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Experimental Study of Thermostructural Design of I.C Engine

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Abstract – *Internal Combustion (IC) engines, produces work by the combustion of fuel and air, i.e. by converting the chemical energy of the fuel into mechanical energy of the reciprocating piston. IC engines are used in marine, locomotives, aircrafts, automobiles and other industrial applications.Fins are provided on the exterior of an IC engine to optimize the performance, and the efficiency of an IC engine, by providing exterior extended cooling surfaces. These fins are designed to optimize the heat loss and the temperature inside an IC engine such that the thermal efficiency is optimal and also the weight of the engine is not increased beyond optimal level.This study is an attempt to understand the effects of the fin material on its functional requirement by experimentally and using commercially available Finite Element Analysis (FEA) code ANSYS 14.0.Varying trends of these parameters are tabulated and determined and the values, which give optimized design of fin configuration and fin material are documented.*

Keywords- *I.C.Engine, Design of fin configuration, fin material, Finite Element Analysis (FEA), ANSYS 14.0, Computational Fluid Dynamics.*

I. INTRODUCTION

Internal combustion (IC) engines may be most generally classified by the method used to initiate combustion as either spark ignition (SI) or compression ignition (CI or diesel) engines.In an internal combustion engine, the expansion of the high-temperature and pressure gases produced by combustion applies a direct force to all component of the engine, such as pistons, piston rings, or the combustion chamber.When the combustion of air-fuel mixture takes place in the engine cylinder, a temperature as high as 2500^{O}C is reached.Air-cooling is one of the very efficient and cheap method of cooling IC engines which uses the extended surfaces called 'Fins' extended from the combustion chamber to cool the engine. These fins are designed to optimize the heat loss and the temperature inside an IC engine such that the thermal efficiency is optimal and also the weight of the engine is not increased beyond optimal level. Fin cooling is extensively used in all low power IC engines used in motorcycles, scooters etc.

II. PRINCIPAL BEHIND USAGE OF FINS

Convection heat transfer between a surface (at T_W) and the fluid surrounding (at T_∞) is given by:
$Q = h A (T_W - T_\infty)$Where, h is the heat transfer coefficient and A is the surface area of heat transfer. For gases h = (k_f/δ_t) is low, since the thermal conductivity $k_f$of a gas film is low. For transfer from a hot gas to a liquid through a wall $h_{gas} << h_{liquid}$ .To compensate for low heat transfer coefficient, surface area A on the gas side may be extended for a given Q. Such an extended surface is termed a 'Fin'.

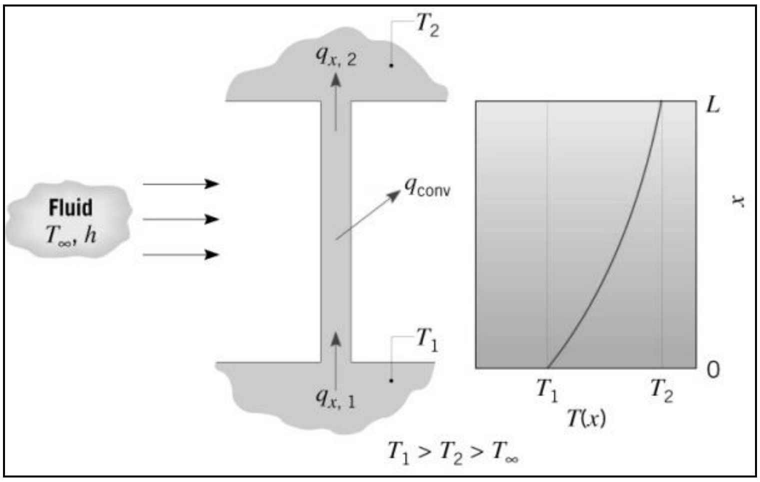

Fig. 1. Combined Convection and Conduction in a bar

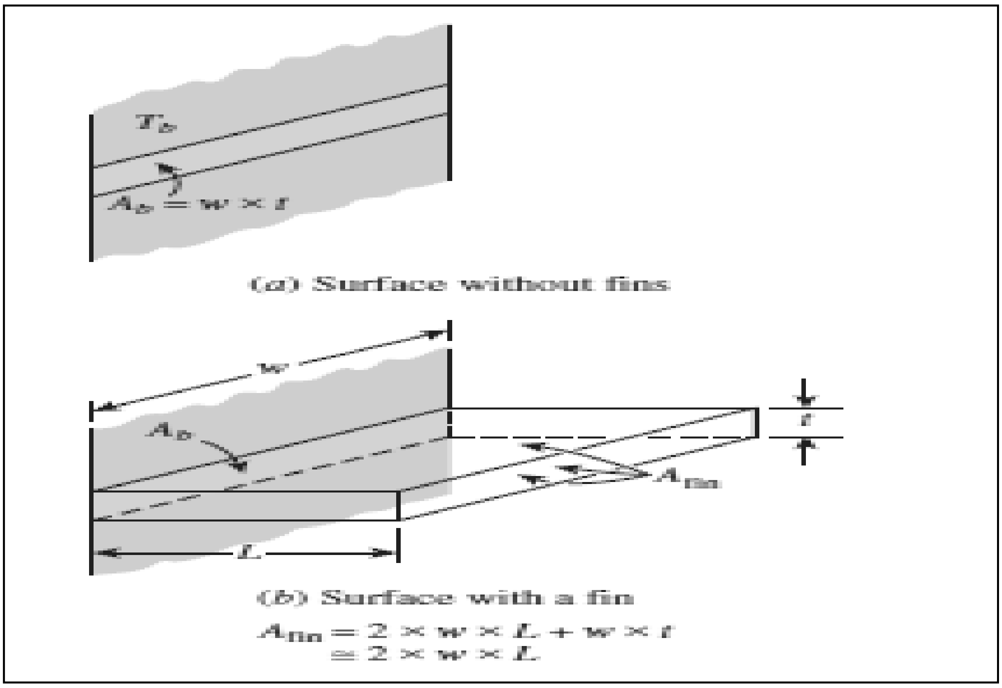

Fig. 2. Use of Fin enhances heat transfer from a plane wall by increasing Surface area

III. DIFFERENT TYPICAL FIN CONFIGURATION

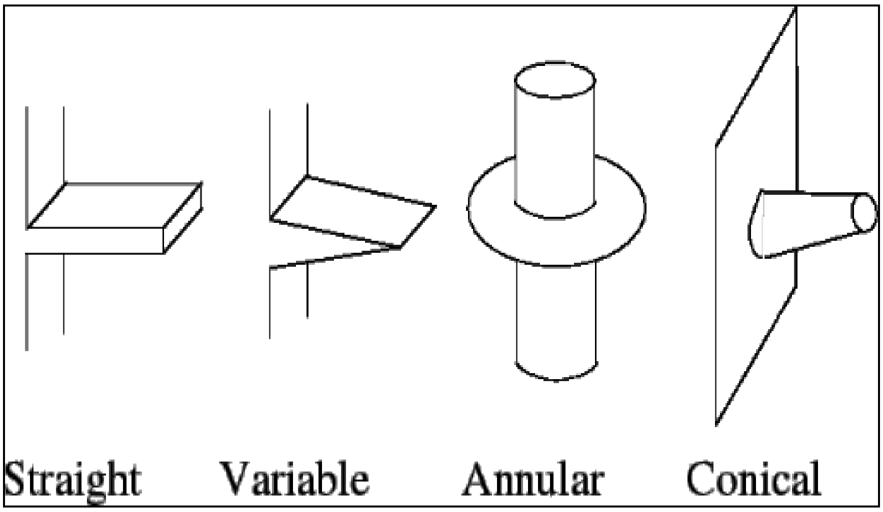

Fig.3. Some Typical straight fin configuration of (a) uniform/ rectangular and (b) non-uniform/triangular cross sections; (c) annular fin, and (d) pin fin of non-uniform cross section.

1. The convective heat transfer coefficient *h* could be increased by increasing the fluid velocity or / and fluid temperature T_∞ could be reduced. However, increasing *h* even to the maximum possible value is often insufficient to obtain the desired heat transfer rate or the costs related to blower or pump power required to increase *h* may be prohibitive.
2. The second option of reducing T_∞ is often impractical.
3. The heat transfer rate may be increased by increasing the surface area across which convection occurs. This may be done by using fins that extend from the wall into the surrounding fluid *(Fig. 3.4(b)).* The thermal conductivity of the fin material has a strong effect on the temperature distribution along the fin and thus the degree to which the heat transfer rate is enhanced. *Figure 3.5* shows different fin configurations. A Straight fin is any extended surface that is attached to a plane wall .It may be of uniform cross-sectional area, or its cross –sectional area may vary with the distance x from the wall. An annular fin is one that is circumferentially attached to a cylinder. A pin fin or spine is an extended surface of circular cross-sections. Pin fins may also be of uniform or non-uniform cross-section.

IV. MATERIAL PROPERTIES

The properties of Al alloy AA6061 and boundary conditions are given below:

Table: 1.Material Properties of AA 6061 boundary conditions

Material Properties	Al. alloy AA 6061
Thermal conductivity (W/m K)	210
Specific heat (KJ/kg ^{o}C)	0.9
Density (kg/m^3)	2780
ID wall Temperature (K)	473/500
Ambient Temperature (K)	300
Convective heat transfer coeff.(W/m^{2}K)	40

The following assumptions are made in all analysis:

- The heat flow through the fin is considered as unsteady state, so that the temperature of the fin does not vary with time. The temperature of the inner cylinder is constant.
- The thermal conductivity of the fin material is uniform and constant.
- The radiation heat transfer of the fin is neglected.
- Uniform ambient temperature of 300 K is considered

V. ANALYSIS AND SOLUTION

5.1 Drafting and Modeling

To study the effect of piston geometry on stress generated due to combustion pressure, three shapes of piston is drawn namely flat, concave and convex and the same is modeled in solid works. Also to study the effect of fin shape for the total heat dissipated different fin configurations are drawn to be solved in Ansys.

Table 2. The Spark Ignition engine considered for this study is Bajaj Pulsar DTSI 140 cc engine. The engine and fin specifications is as follows:

Engine	4 Stroke, Single Cylinder, Air Cooled
Max. Power	14.4 PS @ 8400rpm
Max. Torque	12.76 Nm @ 6400rpm
Displacement	149.01 cc
Bore and Stroke	46 × 48.8 mm
Piston	Al. alloy, flat top Piston
Idling speed	1400 RPM
Compression Ratio	9.4:1
Fin Material	Al. Alloy
No. of fins	12
Fin Pitch	10
Fin Thickness	2mm
Fin Profile	Rectangular (uniform cross section) with curved edges
Max. Fin Height	34mm
Min. Fin Height	10mm

The three geometries that are studied for the design of piston crown are flat plate, concave crown and convex crown.

The study to optimize the Fin configuration for a four-stroke air-cooled engine, Bajaj Pulsar DTSI 140 cc, was done in the following stages:

- Modeling and Analysis of different Fin geometries for a given material and heat transfer coefficient for Bajaj Pulsar DTSI 140 cc engine - to study the effect of fin shape on heat transfer rate.
- Modeling and analysis of same fin configuration for different material (K) - To study the effect of material on rate of heat transfer.

5.2: Meshing

- After the piston geometries are modeled in Solid works, they are imported in Ansys 14.0 and meshed using SOLID PLANE 183 Structural axis symmetric element for piston analysis. A 2-D axis-symmetric analysis is done in Ansys.
- After the fin geometries are modeled in Solid works, they are imported in Ansys 14.0 and meshed using SOLID87 - 3-D 10-Node Tetrahedral Thermal Solid element for fin analysis. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element has one degree of freedom, temperature, at each node.
- The elements are made finer (increase in the number of elements) till the error is reduced to unit place of decimal.

5.3 Boundary Condition

For Fin Heat Transfer Analysis

For Modeling and Analysis of different Fin geometries for a given material and heat transfer coefficient for Bajaj Pulsar DTSI 140 cc engine, the boundary conditions are shown in Fig 4.1, the combustion chamber inner wall temperature is taken as 240^{o}C (423K). The material coefficient of thermal conductivity is 210 W/mK. The convective heat transfer coefficient is 40W/m^{2}K.

For Modeling and analysis of same fin configuration for different material (K), three different materials namely, Copper alloy (K=380W/mK), aluminum alloy (K=210W/mK) and Steel alloy (K=44W/mK) are considered. The convective heat transfer coefficient h= 40W/m^{2}K.The combustion chamber ID temperature is 400K and the ambient temperature is 300K.

The convective heat transfer coefficients are documented by the below mentioned references:

Table 3. Boundary conditions for finding h for Thornhill et al. [1] & Gibson [2]

	Thornhill et al. [1]	Gibson [2]
Cylinder Diameter[mm]	100	32-94
Fin Pitch [mm]	8-14	4-19
Fin Length mm]	10-40	16-41
Material	Aluminium Alloy	Copper, Steel, Aluminium
Wind Velocity [km/hr]	7.2-72	32-97

Thornhill[1] gives the heat transfer coefficient(α) as

$$\alpha = 2.11u^{0.71} \text{ x } s^{0.44} \text{ x } h^{-0.14}$$

Gibson[2] gives the heat transfer coefficient(α) as

$$\alpha = 241.7\{0.0247-0.00148(h^{0.8}/p^{0.4})\}\ u^{0.73}$$

where: α: Fin surface heat transfer coefficient (W/m^{2}K)

h: Fin length [mm],

u: Wind velocity[km/hr],

s: fin pitch length[mm]

The value of h as computed both equations for different wind velocities and a pitch of 10 mm and fin height of 34 mm is tabulated below:

Table 4. Different values of convective heat transfer coefficient (h) as per Thornhill et al. [1] & Gibson [2] equations

Relative Wind Velocity(Km/hr)	Thornhill et al. [1] h (W/m^{2}K)	Gibson [2] h (W/m^{2}K)
10	18.1	18.9
20	29.6	31.4
30	39.4	42.2
40	48.4	42
40	46.8	61.2
60	64.7	70
70	72.1	78.3
80	79.3	86.3
90	86.2	94.1
100	92.9	101.6

From the above table, the convective heat transfer coefficient is taken as 40 W/m^{2}K, for vehicle velocity of 30km/hr, for this study.

5.4 Fin Analysis of heat transfer

Study 1:Effect of Fin geometry on Heat Transfer

The temperature profile, thermal gradient and thermal flux for different fin configurations and for the boundary conditions as explained in 4.2 is plotted below:

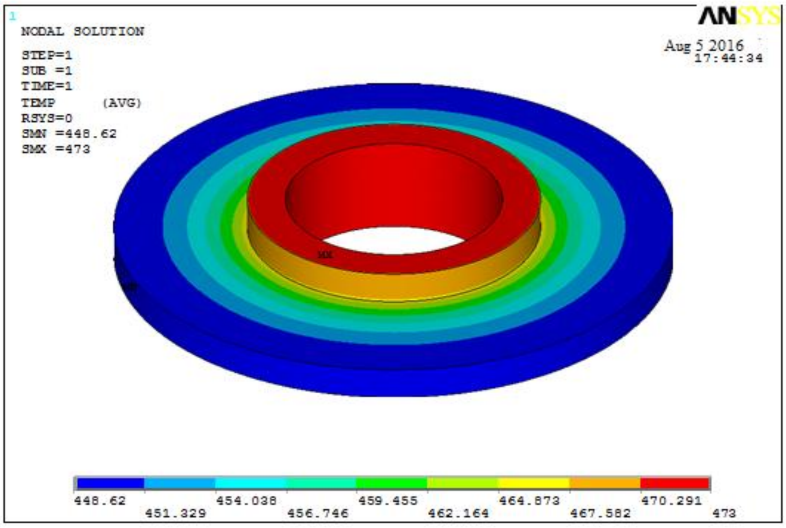

Fig4 (a): Temperature Profile across a Rectangular fin

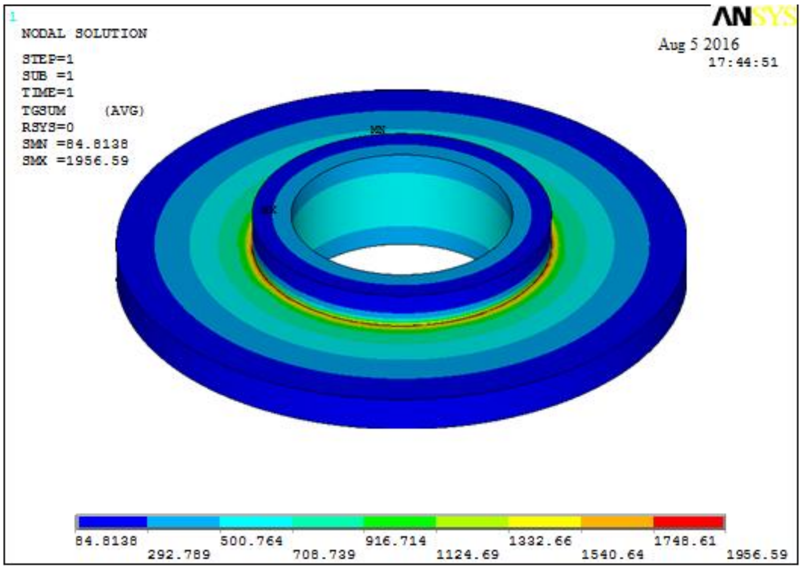

Fig4 (b): Thermal Gradient across a Rectangular fin

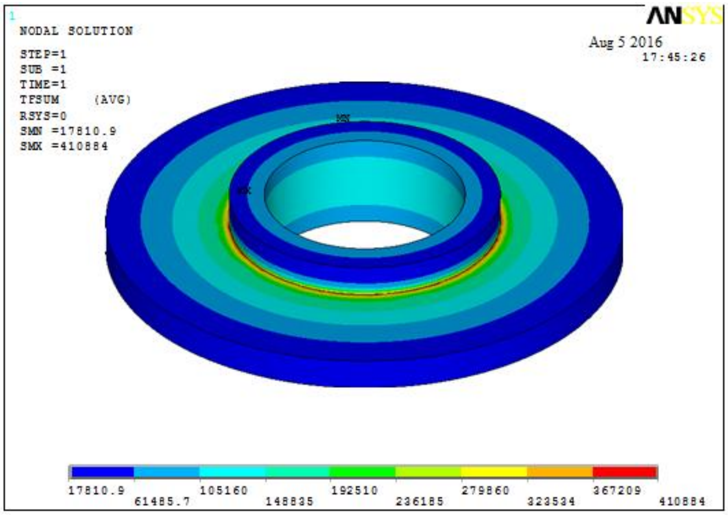

Fig4 (c): Thermal Flux across a Rectangular fin

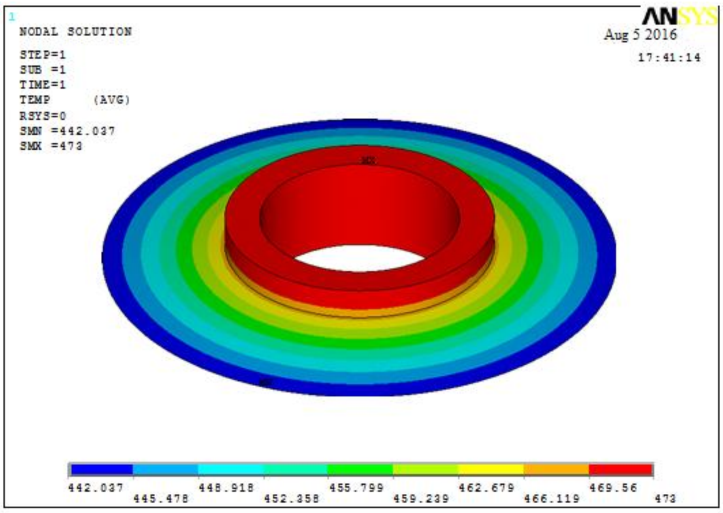

Fig 5 (a): Temperature Profile across a Conical fin

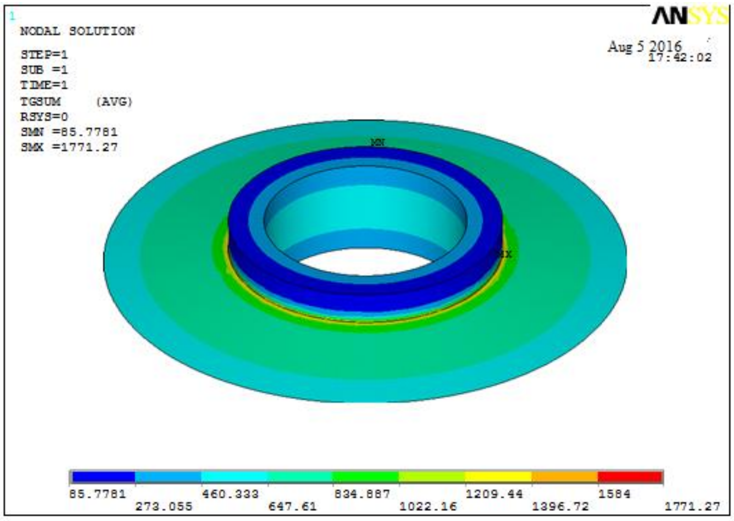

Fig 5 (b): Thermal Gradient across a Conical fin

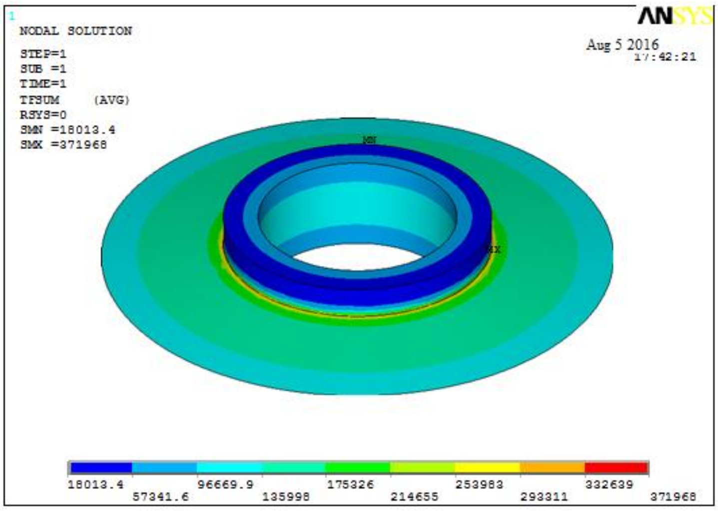

Fig 5 (c): Thermal Flux across a Conical fin

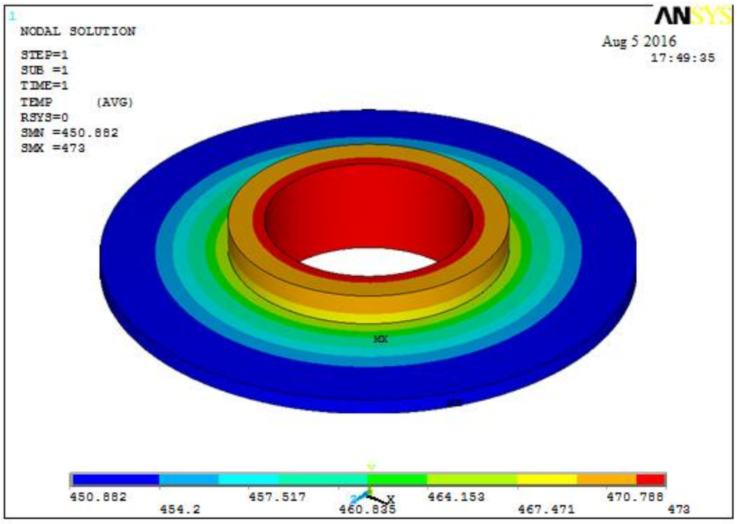

Fig 6 (a): Temperature Profile across a Trapezoidal fin

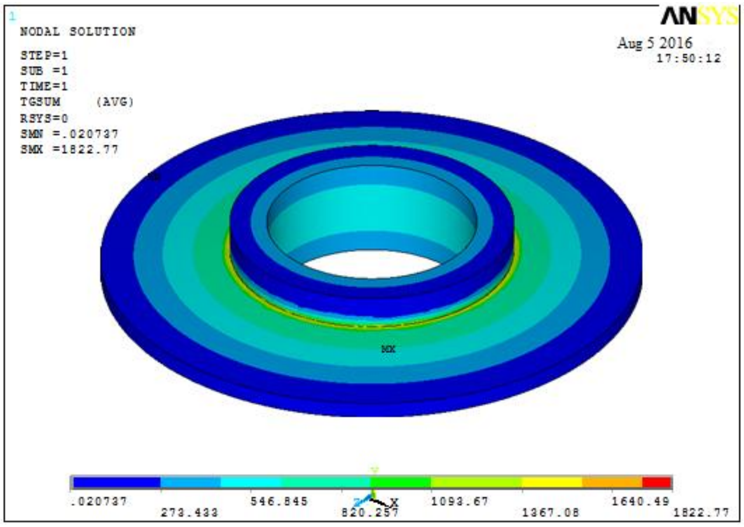

Fig 6 (b): Thermal Gradient across a Trapezoidal fin

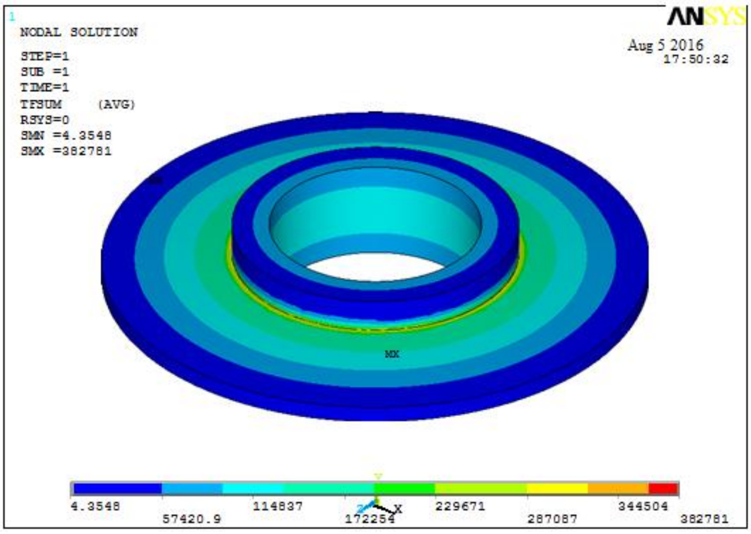

Fig 6 (c): Thermal Flux across a Trapezoidal fin

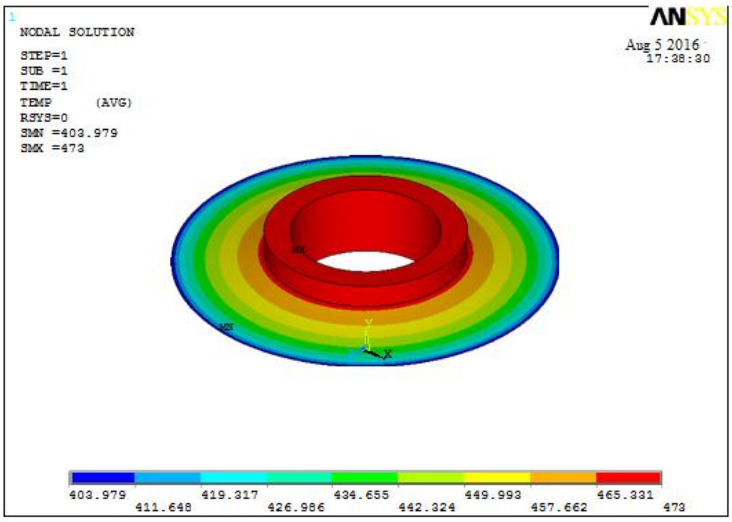

Fig 7 (a): Temperature Profile across an Ellipsoidal Concave fin

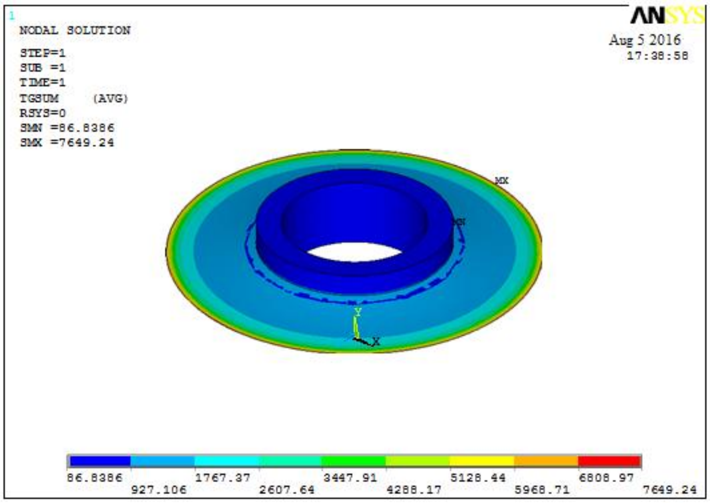

Fig 7 (b): Thermal Gradient across anEllipsoidal Concave fin

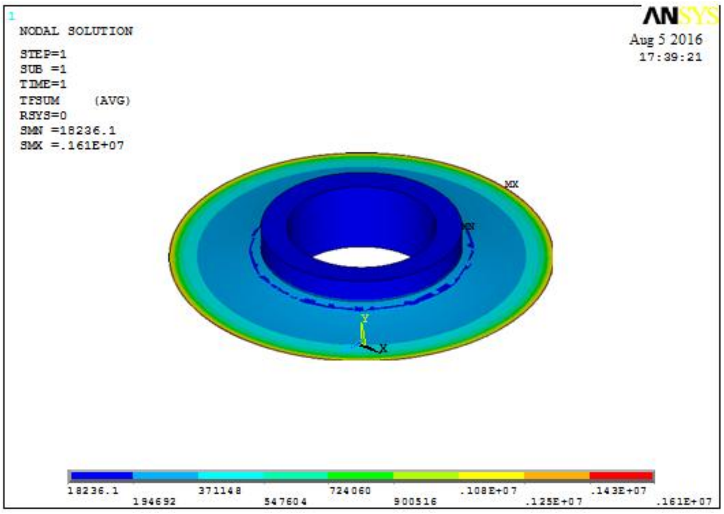

Fig 7 (c): Thermal Flux across anEllipsoidal Concave fin

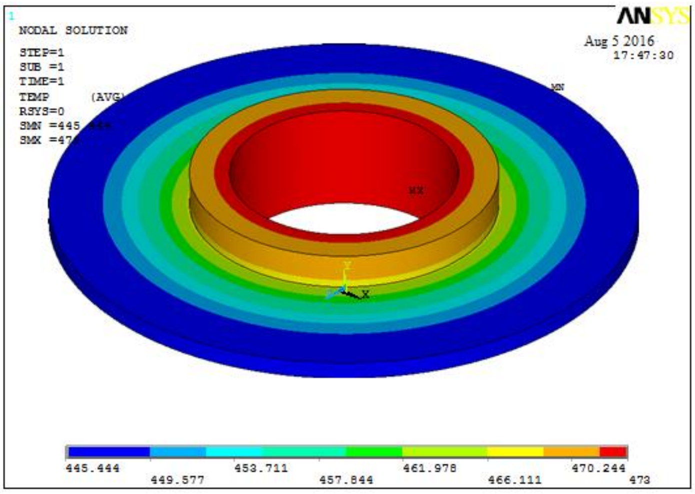

Fig 8 (a): Temperature Profile across a flat curve fin

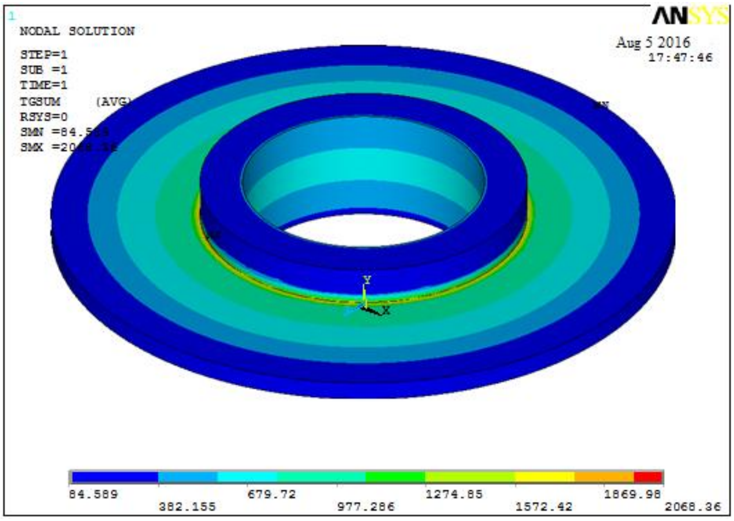

Fig 8 (b): Thermal Gradient across a flat curve fin

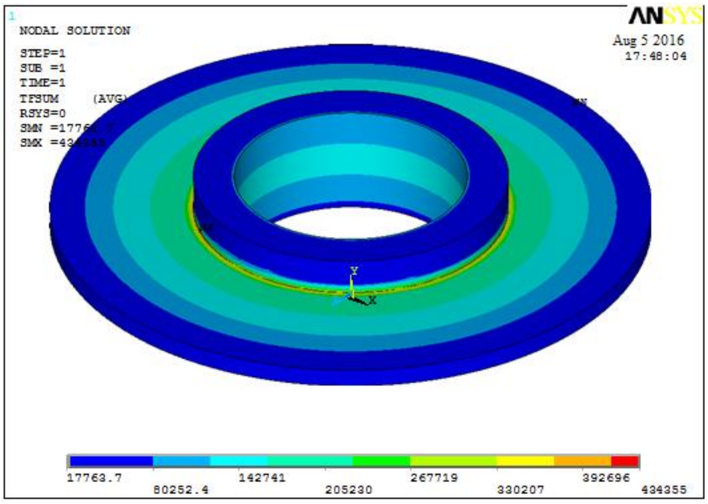

Fig 8 (c): Thermal Flux across a flat curve fin

Table 5. Results of CFD analysis on the basis of different fin geometry

Fin Configuration	Min. Fin Temperature(K)	Heat Transfer (W)	Fin Weight (gm.)	Effectiveness
Rectangular	448.62	620.71	340	7
Trapezoidal	440.88	440.93	240	6.1
Ellipsoidal Concave	403.98	432.44	100	6
Conical	442.04	441.17	140	6.1
Traingular	444.44	480.11	220	6.4

5.4.1 Observations:

The effectiveness of all fins ranges from 6-7.

The effectiveness of Rectangular cross section fin is highest for the studied configurations. However, the weight of rectangular fin configuration is also highest amongst all the geometries.

1. The effectiveness of conical and trapezoidal fins are the same, however the weight of conical fin is 40% less than trapezoidal fin. Hence conical fins are better than trapezoidal fins.
2. The weight of ellipsoidal concave fins is 70.6% lesser than rectangular fins. However the effectiveness of rectangular fins is 16.67% more than concave fins. Hence wherever weight is a criteria, ellipsoidal concave fins may be used, sacrificing small percentage of effectiveness.

Study 2:Study of effect of material on rate of heat transfer:

The circular rectangular, tapered fin configuration is solved for three different material viz , Copper alloy (K=380 W/mK), Al. alloy (K=210 W/mK),& Steel alloy (K=44 W/mK). The temperature profile across the fin is plotted and shown below:

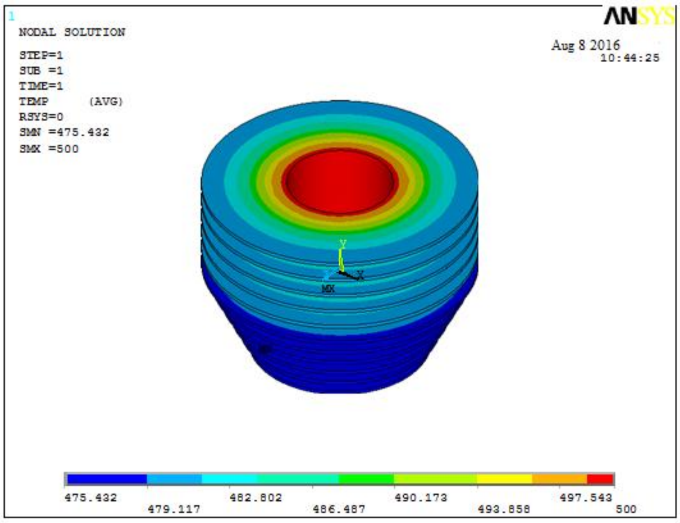

Fig 4.8 Temperature profile for Copper Alloy

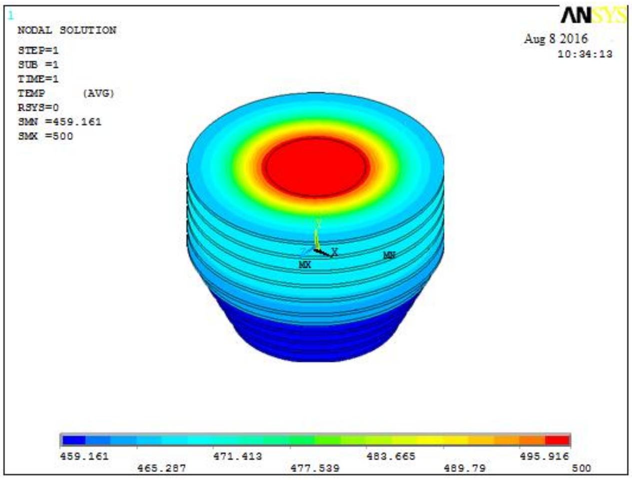

Fig 4.9 Temperature profile for Al. Alloy

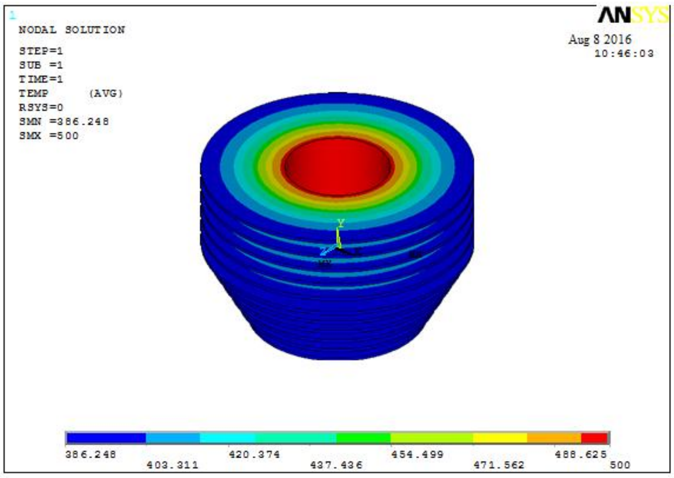

Fig 4.10 Temperature profile for Steel Alloy

Table 6. Results of CFD analysis on the basis of different material used

Material	Heat Transfer(W)	Weight(kg.)
Copper Alloy	1844.1	1.898
Al. Alloy	1729.3	0.490
Steel	1170.6	1.664

5.4.1 Observations:

1. Between the three materials, copper alloy has the best heat transfer due to higher K. However, due to higher density (8960kg/m^3), the weight of copper alloy fins is also highest.
2. Steel alloy fins also have a high weight but low heat transfer capacity.
3. Al. alloy fins weight is 69% lower than copper alloy fins and the heat transfer rate is only 6.2% lower. Also, Al. alloy being cheaper than copper is a better material for fin design.

VI CONCLUSION

The effect of fin geometries, and material (K) is studied for the heat loss for air cooling of an IC engine. The temperature profile, thermal gradient and thermal flux is plotted and studied for all configurations. It is found that providing an arch shape to fin, instead of rectangular cross section increases the heat transfer. The provision of arching will also increase the turbulence, increasing the h and hence the heat transfer. Also heat transfer per unit weight of fin is larger for conical fin than rectangular fins, hence conical fins are preferred over rectangular cross section fins.Aluminum is the better material for designing fins for air-cooled IC engines due to low weight, high rate of heat transfer and lower cost.There is further scope to do a 3-D analysis of the configurations to accurately account for the convective heat transfer coefficient. Also the effect of introducing waviness in the fin design can be studied.

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