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ANALYSIS OF FINS OF AN IC ENGINE CYLINDER FOR VARYING GEOMETRY AND MATERIAL

Kishan Hirpara[1], Kunj Mehta[2], Nirmit Jain[3], Priyanka Sharma[4]
[1]*Automobile Department, Indus University, Ahmedabad, hirpara.kishan33@gmail.com*
[2]*Automobile Department, Indus University, Ahmedabad, kunjmehta32@gmail.com*
[3]*Automobile Department, Indus University, Ahmedabad, nirmitjain.nj@gmail.com*
[4]*Automobile Department, Indus University, Ahmedabad, priyankasharma.am@indusuni.ac.in*

Abstract— In an internal combustion engine, heat is produced during combustion which leads to temperature rise. Temperature must be maintained at optimum stage for efficient use, Fins are surfaces that extend from an object to increase rate of heat transfer by maintaining operating temperature. With an aim to analyse thermal properties of fin by varying geometry, Aluminum, Copper, Cast iron, Magnesium are materials which are used in this procedure and thickness is also considered. Two geometries are used: rectangular and triangular for various thicknesses. For modelling purpose, CREO 2.0 is used and analysis of the fins under boundary conditions is performed in ANSYS. From thermal analysis of fins, results will show effectiveness and cooling rate of fins and would give us the optimized length and the material to ensure optimum performance of the engine block.

Keywords— Fins, Aluminum, Copper, Cast iron, Magnesium, Fin efficiency and effectiveness

I. INTRODUCTION

Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy between physical systems. There are basically three modes of heat transfer: Conduction, Convection and Radiation. As per the second law of thermodynamics the transfer of heat takes place from the body with high temperature to body with low temperature and for reverse process some external work has to be done. Optimum heat transfer will increase performance of particular engine. There are many ways to increase the heat transfer: (1) by increasing the temperature gradient between the object and environment, (2) by increasing the convection heat transfer coefficient, and (3) by increasing the surface area of the object. From these options increasing the surface area is the most significant solution to improve heat transfer. Fins are defined as extended surfaces which increase rate of heat transfer. There are various geometries of fin, viz. Rectangular, Triangular, Trapezium and Pin Fins. Mainly, Rectangular fins prevail over all the other type as these are easy to design and also offer optimum results.

Some of the applications where finned surfaces are used for heat transfer:

- Economizers for steam power plants;
- Converters for steam and hot water heating systems;
- Air cooled cylinders of aircraft engines, I.C. Engines and air compressors;
- Electrical transformers and motors; and
- Cooling coils and condenser coils in refrigerators and air conditioners.

II. DETAILS EXPERIMENTAL

A. *Methodology*

Step 1: Collection of information and data related to traditional cooling fins of IC Engine

Step 2: A fully parametric model of the Engine Block with fin is created in CREO 2.0

Step 3: Model obtained in Step 2 is analysed using ANSYS, to obtain the heat rate, thermal gradient and nodal temperatures.

Step 4: Manual Calculations are done.

Step 5: Finally, we compare the results obtained from ANSYS and manual calculations for different material, shapes and thickness.

B. Selection of Material

Selection of material is done using various properties of materials. The table below illustrates the material selected and used for manual calculations of fin efficiency and effectiveness.

Cast Iron	Aluminum 6061 T-6	Copper	Magnesium
Density : 7800 Kg/m^3	Density 2700 Kg/m^3	Density 8950 Kg/m^3	Density 1740Kg/m^3
Oxidation takes place at faster rate	Oxidation takes place at slower rate	Oxidation takes place at faster rate	Oxidation takes place at faster rate
Inhibits corrosion	High resistance to corrosion	Inhibits corrosion	Inhibits corrosion
Conductivity is less i.e. 55 W/ m^o C	Conductivity is more than that of CI i.e. 167 W/m $^\circ$C	Conductivity is 400 W/m $^\circ$C	Conductivity is 75 W/m $^\circ$C
Melting point : 1200 ^{o}C	Melting point : 594 ^{o}C	Melting point : 1083 ^{o}C	Melting point : 650 ^{o}C
Cost is less than Aluminum	Cheaper than Copper	Expensive	Cheaper than Aluminum
Excellent wear resistance	Moderate wear resistance	Excellent wear resistance	Poor wear resistance

TABLE I: SELECTION OF MATERIAL

C. Calculation

i. **Engine Specification**

a. Displacement – 100 CC
b. Power – 6.15 KW @ 8000 rpm
c. Torque – 8.05 N-m @ 5000 rpm
d. Compression Ratio – 9.9:1
e. Bore * Stroke – 50*49.5

ii. **Rectangular Fin Equation**: To create a plausible equation, many assumptions have to be made. Some of them are:

a. System is in Steady State
b. Constant material properties (Independent of temperature and pressure)
c. No internal heat generation
d. One-dimensional conduction
e. Uniform Cross-Sectional Area
f. Uniform Convection Across the surface area under consideration

Consider a volume element of a fin at location x having a length of x, cross-sectional area of Ac, and a perimeter of p.

- Q_{fin} = [$\sqrt{hp/kAc}$](T_0 – T_a) [{tan h ml +(h/Km)}] /[1+(h/Km) tan h(ml)]

Where Length of fin = l
Conductivity of Cast iron = k
Thickness of Fins, δ = 2mm
Film Coefficient, h = 20W/m^2°C
Width of fin = W
Fin base temperature = T_0
Perimeter p = 2 (l+W)
Cross-section of fin, A_c= W* δ

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

Efficiency of Rectangular Fin:

- $\eta = Q_{max} / Q_{fin}$;

Where $Q_{max} = hpl\ (T_0 - T_a)$

$T_{a=}$ ambient Temperature

Effectiveness of Rectangular Fin:

- € = $Q_{fin} / Q_{\text{no fin}}$;

Where $Q_{\text{no fin}} = hA_{c2}(T_0 - T_a)$

- k should be as high as possible (Copper, Aluminum, Cast Iron).
- Aluminum is preferred: low cost and weight and also corrosion resistant
- p/Ac should be as high as possible (Thin plate fins).
- Most effective in applications where h is low (Use of fins justified when the medium is gas and heat transfer is by natural convection).

iii. Triangular Fin Equation

For a triangular fin representing length of fin l, thickness, and width of fin, W and assuming the heat flow is unidirectional and it is along length and the heat transfer coefficient (h) on the surface of the fin is constant.

Heat lost by triangular fin, $Q = 2W\ (T_0 - T_a)(\sqrt{hk\delta})\ [I_1 (2B\sqrt{l})] / [I_0 (2B\sqrt{l})]$

Where $(T_0 - T_a)$ = temperature difference, K

k = thermal conductivity, W/mK

B= fin parameter, $(\sqrt{hl/k\delta}$

W=width of fin, mm

I_1= Bessel function of first kind

I_0=Bessel function of second kind

Efficiency of Triangular Fin:

- $\boldsymbol{\eta_t} = Q / 2Wlh(T_0 - T_a)$;

Where $T_{a=}$ ambient Temperature

Effectiveness of Triangular Fin:

- € $= Q / 2Wh\delta\ (T_o - T_a)$

Where δ= thickness of fin

D. Design Considerations for Fins:

The following factors need to be considered for optimum fin design

- Cost
- Manufacturing difficulties
- Pressure drop caused by fins
- Space considerations
- Weight considerations

The design will be considered optimum when the fins require minimum cost of manufacture, offer minimum resistance to the fluid flow, are light in weight, and are easy to manufacture. There is a limit on the length of fin imposed by manufacturing difficulties, so this also needs to be looked upon.

III. THERMAL ANALYSIS

The ANSYS/Multiphysics, ANSYS/Mechanical, ANSYS/FLOTRAN and ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. Using steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convections
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear.

The procedure for doing a thermal analysis involves three main tasks:

- Build the model.
- Apply loads and obtain the solution.
- Review the results.

IV. RESULT

	Cast Iron						Aluminum					
Fin Length	Q		η		€		Q		η		€	
	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c
56	43.08	36.93	66.2	66.2	2.48	2.48	55.49	47.56	85.2	85.2	3.2	3.2
58	43.98	37.70	64.4	64.4	2.53	2.53	57.4	49.2	84.1	84.1	3.31	3.31
60	44.83	38.42	62.7	62.7	2.58	2.58	59.28	50.81	83	83	3.42	3.42
63	46.02	39.44	60.3	60.3	2.65	2.65	62.03	53.17	81.3	81.3	3.58	3.58

TABLE II: CALCULATION FOR CAST IRON AND ALUMINUM RECTANGULAR FINS

	Magnesium						Copper					
Fin Length	Q		η		€		Q		η		€	
	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c
56	47.1	40.37	72.3	72.3	2.71	2.71	60.98	52.27	93.7	93.7	3.51	3.51
58	48.27	41.37	70.7	70.7	2.78	2.78	63.49	54.42	93.09	93.09	3.66	3.66
60	49.40	42.34	69.1	69.1	2.85	2.85	66.02	56.58	92.46	92.46	3.81	3.81
63	51	43.71	66.8	66.8	2.94	2.94	69.79	59.82	91.48	91.48	4.02	4.02

TABLE III: CALCULATION FOR MAGNESIUM AND COPPER RECTANGULAR FINS

	Cast Iron						Aluminum					
Fin Length	Q		η		€		Q		η		€	
	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c
56	28.51	24.43	80.8	80.8	22.62	22.62	32.37	27.74	91.75	91.75	25.69	25.69
58	29.07	24.92	79.56	79.56	23.07	23.07	33.33	28.57	91.2	91.2	26.45	26.45
60	29.59	25.37	78.3	78.3	23.4	23.4	34.26	29.37	90.6	90.6	27.1	27.1
63	30.33	26	76.4	76.4	24.07	24.07	35.62	30.53	89.74	89.74	28.2	28.2

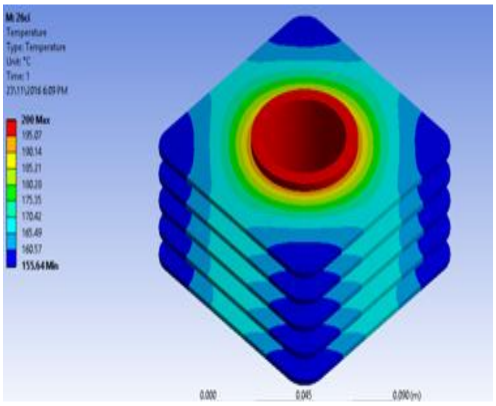
TABLE IV: CALCULATION FOR CAST IRON AND ALUMINUM TRIANGULAR FIN

	Magnesium						Copper					
Fin Length	Q		η		€		Q		H		€	
	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c	25°c	50°c
56	30.21	25.89	85.6	85.6	23.97	23.97	29.72	25.47	84.2	84.2	23.58	23.58
58	30.94	26.52	84.6	84.6	24.56	24.56	32.97	28.26	90.2	90.2	26.16	26.16
60	31.63	27.11	83.6	83.6	25.1	25.1	36.21	31.04	95.8	95.8	28.73	28.73
63	32.58	27.93	82.1	82.1	25.85	25.85	37.90	32.48	95.49	95.49	30.07	30.07

TABLE 5: CALCULATION FOR MAGNESIUM AND COPPER TRIANGULAR FIN

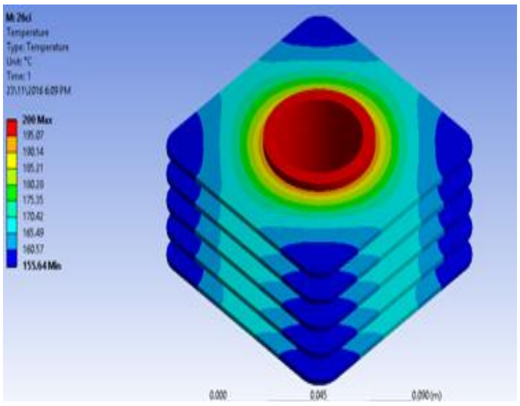
On performing the analysis of rectangular and triangular fins with different lengths, material of fin and ambient temperature gives out 64 set of observations. Out of these 64 set, the optimised performance for heat transfer was observed in Rectangular fin with 60 mm length and Aluminum as material. The following shows the result, observed in ANSYS.

Ambient temperature-25°C



Tip Temperature: 175°C

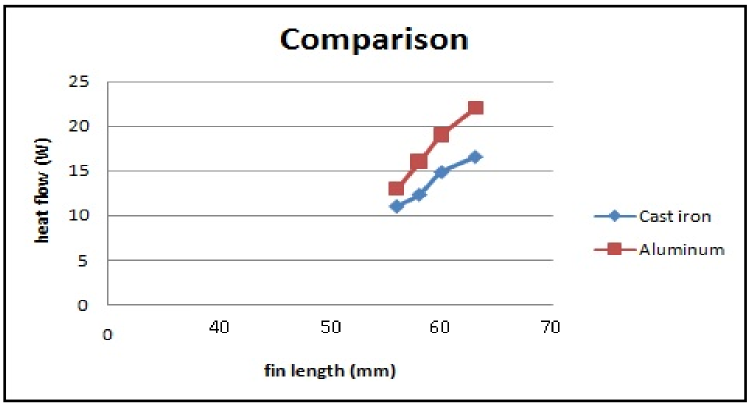
Ambient temperature-50°C



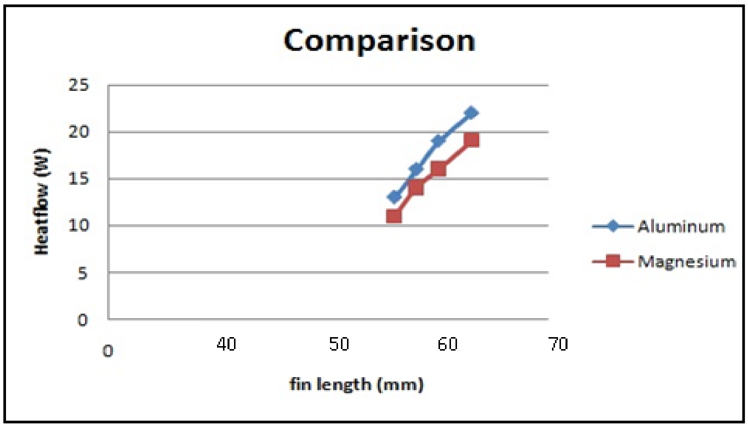
Tip Temperature: 178°C

For Rectangular Fin

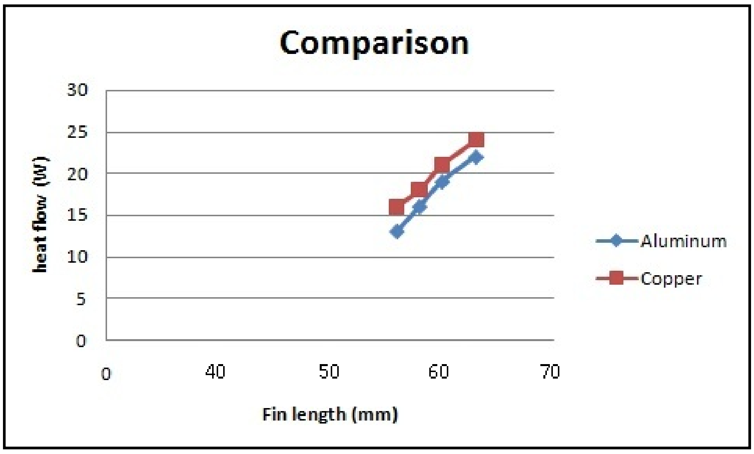
From the above calculations and thermal analysis in ANSYS, it is found that Aluminum is the best suitable material for optimized performance of engine. The graphs below support the same.



Comparison of Cast Iron with Aluminum



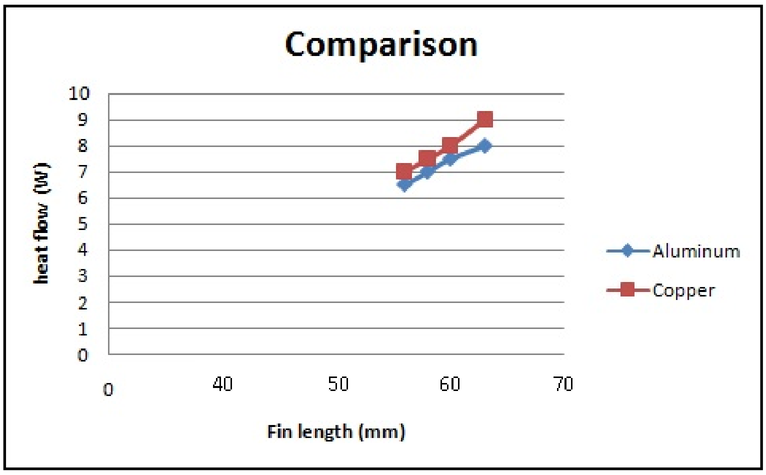
Comparison of Magnesium with Aluminum



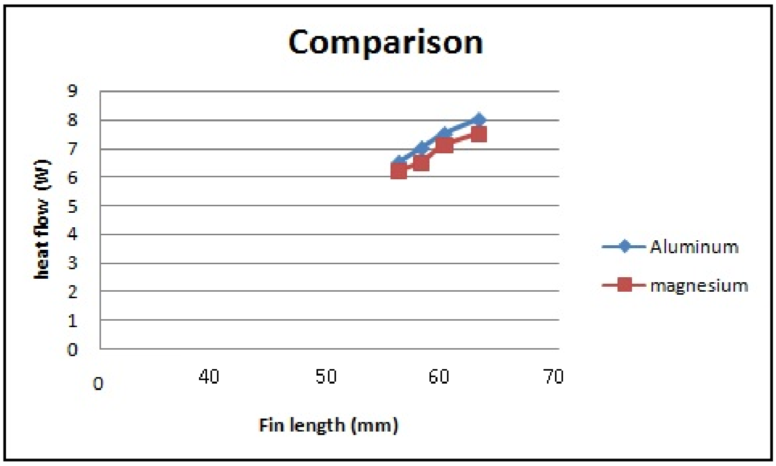
Comparison of Copper with Aluminum

- From the aforementioned comparison graphs for rectangular fins, it is observed that heat flow rate from Aluminum fin is more than that of cast iron and magnesium for entire fin length from 56 mm to 63 mm while copper fin offers more heat flow rate than that of Aluminum for entire fin length of 56 mm to 63 mm.

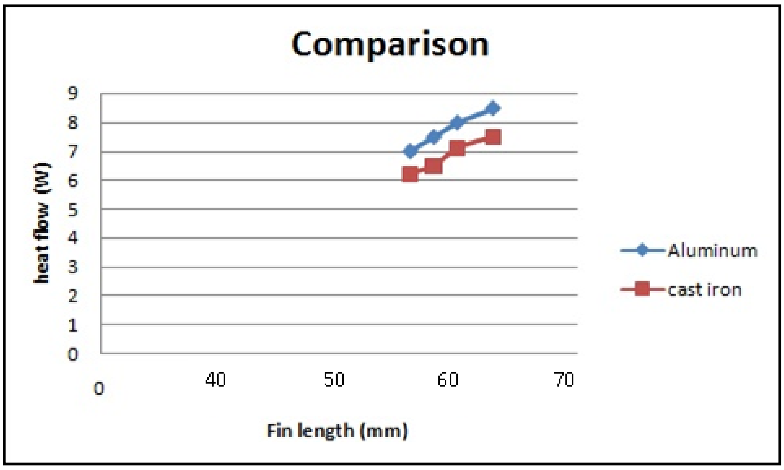
For Triangular Fin



Comparison of Copper with Aluminum



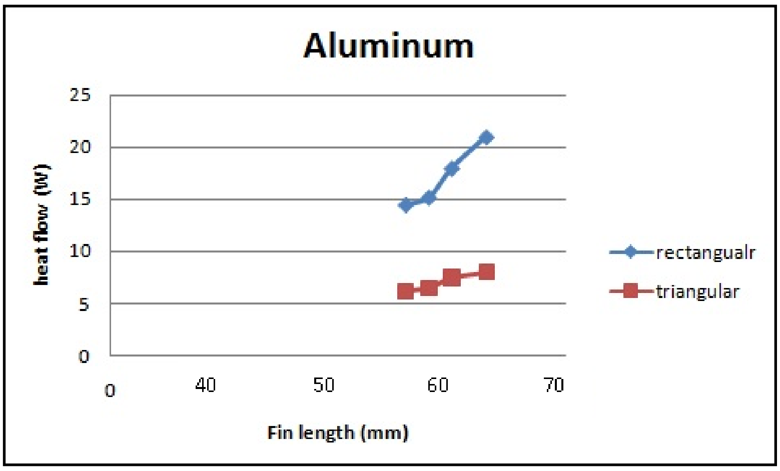
Comparison of Magnesium with Aluminum



Comparison of Cast Iron with Aluminum

From the comparison graphs, it can be noted that heat flow rate for Aluminum fin is more than Cast Iron and Magnesium but not less than Copper fin. As density of copper is more than that of Aluminum and other materials, it is not preferable to use it as it would make the assembly bulky.

V. CONCLUSION



Rectangular fin vs Triangular fin

- From the above graph, it is concluded that heat flow for rectangular fin is more than that of triangular fin for entire range of fin length from 56 mm to 63 mm.
- From ANSYS Analysis, it is concluded that Aluminum fin has ideal temperature distribution over its entire length.
- It is difficult to manufacture triangular fin cylinder block due to its complex structure and shape than rectangular fin. Hence, rectangular fin is preferred.
- Optimized fin model with improved performance and better life will be obtained through these results.
- From ANSYS result and theoretical calculations, it is concluded that proposed fin length of 60mm and thickness of 2 mm can provide better heat transfer.

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