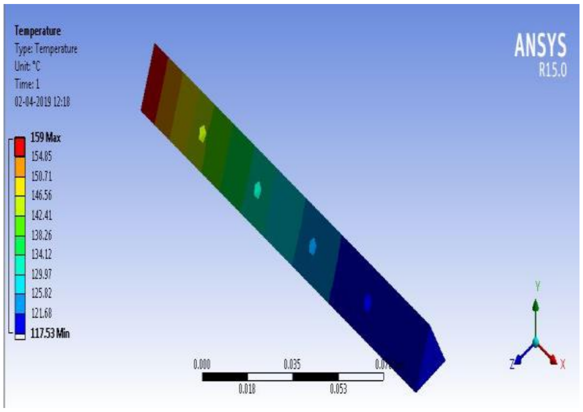


Fig.6.147 aluminium triangular fin pentagonal hole

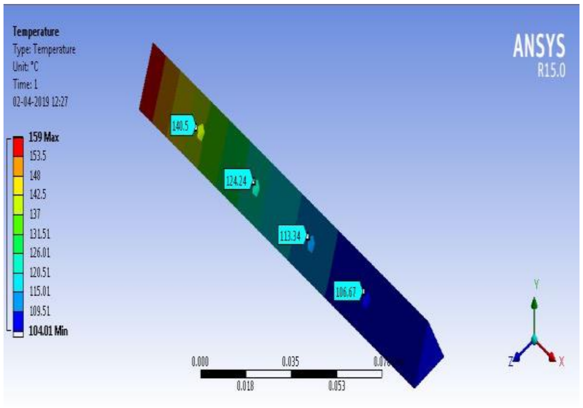


Fig.6.148 brass triangular fin pentagonal hole

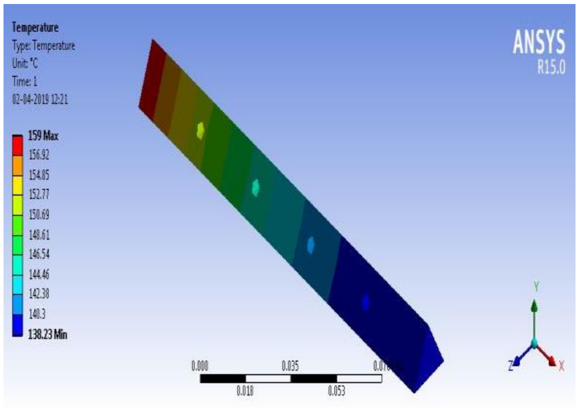


Fig.6.149 copper triangular fin pentagonal hole

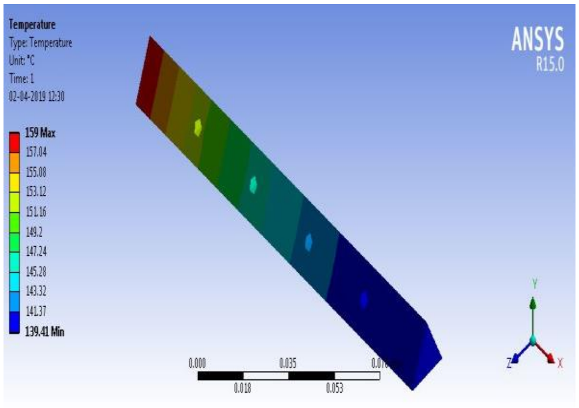


Fig.6.150 silver triangular fin pentagonal hole

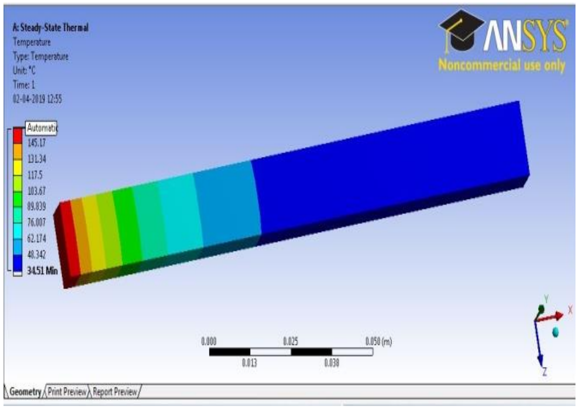


Fig.6.151 SS rectangular fin

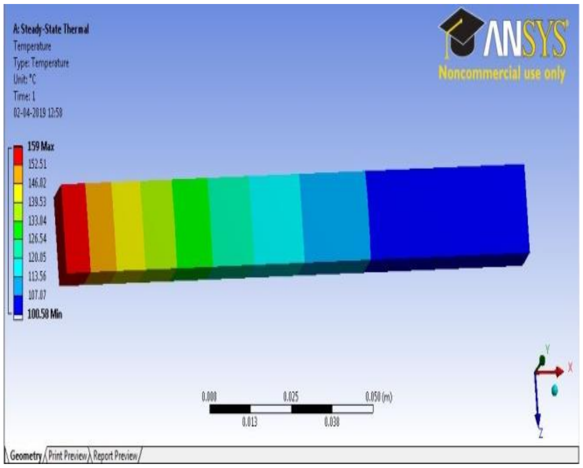


Fig.6.152 aluminium rectangular fin

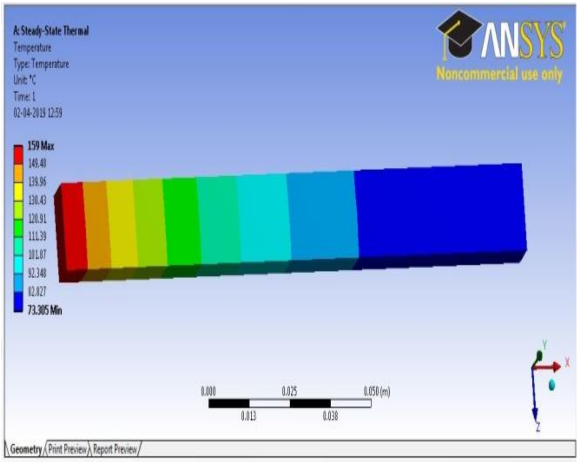


Fig.6.153 brass rectangular fin

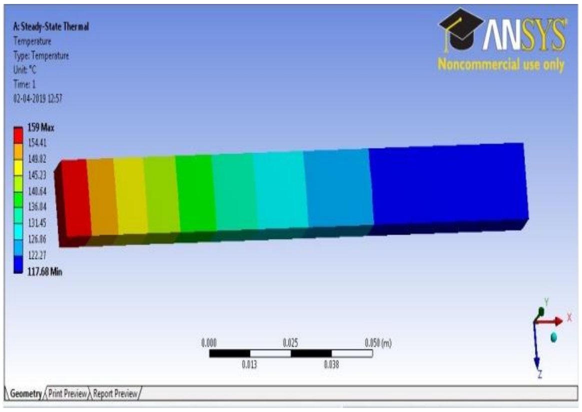


Fig.6.154 copper rectangular fin

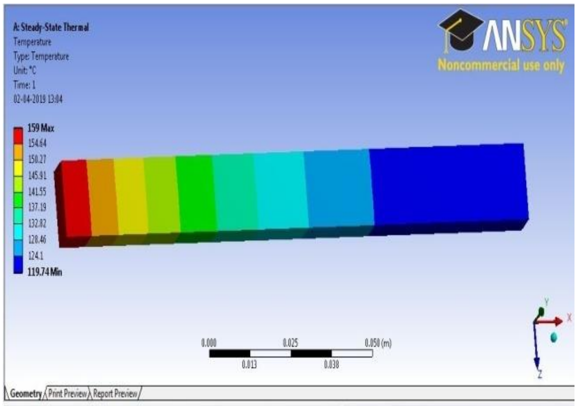


Fig.6.155 silver rectangular fin

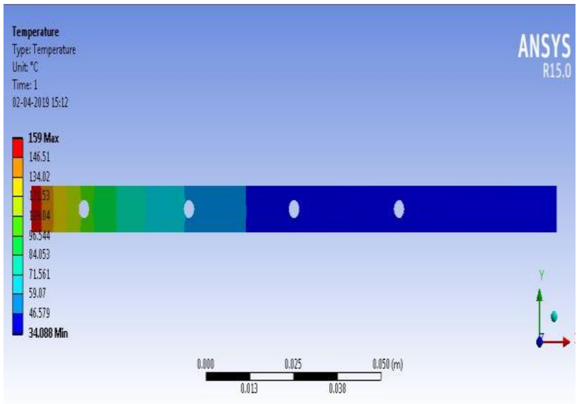


Fig.6.156 SS rectangular fin circular hole

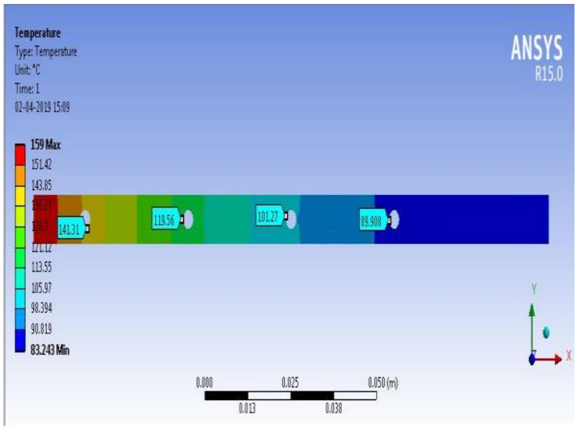


Fig.6.157 aluminium rectangular fin circular hole

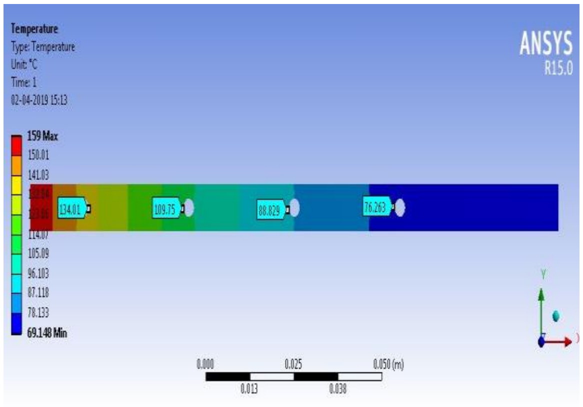


Fig.6.158 brass rectangular fin circular hole

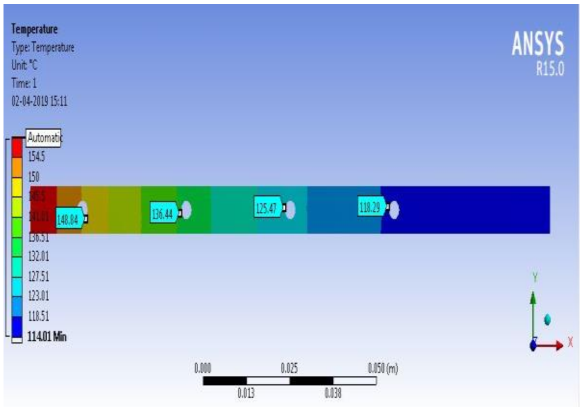


Fig.6.159 copper rectangular fin circular hole

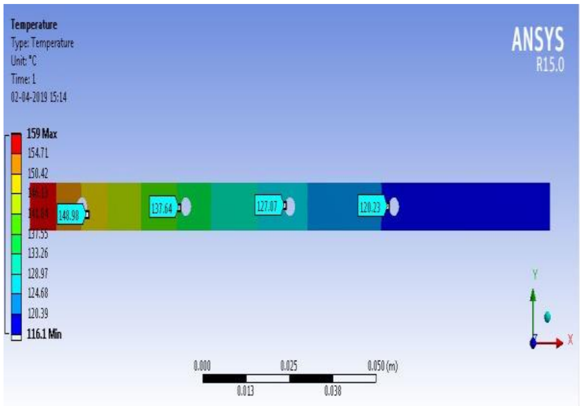


Fig.6.160 silver rectangular fin circular hole

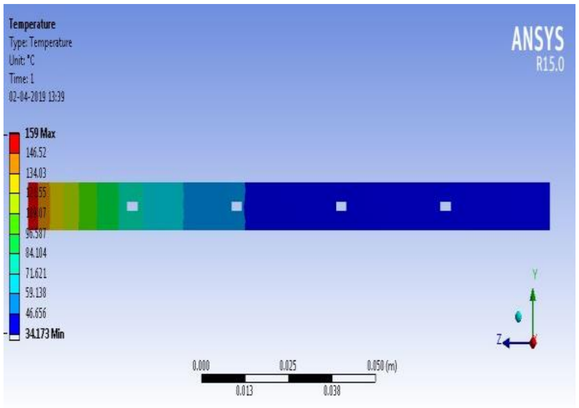


Fig.6.161 SS rectangular fin rectangular hole

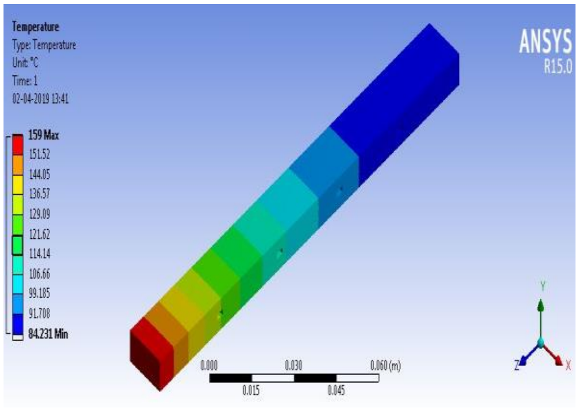


Fig.6.162 aluminium rectangular fin rectangular hole

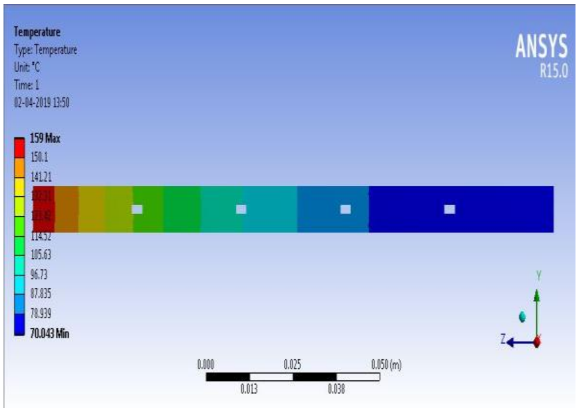


Fig.6.163 brass rectangular fin rectangular hole

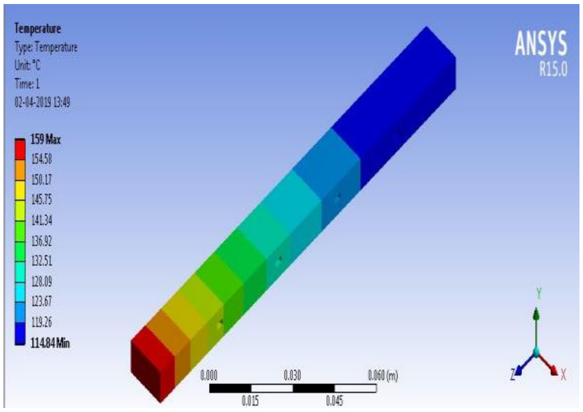


Fig.6.164 copper rectangular fin rectangular hole

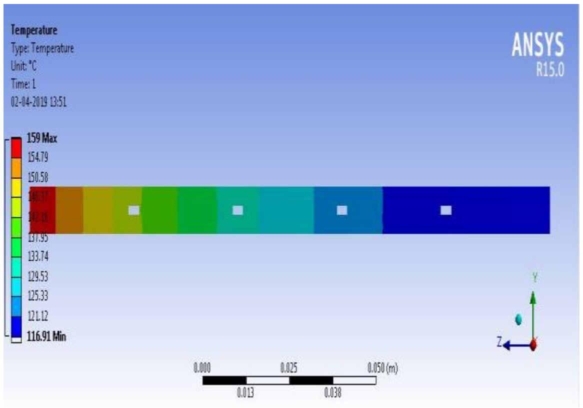


Fig.6.165 silver rectangular fin rectangular hole

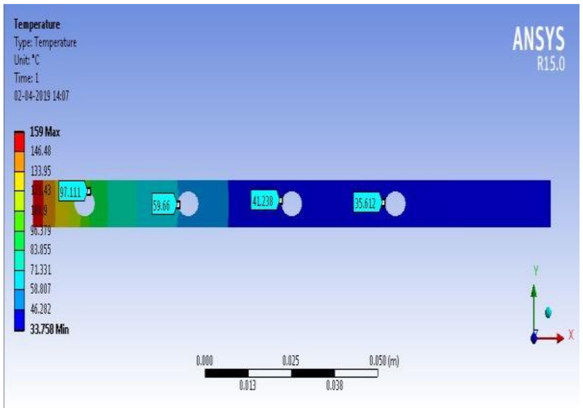


Fig.6.166 SS rectangular fin elliptical hole

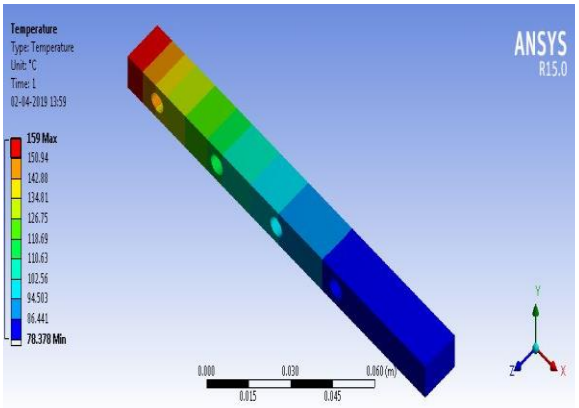


Fig.6.167 aluminium rectangular fin elliptical hole

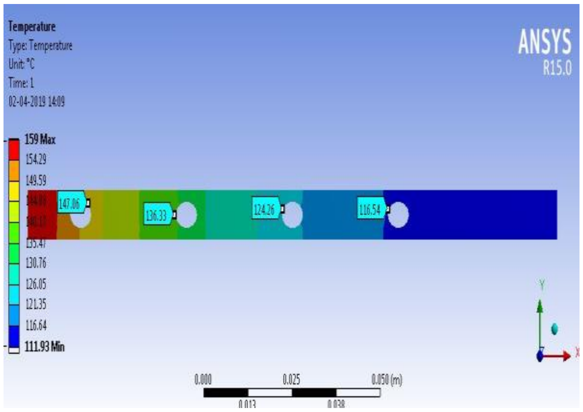


Fig.6.170 silver rectangular fin elliptical hole

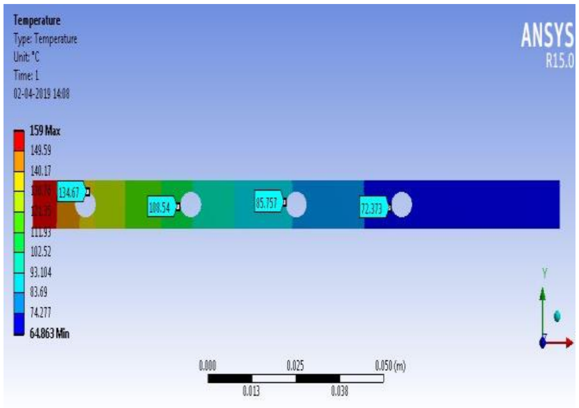


Fig.6.168 brass rectangular fin elliptical hole

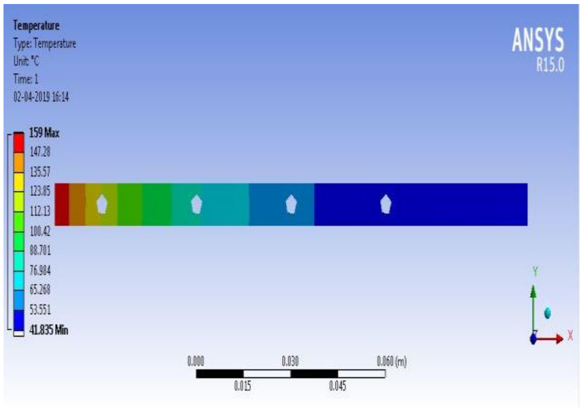


Fig.6.171 stainless steel rectangular fin pentagonal hole

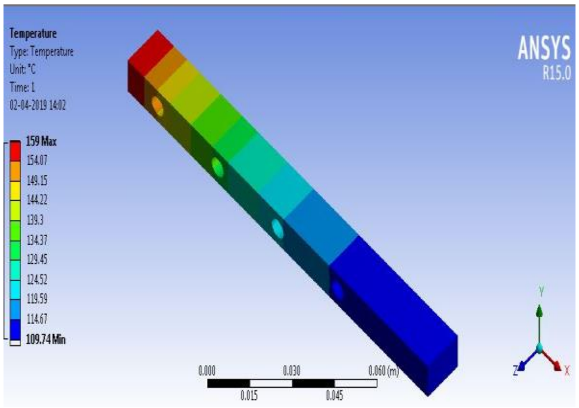


Fig.6.169 copper rectangular fin elliptical hole

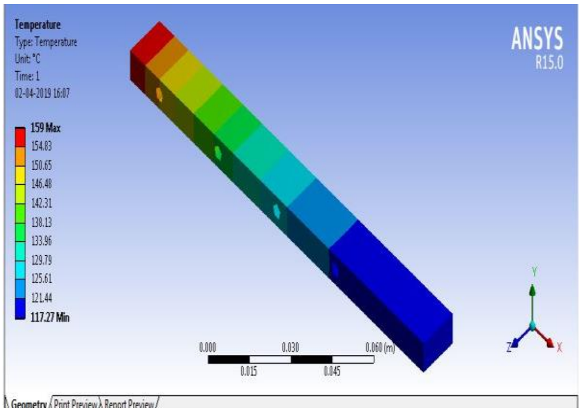


Fig.6.172 aluminium rectangular fin pentagonal hole

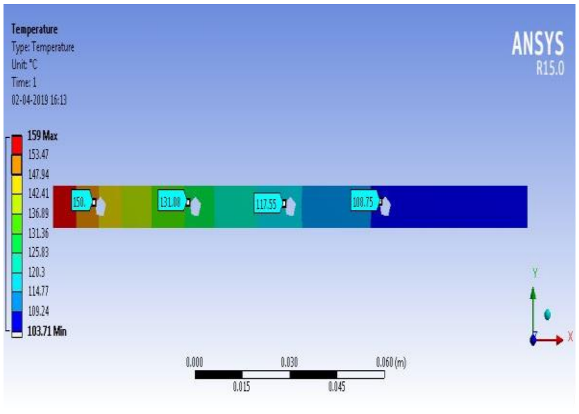


Fig.6.173 brass rectangular fin pentagonal hole

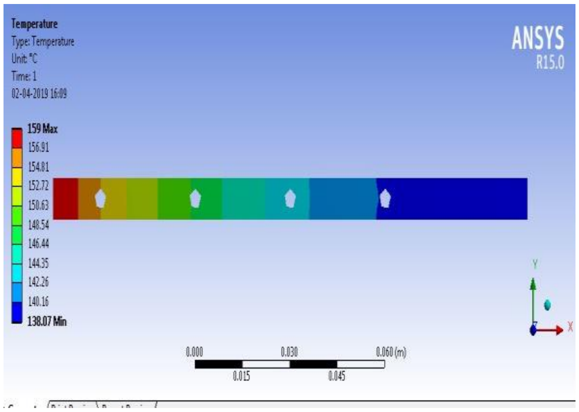


Fig.6.174 copper rectangular fin pentagonal hole

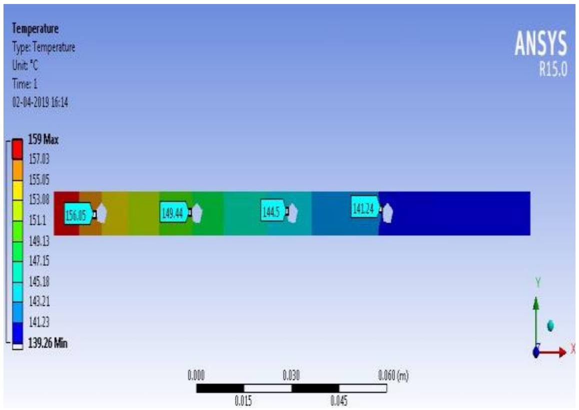


Fig.6.175 silver rectangular fin pentagonal hole

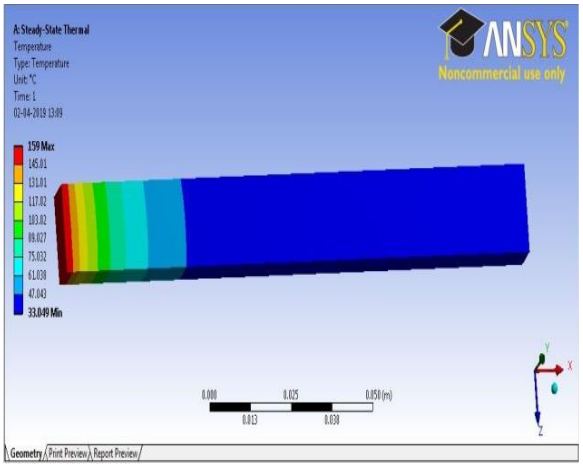


Fig.6.176 SS rectangular fin

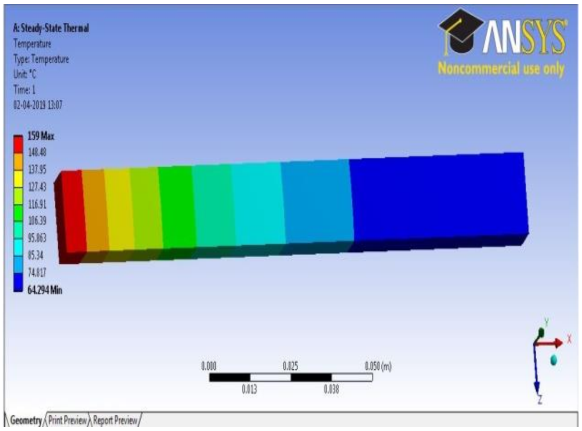


Fig.6.177 aluminium rectangular fin

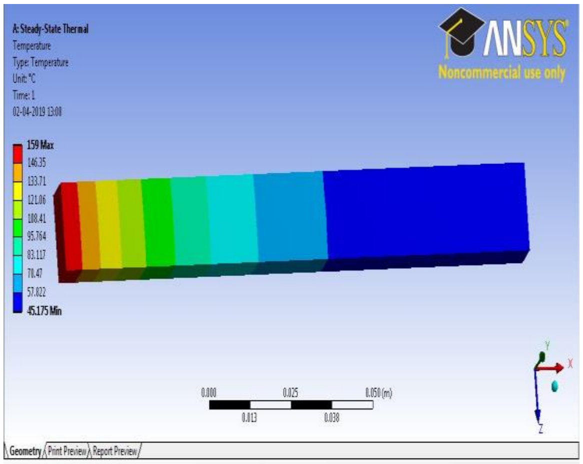


Fig.6.178 brass rectangular fin

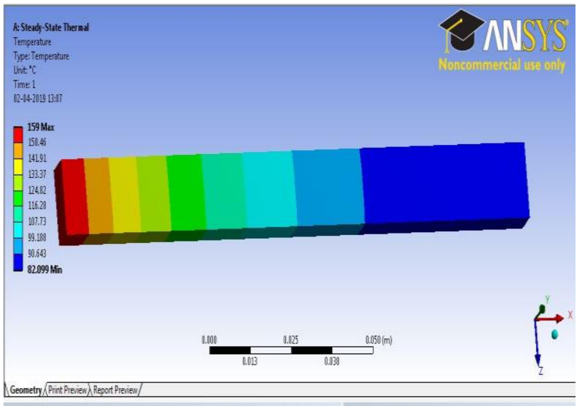


Fig.6.179 copper rectangular fin

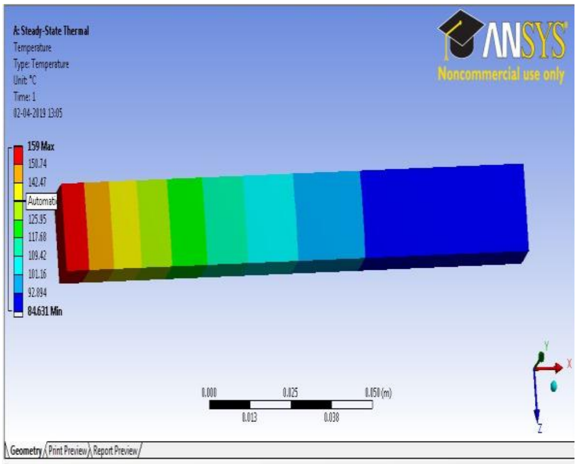


Fig.6.180 silver rectangular fin

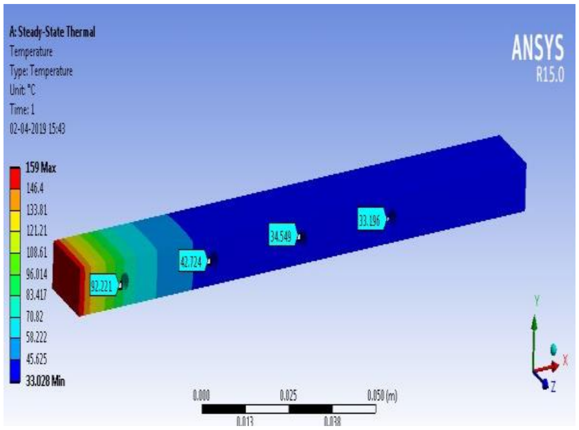


Fig.6.181 SS rectangular fin circular hole

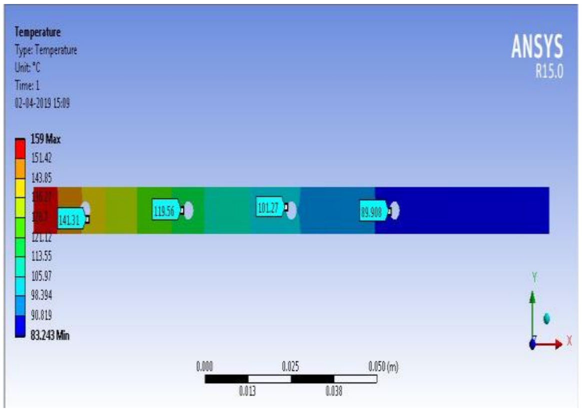


Fig.6.182 aluminium rectangular fin circular hole

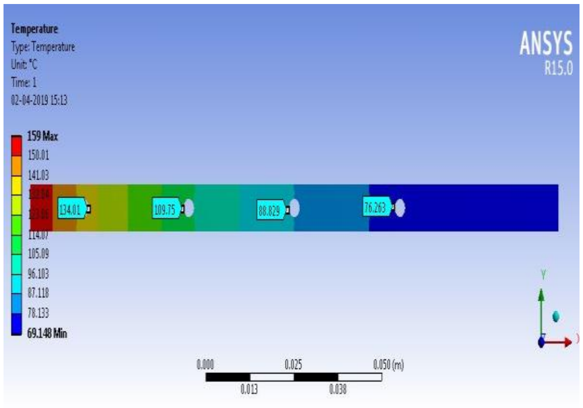


Fig.6.183 brass rectangular fin circular hole

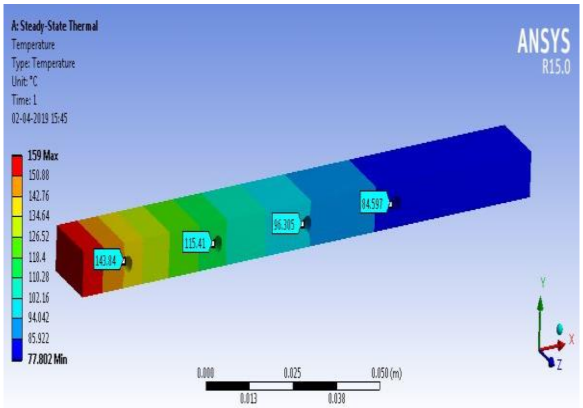


Fig.6.184 copper rectangular fin circular hole

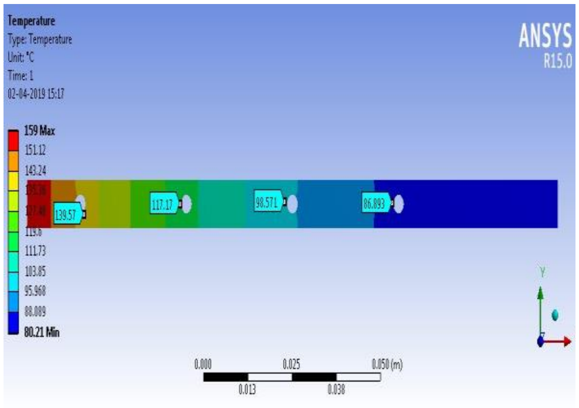


Fig.6.185 silver rectangular fin circular hole

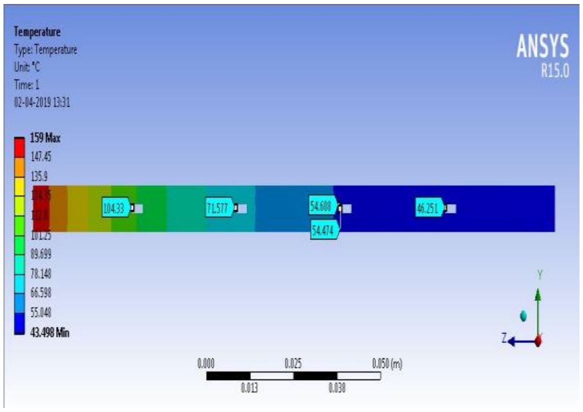


Fig.6.188 brass rectangular fin rectangular hole

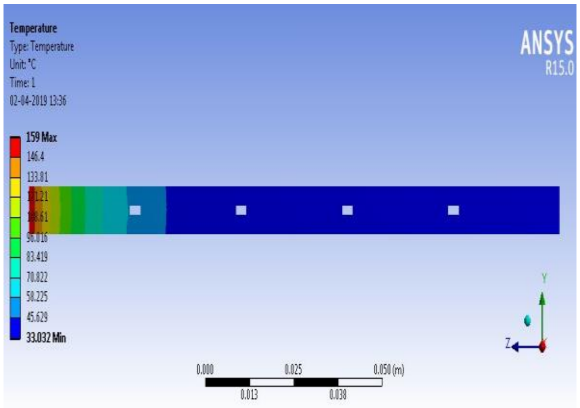


Fig.6.186 SS rectangular fin rectangular hole

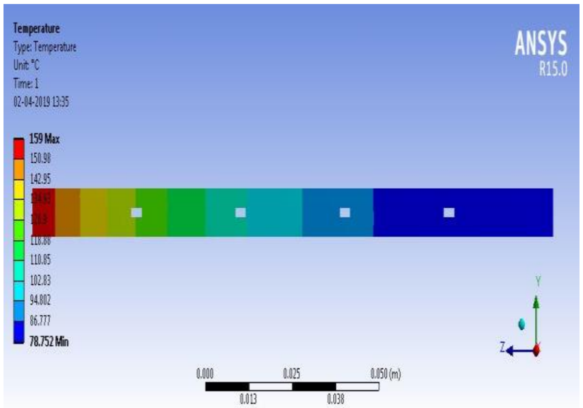


Fig.6.189 copper rectangular fin rectangular hole

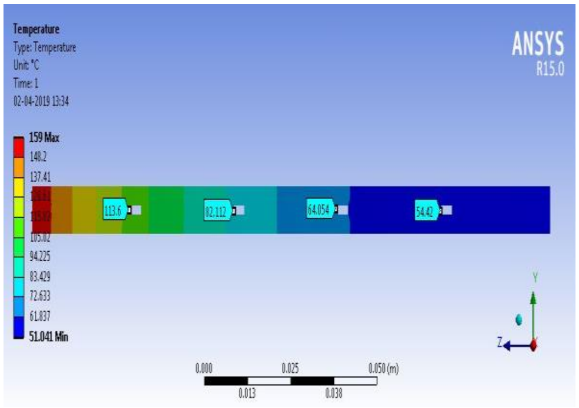


Fig.6.187 aluminium rectangular fin rectangular hole

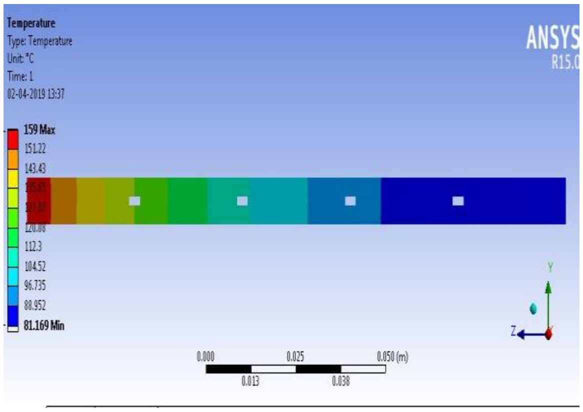


Fig.6.190 silver rectangular fin rectangular hole

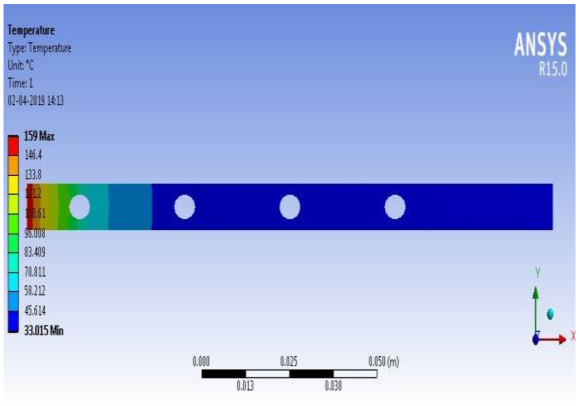


Fig.6.191 SS rectangular fin elliptical hole

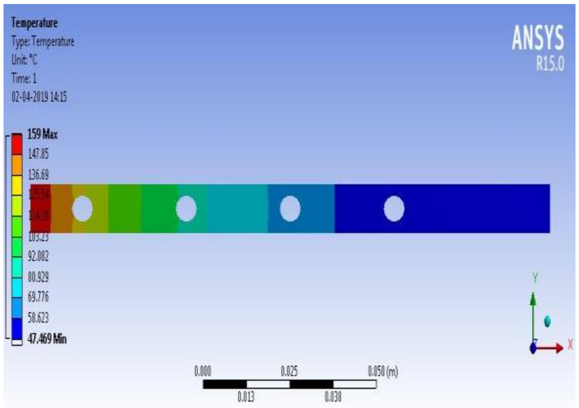


Fig.6.192 aluminium rectangular fin elliptical hole

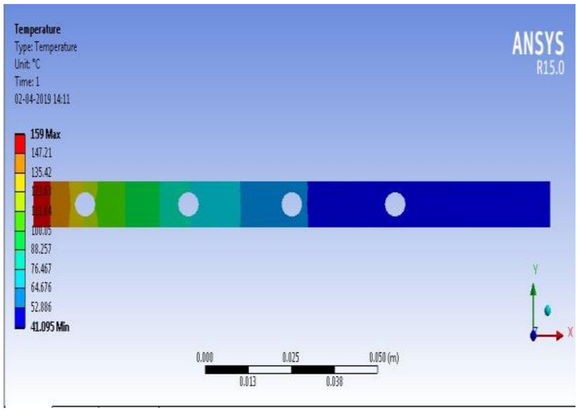


Fig.6.193 brass rectangular fin elliptical hole

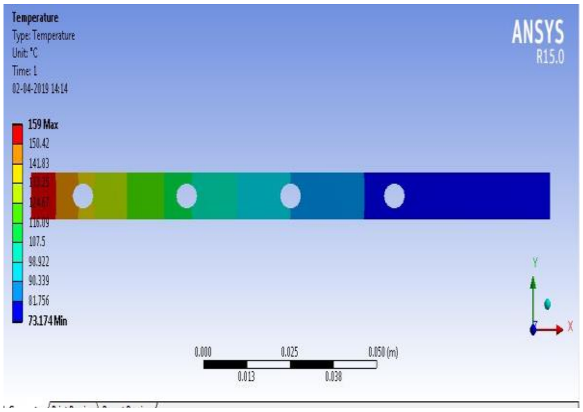


Fig.6.194 copper rectangular fin elliptical hole

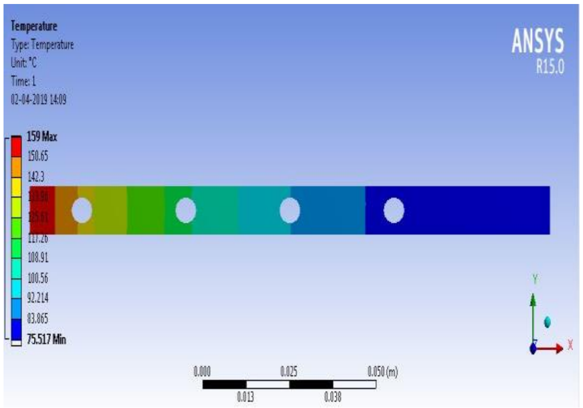


Fig.6.195 silver rectangular fin elliptical hole

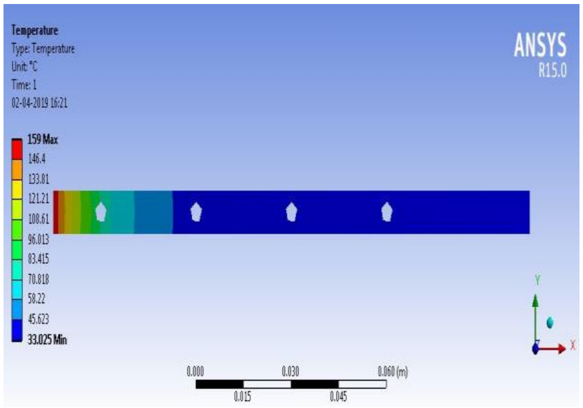


Fig.6.196 SS rectangular fin pentagonal hole

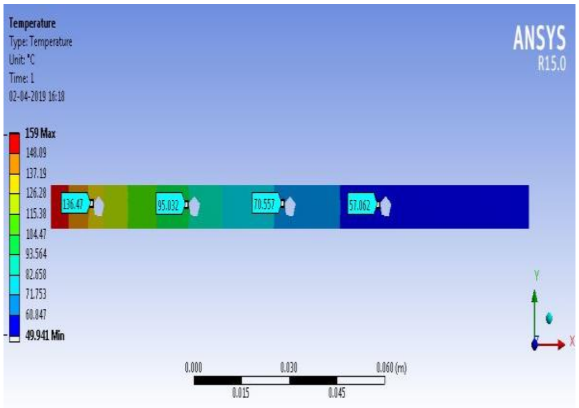


Fig.6.197 aluminium rectangular fin pentagonal hole

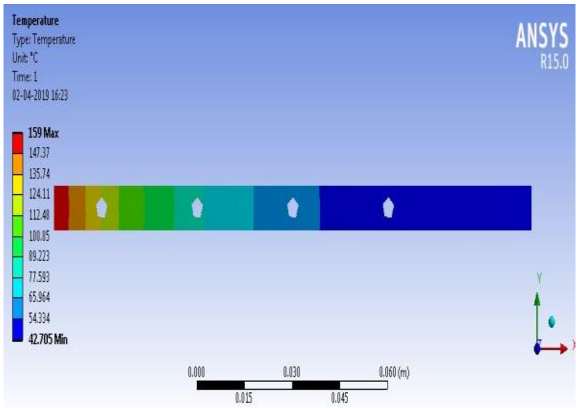


Fig.6.198 brass rectangular fin pentagonal hole

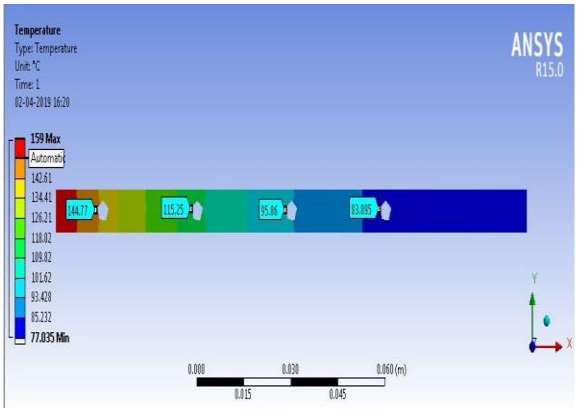


Fig.6.199 copper rectangular fin pentagonal hole

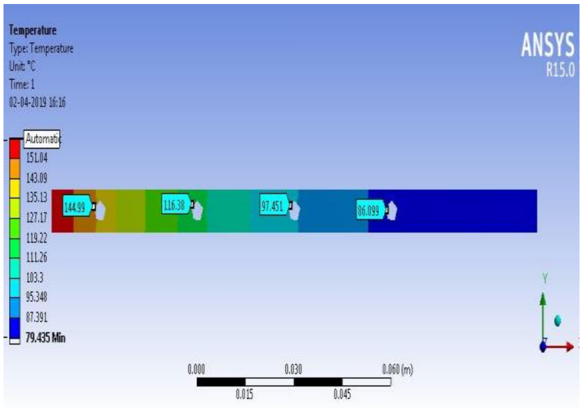


Fig.6.200 Silver rectangular fin pentagonal hole

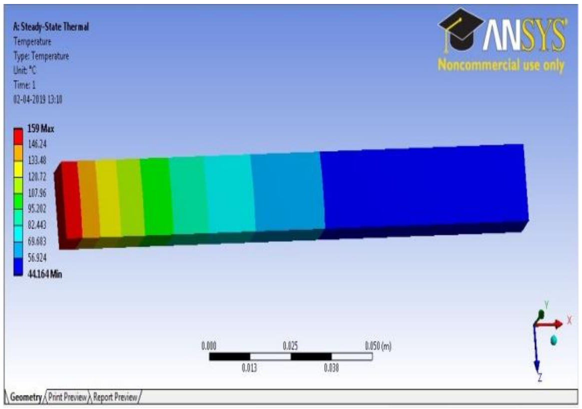


Fig.6.201 SS rectangular fin

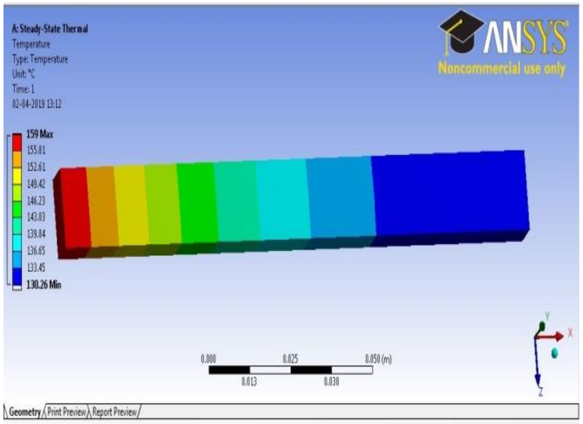


Fig.6.202 aluminium rectangular fin

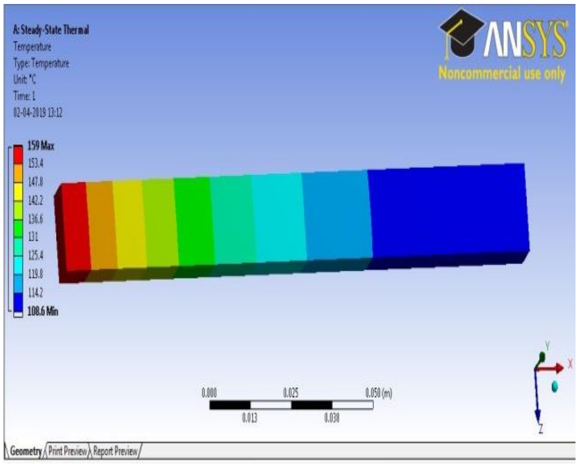


Fig.6.203 brass rectangular fin

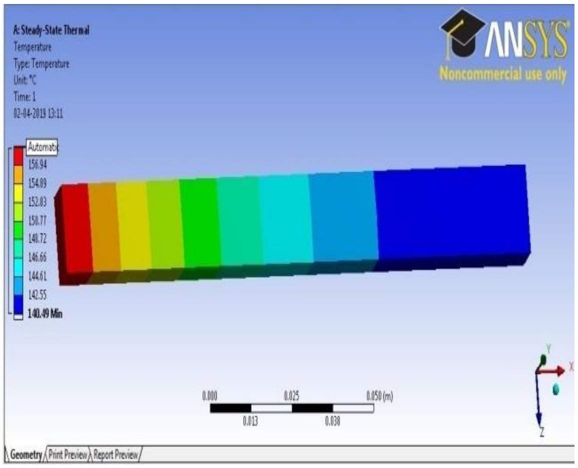


Fig.6.204 copper rectangular fin

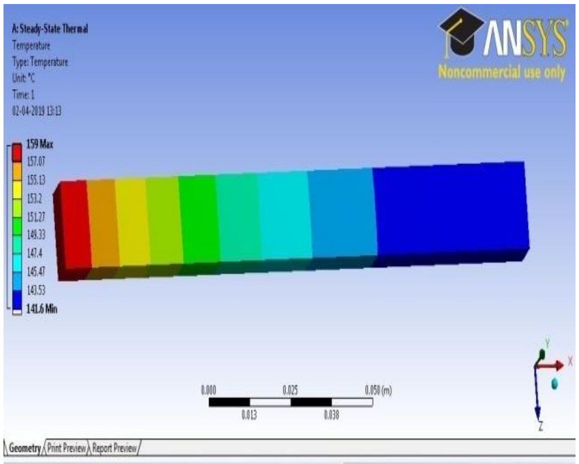


Fig.6.205 silver rectangular fin

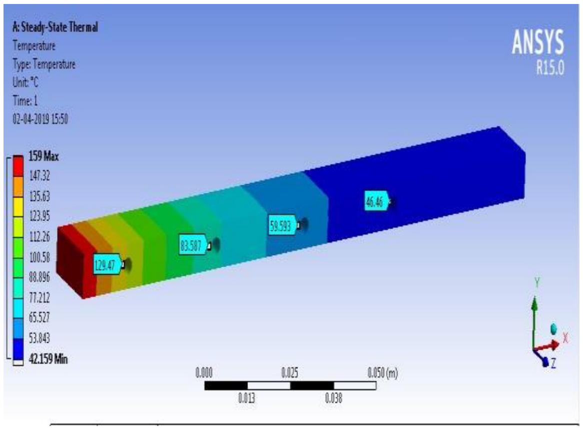


Fig.6.206 SS triangular fin circular hole

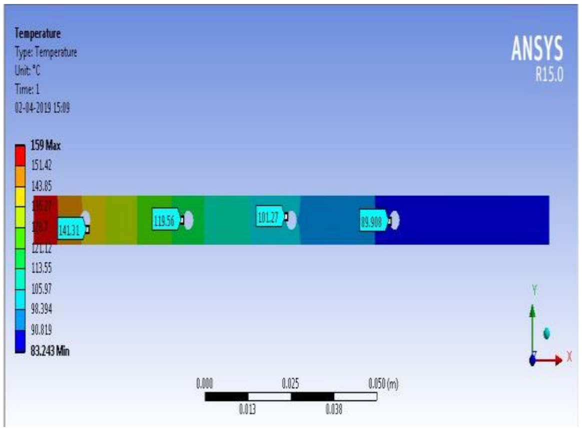


Fig.6.207 aluminium rectangular fin circular hole

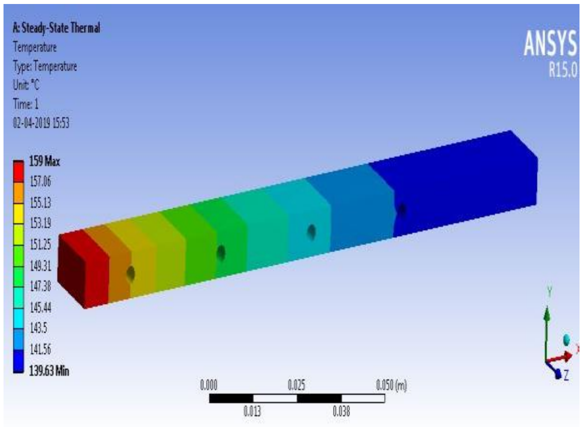


Fig.6.208 brass rectangular fin circular hole

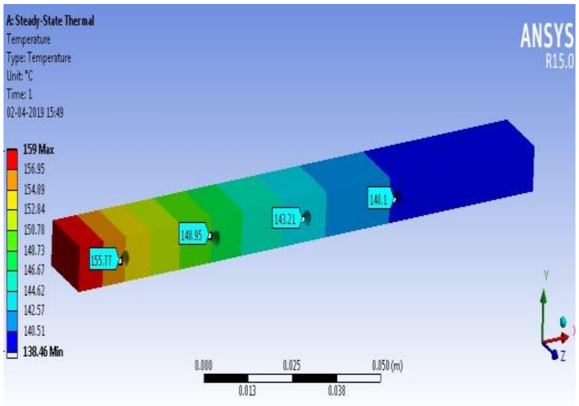


Fig.6.209 copper rectangular fin circular hole

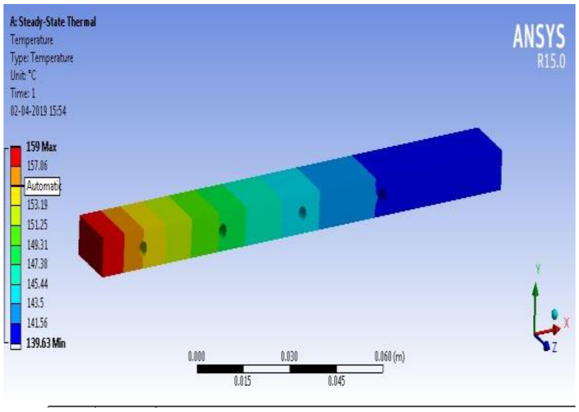


Fig.6.210 silver rectangular fin circular hole

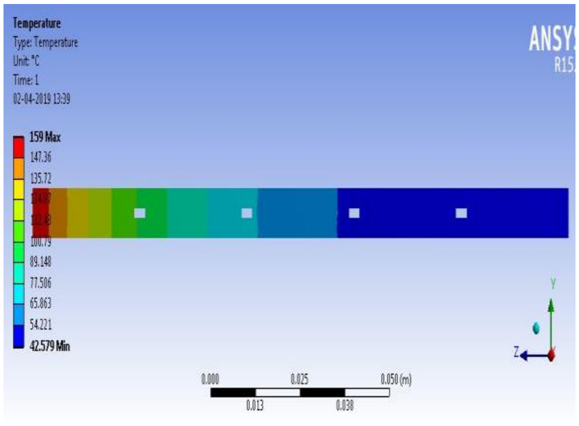


Fig.6.211 SS rectangular fin rectangular hole

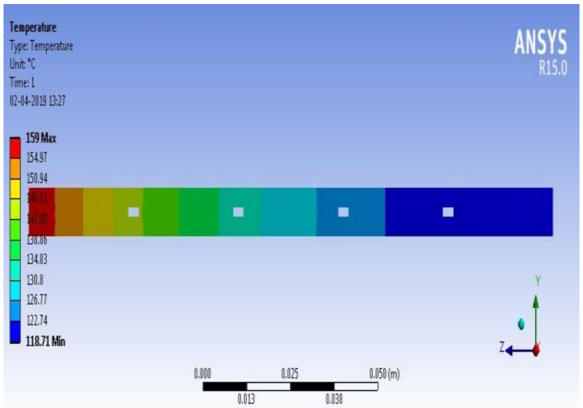


Fig.6.212 aluminium rectangular fin rectangular hole

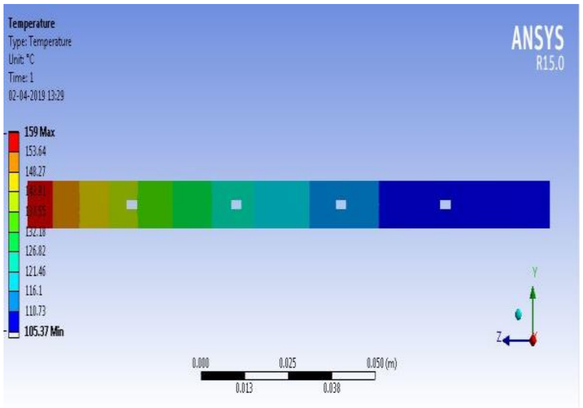


Fig.6.213 brass rectangular fin rectangular hole

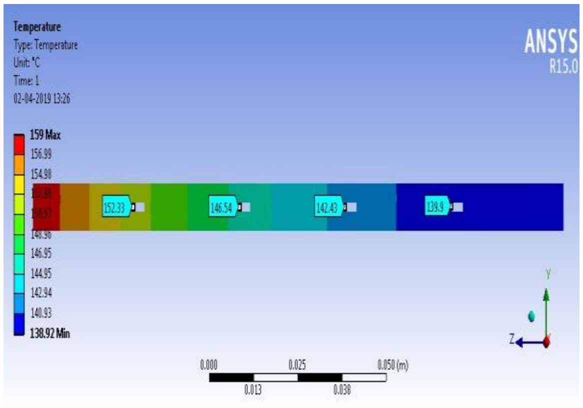


Fig.6.214 copper rectangular fin rectangular hole

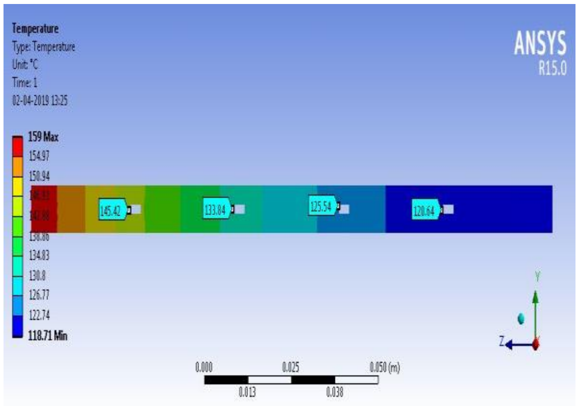


Fig.6.215 silver rectangular fin rectangular hole

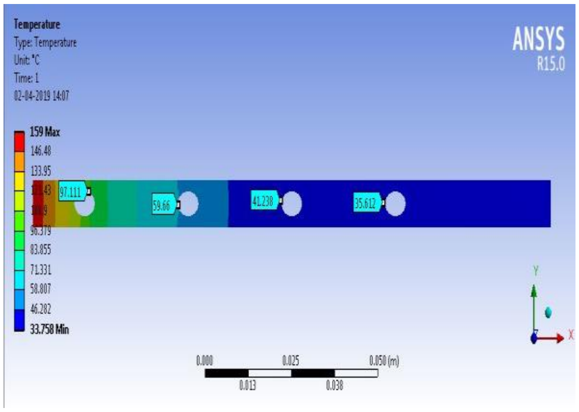


Fig.6.216 SS rectangular fin elliptical hole

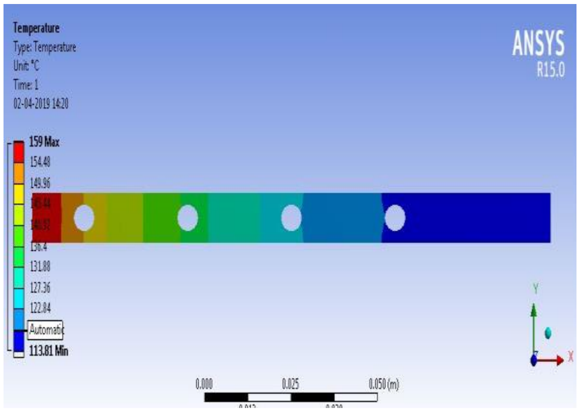


Fig.6.217 aluminium rectangular fin elliptical hole

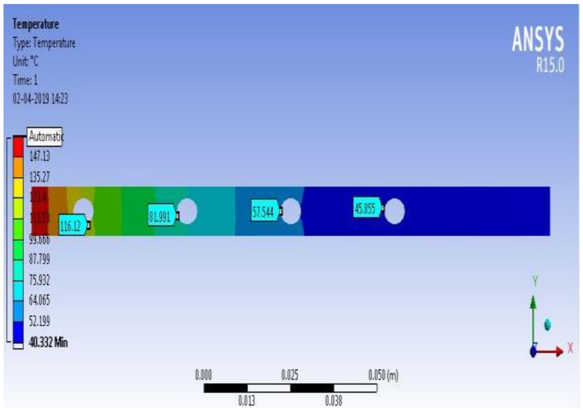


Fig.6.218 brass rectangular fin elliptical hole

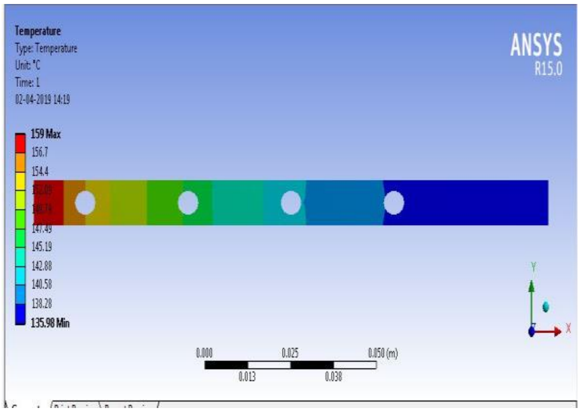


Fig.6.219 copper rectangular fin elliptical hole

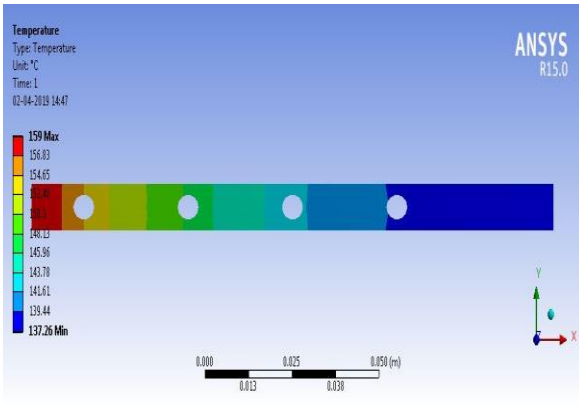


Fig.6.220 silver rectangular fin elliptical hole

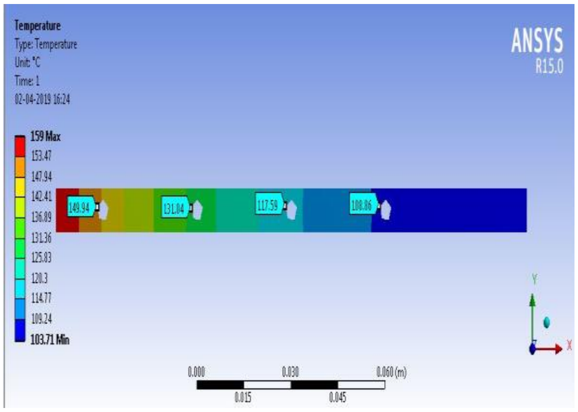


Fig.6.221 SS rectangular fin pentagonal hole

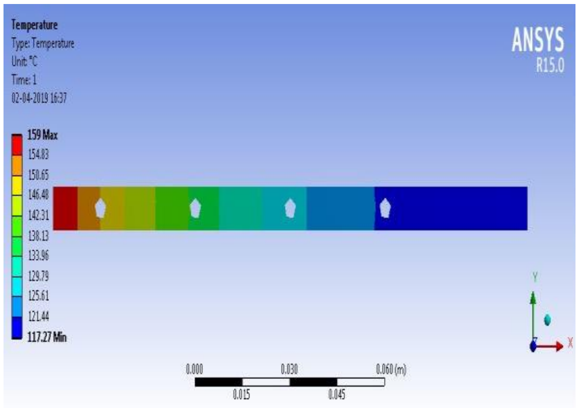


Fig.6.222 aluminium rectangular fin pentagonal hole

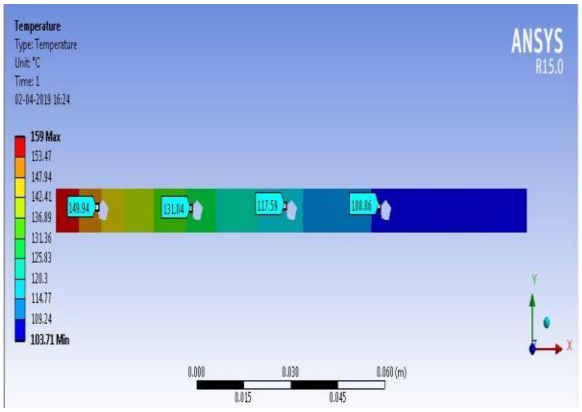


Fig.6.223 brass rectangular fin pentagonal hole

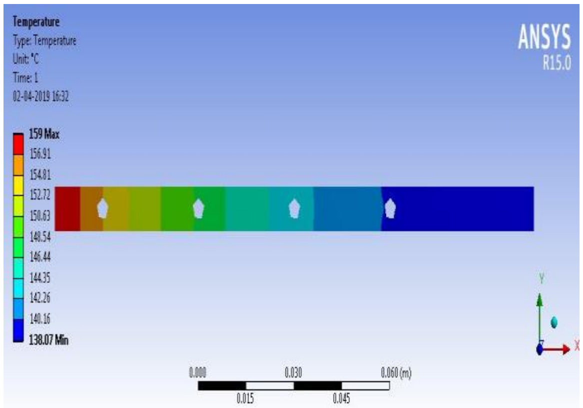


Fig.6.224 copper rectangular fin pentagonal hole

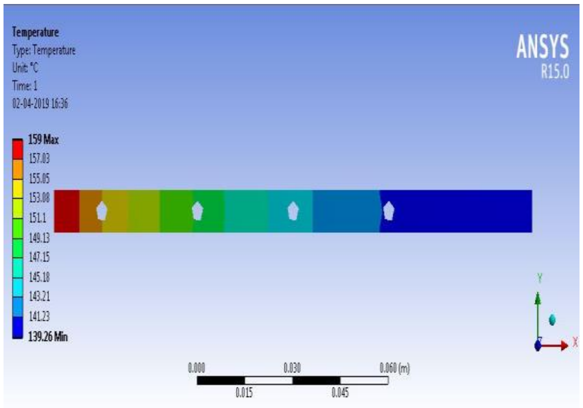


Fig.6.225 Silver rectangular fin pentagonalhole

6.6 Graphs for Solved Models

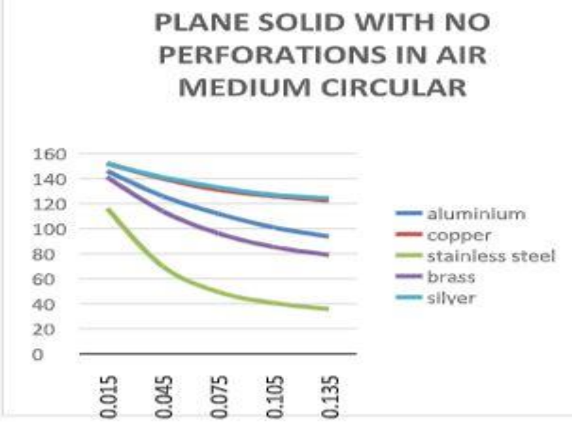


Fig 6.1 circular fin air medium

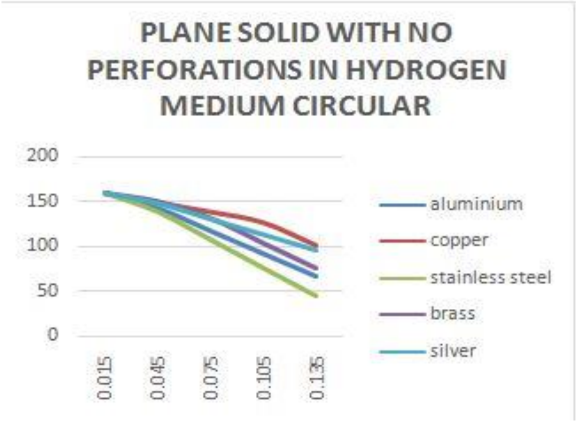


Fig 6.4 circular fin hydrogen medium

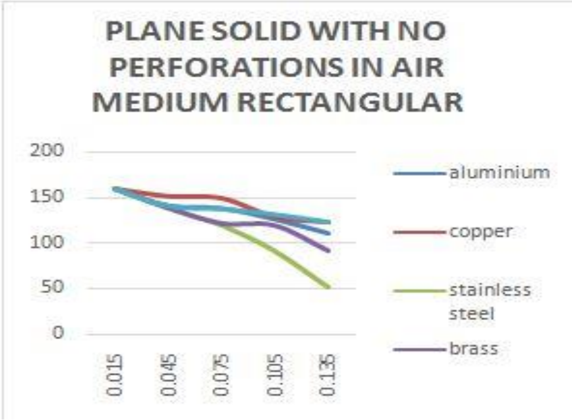


Fig 6.2 rectangular fin air medium

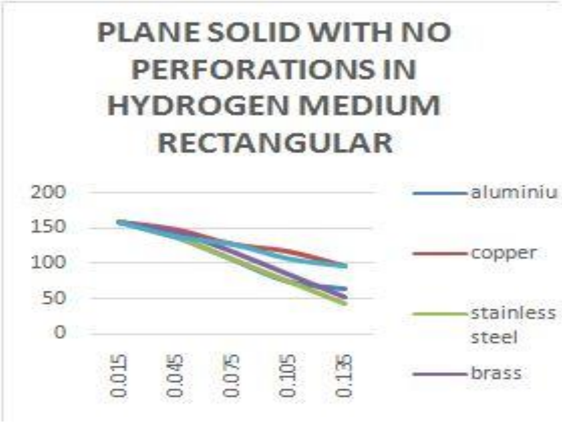


Fig 6.5 rectangular fin hydrogen medium

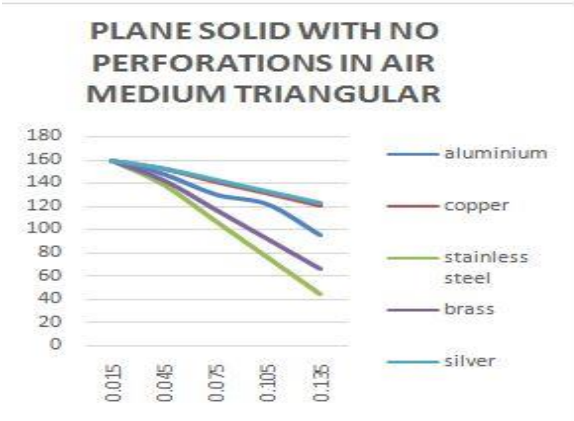


Fig 6.3 triangular fin air medium

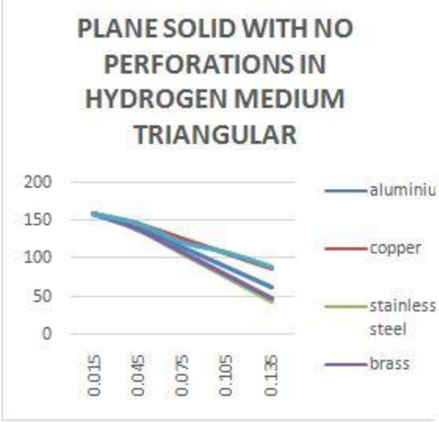


Fig 6.6 triangular fin hydrogen medium

Fig 6.7 circular fin argon medium

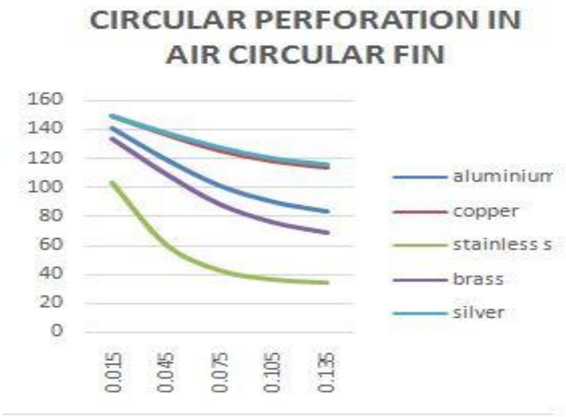


Fig 6.10 circular fin air medium

Fig 6.8 rectangular fin argon medium

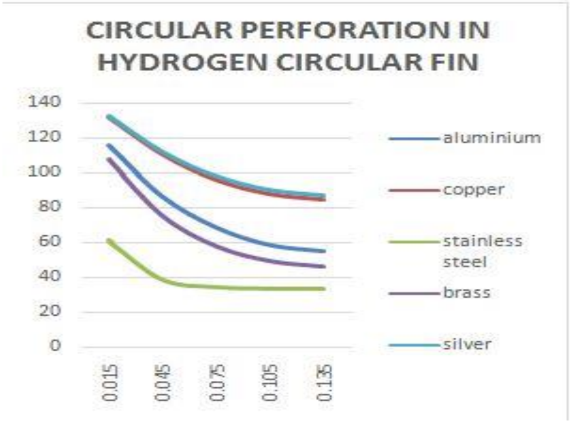


Fig 6.11 rectangular fin air medium

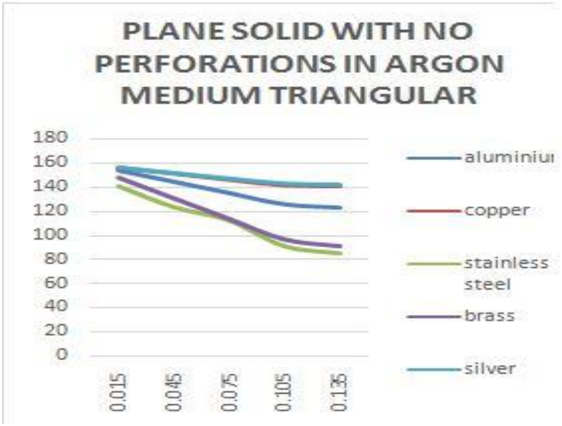


Fig 6.9 triangular fin argon medium

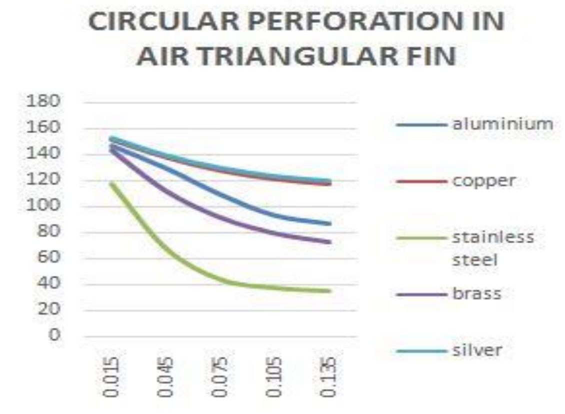


Fig 6.12 triangular fin air medium

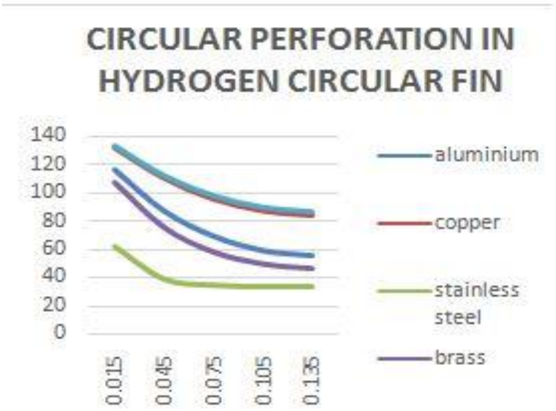


Fig 6.13 circular fin hydrogen medium

Fig 6.16 circular fin argon medium

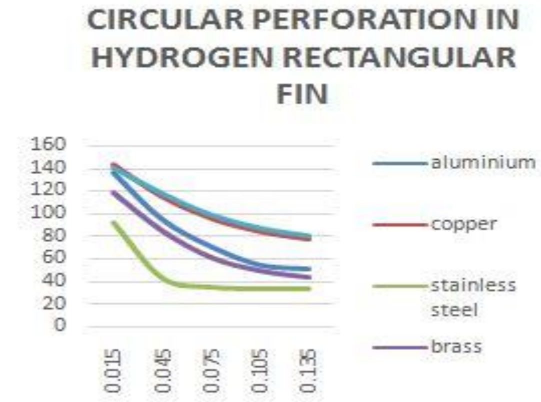


Fig 6.14 rectangular fin hydrogen medium

Fig 6.17rectangular fin argon medium

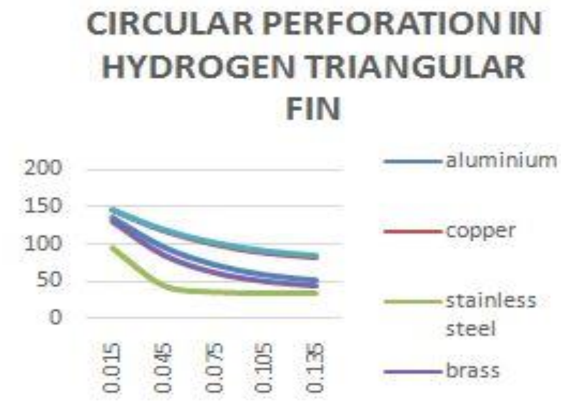


Fig 6.15 triangular fin hydrogen medium

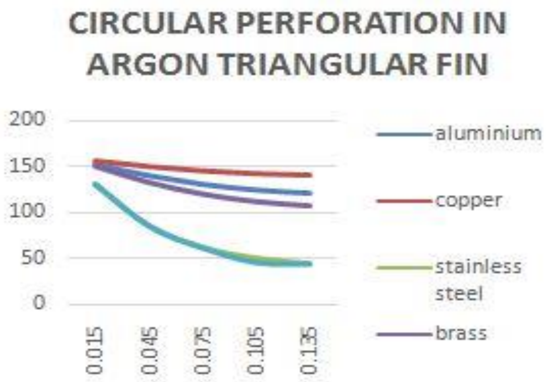


Fig. 6.18 Triangular fin argon medium

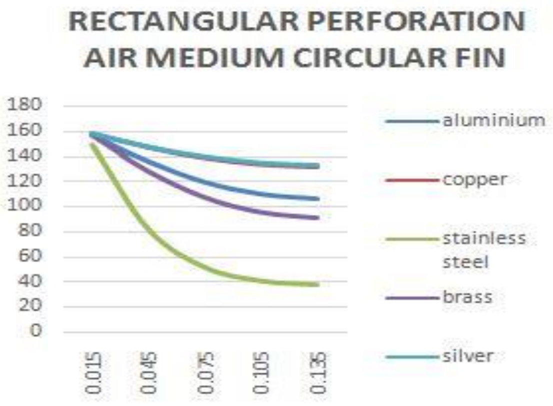


Fig 6.19 circular fin air medium

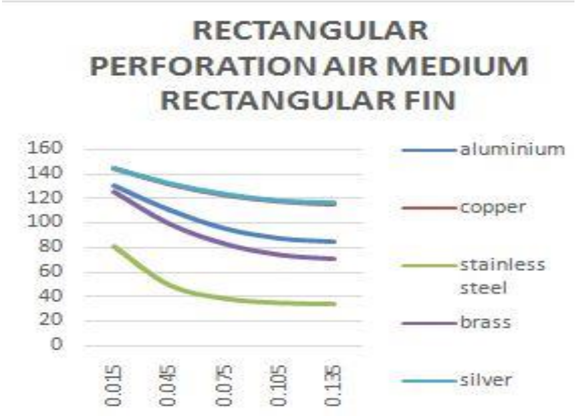


Fig 6.20 rectangular fin air medium

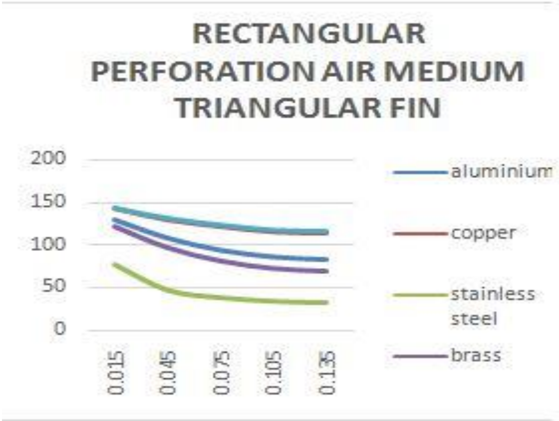


Fig 6.21 triangular fin air medium

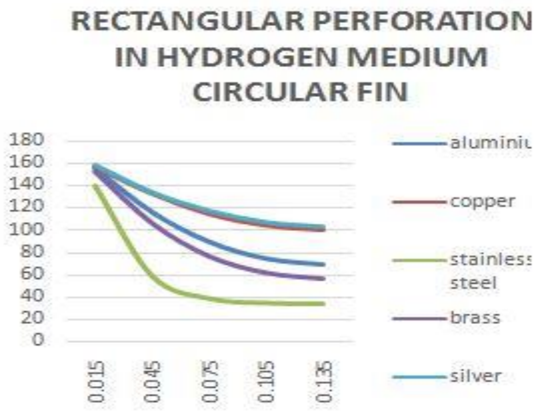


Fig 6.22 circular fin hydrogen medium

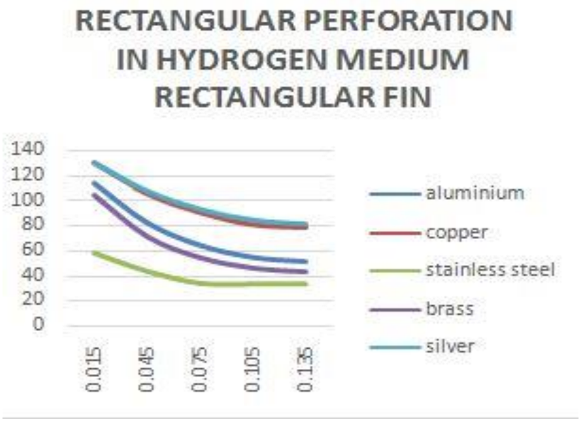


Fig 6.23 rectangular fin hydrogen medium

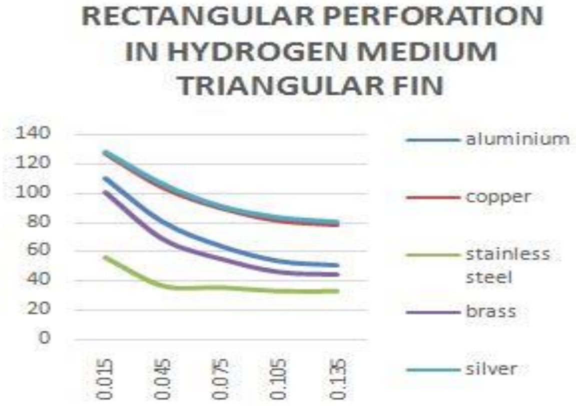
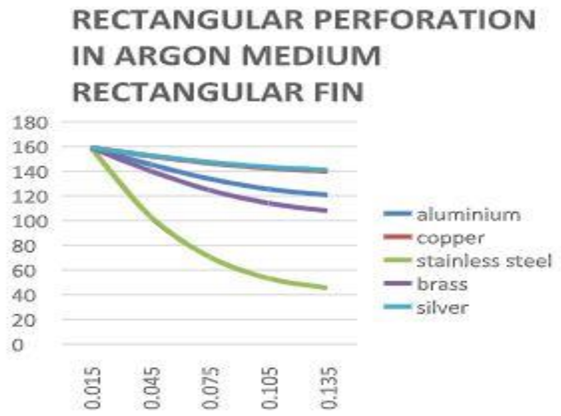


Fig 6.24 triangular fin hydrogen medium



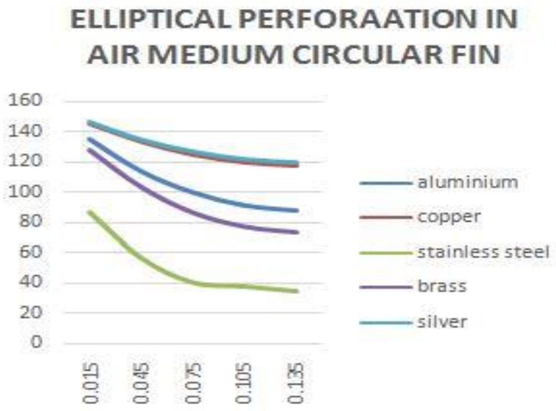
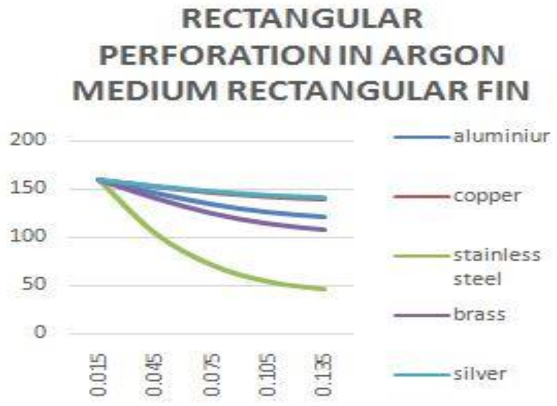


Fig 6.25 circular fin argon medium

Fig 6.28 circular fin air medium



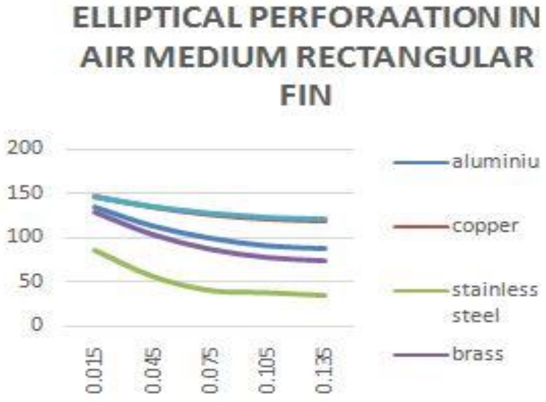
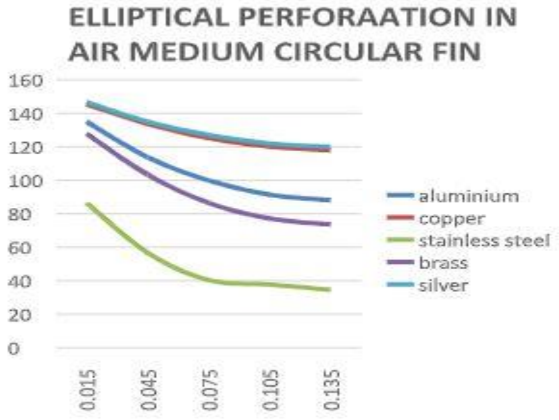


Fig 6.26rectangle fin argon medium

Fig 6.29 rectangular fin air medium



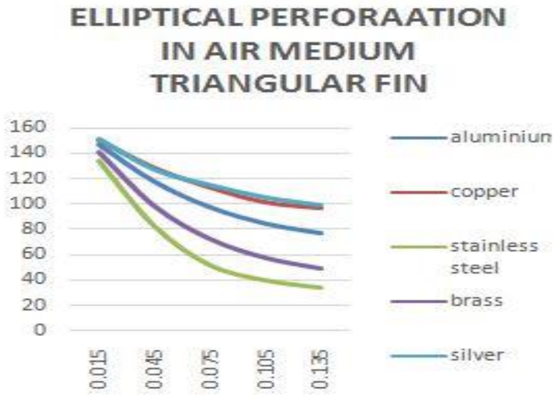


Fig 6.27 triangular fin argon medium

Fig 6.30 triangle fin air medium

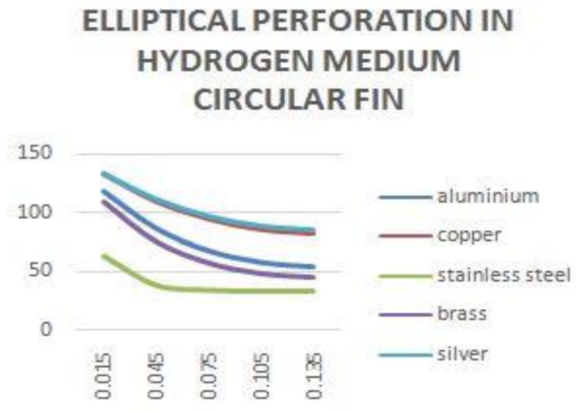


Fig 6.31 circular fin hydrogen medium

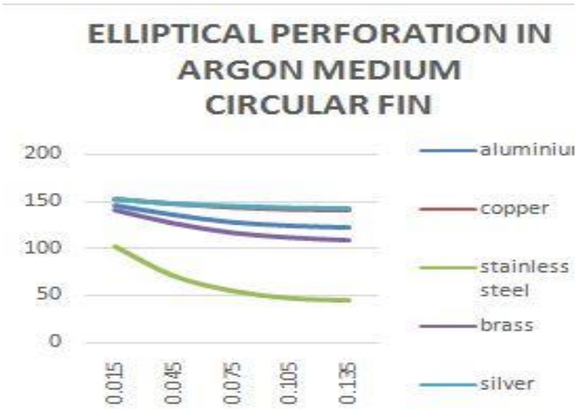


Fig 6.34 circular fin argon medium

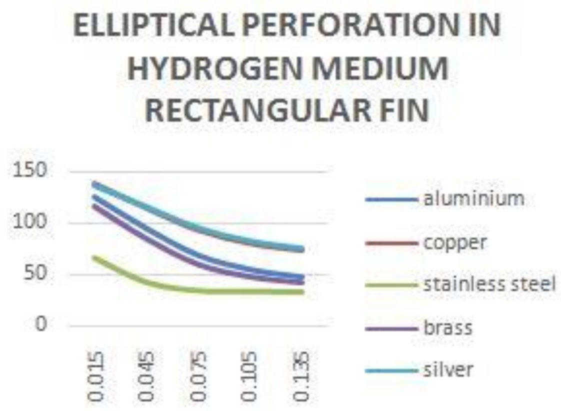


Fig 6.32 triangular fin hydrogen medium

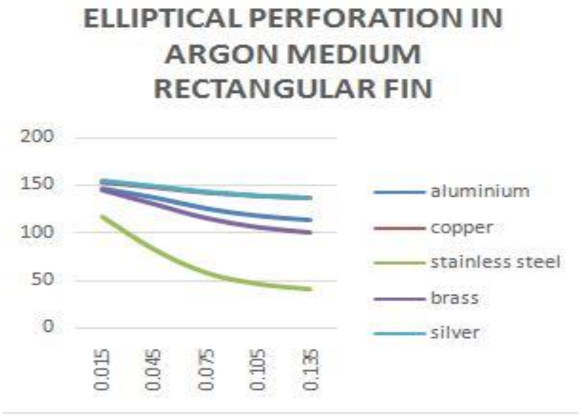


Fig 6.35 rectangular fin argon medium

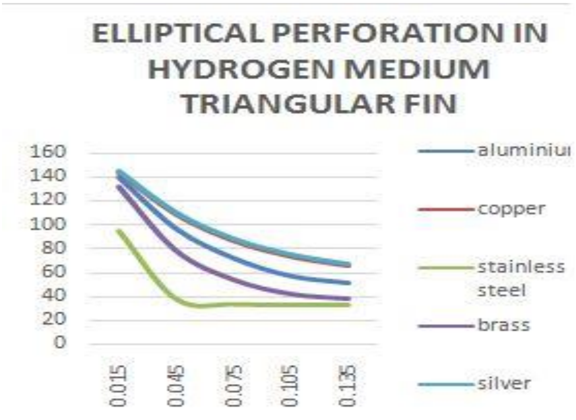


Fig 6.33 rectangular fin hydrogen medium

Fig 6.36triangular fin argon medium

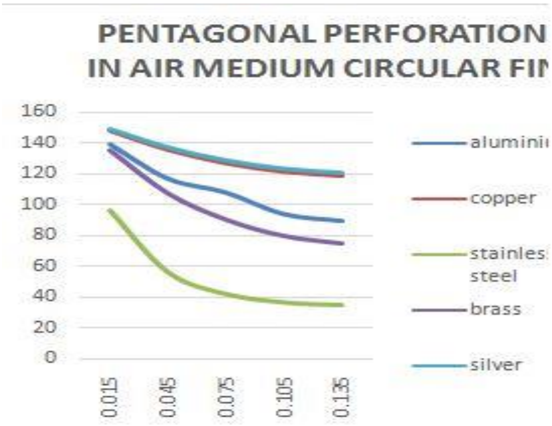


Fig 6.37 circular fin air medium

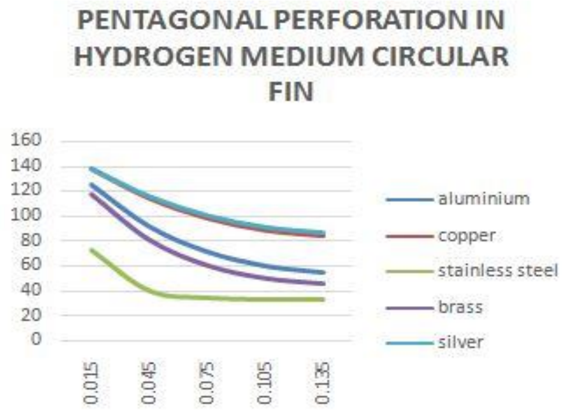


Fig 6.40 circular fin hydrogen medium

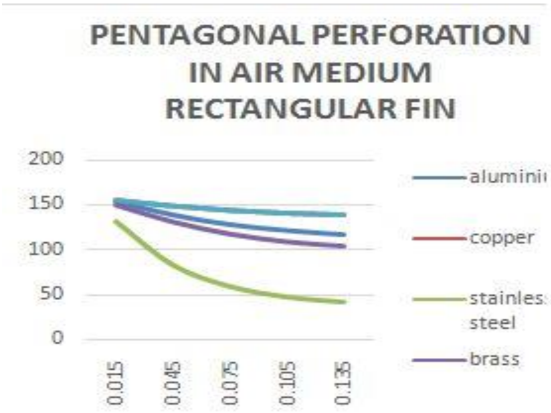


Fig 6.38 rectangular fin air medium

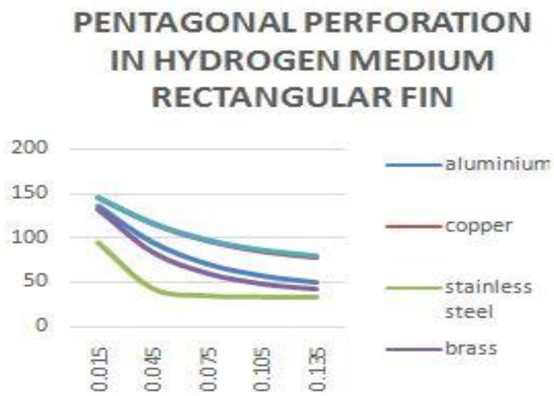


Fig 6.41 rectangular fin hydrogen medium

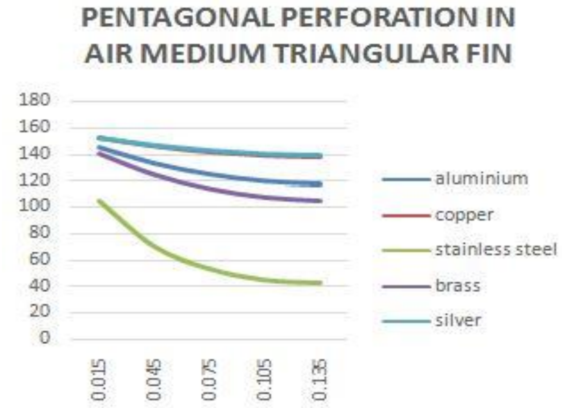


Fig 6.39 triangular fin air medium

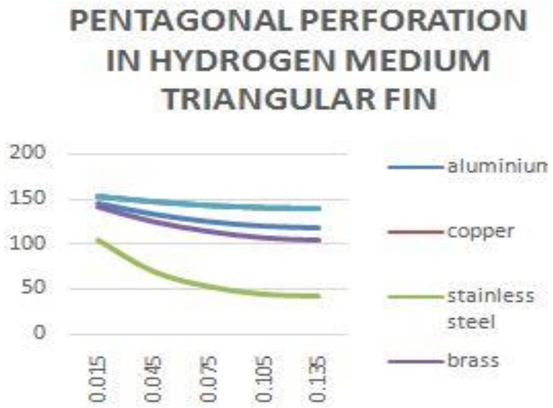


Fig 6.42 triangular fin hydrogen medium

Fig 6.43 circular fin argon medium

Fig 6.44 rectangle fin argon medium

Fig6.45 triangular fin argon medium

CHAPTER VII

CONCLUSIONS

The Theoretical and Experimental analysis was conducted on aluminium fin of circular cross-section of diameter 12 mm and length of 150 mm

The FEA was done for circular, triangular, rectangular fins with rectangular, circular, elliptical, pentagonal perforations and compared with plane solids

The dimensions of perforation was 3 mm, four perforations and spacing is 30mm for each

The work conducted so far gives the following results

- It is found that the temperature drop along the length of perforated fin is consistently higher than non perforated fin
- The heat transfer is more for different perforated fins compared to plane fin
- Rectangular fin with rectangular perforations has the maximum heat dissipation rate
- The Nusselt number and heat transfer coefficient and heat transfer is maximum incase of perforated fin
- Of all mediums hydrogen medium gives the best dissipation rate as mentioned above
- Owing to highest thermal conductivities silver and copper has maximum heat transfer compared to aluminium, brass, stainless steel
- Of all the materials used stainless steel has the least heat transfer
- The heat transfer is maximized when the conduction of fin is replace by convection by using perforations
- The heat dissipation increases with pentagonal perforation and decreased for hexagonal perforation
- The rectangular perforation increases heat transfer next stands the elliptical hole which increases 2 percentage of heat transfer when compared to circular and polygonal perforations

- The circular and polygonal perforations doesn’t vary much both have same effect on the fin in various mediums
- Perforations leads to decrease in material cost and weight of the system
- The perforations can be further used in inclined positions to enhance heat transfer rate as the inclination will increase the surface under convection

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