Thermal analysis of fin materials for engine cylinder heat transfer enhancement

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Abstract. In automobiles the internal combustion engine cylinder is one of the major component which is subjected to high thermal stresses and temperature variations. Engine cylinders come up with fins or extended surfaces. The heat transfer enhancement from engine cylinder is mainly depends on fin material and shape. We can use different fin materials and fin geometries in order to increase heat transfer rate. In this work heat transfer rate through fins with different materials was evaluated. The fin geometries such as the rectangular fins attached to the cylinder block. In this analysis different physical and thermal properties along with cost associated with the fin materials are considered. The 3D model of geometries are created using CATIA - V5, and thermal properties are analyzed using commercial software ANSYS FLUENT 2020 R1. From the results of steady state thermal analysis of engine cylinder it is found that the value of heat flux increased through cylinder block to the surroundings. The weighted point method applied to find performance of fins based on material that is best suited for manufacturing of fins.

Keywords: Thermal conductivity, specific heat capacity, heat transfer enhancement, fins, ANSYS.

1. Introduction
The engine cylinder is to be cooled in order to prevent it from the ill effects of the high temperature and thermal stresses. Internal combustion engine cooling uses either air or liquid cooling to remove the heat from IC engine cylinder block. For increasing the rate of heat transfer we require either large surface area or high value of convective heat transfer coefficient, but increasing heat transfer area is easy and effective method. This is accompanied by using extended surfaces or Fins. Kummitha and Reddy [1] analyzed fins made up of different materials like aluminium alloys, magnesium alloys and gray cast iron and compared them on parameters like strength, weight, and concluded that aluminium A 380 is better among selected materials. Kanna [2] have numerically studied thermal performance of straight fin and wavy fin of different pitch for motorcycle engine. They found that 8 mm pitch straight fin is a better choice over wavy fins in heat transfer point of view. Thornhill et al. [3] conducted experiments for heat transfer from aluminum alloy engine cylinders with fins in to a free air. They found heat transfer enhancement with air velocity in the range 2 - 20 m/s with separated and shortened fins. Dubey et al. [4] studied thermal analysis of engine cylinder with thick tip fin having varying slot sizes and material. They found that 75 mm slotted fins have maximum heat transfer and Aluminium alloy 2014 having 75 mm slotted fin engine with thick tip fin have maximum heat transfer rate.
karthik et al. [5] analyzed the fin performance by taking into consideration four different materials and found that Aluminum alloys is best among them. Several authors [6, 7, 8, 9, 10, 11, 12] have studied heat transfer from different fin geometries and fin parameters for engine cylinder cooling applications. The above literature shows many studies are available on heat transfer enhancement from fins for engine convective air cooling applications. Though the studies on heat transfer studies from different fin materials are limited. Therefore the present study is focused on the heat transfer from the fins made up of different materials. In this work the properties of materials viz., density, thermal conductivity, specific heat capacity and strength are considered to show their effect on fin heat transfer enhancement. The studies have been performed on the thermal analysis using ANSYS software for finned surfaces having different materials, and considering cost as the main influencer on selection of the material.

2. Extended surfaces or Fins
Finned surfaces are commonly used in practice to enhance heat transfer, and they often increase the rate of heat transfer from a surface several fold. Fins are having different applications in heat exchanging devices such as economizers, heat exchangers etc. Applications of fins:

(i) Engine cylinder cooling, radiators in cars
(ii) Computer CPU heat sinks.
(iii) Fins are most important where convective heat transfer coefficient (h) have lower value.
(iv) Fins are commonly used as heat management in electrical applications.
(v) They are also used in newer technology such as hydrogen fuel cells and heat exchangers in power plants.

3. Methodology
The methodology followed in the present work is given in flow chart in Fig. 1

![Figure 1. Flow chart showing methodology used in the study](image-url)
4. Selection of different materials
The fins should be made up of such materials which have following properties:

- It should have high thermal conductivity
- It should have low specific heat capacity
- Relatively cheap and easily machined
- Must be having low density

We have chosen four different materials which satisfies most of the desired properties which mentioned above.

(i) Gray cast iron: Gray cast iron is best material which satisfies most of the desirable properties. It is generally used for making engine block because of its ability of dimensional stability under heating or thermal stress.

(ii) Aluminum (Al) alloy 6061 and Aluminum alloy 356: They are most widely used non-ferrous metals. They offer following advantages:

- Low specific gravity.
- Ease of fabrication.
- Corrosion resistance.
- High thermal conductivity.

(iii) Copper alloys: Copper possesses excellent electrical and thermal conductivity. It can be easily cast, machined and brazed. It has good corrosion resistance; but has poor strength. So it can be alloyed with zinc in various proportions for making substance according to the need of application.

| Properties                  | Gray Cast Iron | Al alloy - 6061 | Al alloy - 356 | Brass C37700 |
|-----------------------------|----------------|-----------------|----------------|--------------|
| Density, kg/m³              | 7200           | 2713            | 2685           | 8267         |
| UTS*, Mpa                   | 240            | 313.1           | 246.7          | 502          |
| YTS**, Mpa                  | 230            | 259.2           | 172.8          | 367.4        |
| Young’s modulus, GPa        | 110            | 69.1            | 72.1           | 99.95        |
| Sp. heat capacity, J/kg K   | 447            | 914.71          | 894.21         | 377.1        |
| Thermal conductivity k, W/m K | 52             | 155.12          | 158.75         | 107.66       |

UTS* Ultimste tensile strength, YTS** Yield tensile strength

5. Creation of 3D model in CATIA V5
IC Engine cylinder block along with fins was modelled in Catia V5. First, Cylinder block was modelled and then outer surface which is having fins were modelled. Dimensions of the model are as follow: Bore of cylinder = 50 mm
Stroke length = 64 mm
Length of fins = 13mm
Thickness of fins = 3 mm
Fig. 2 shows the 3D model of assembly of cylinder block and fins.
6. CFD Analysis
The 3D geometry of model is then taken to the ANSYS FLUENT and the Tetrahedron meshing of the model is generated. Then the naming of sections is given in the model for computational purpose. The steady state thermal analysis of fin surface have been performed. The interior wall of engine cylinder block is chosen as inlet and outer surface along with fin surface as outlet. The inlet portion has given temperature of 300 \(^{\circ}\)C. Outer surface is surrounded by stagnant air and has temperature of 27 \(^{\circ}\)C. The four different materials considered are cast iron, aluminum alloy 6061, aluminum alloy 356 and brass C37700. In this analysis we have taken cylinder block of Gray cast iron and by changing the fin material for each subsequent analysis we found out simulation results. In the first case we applied fins of Gray cast iron over the cylinder block. Steady state thermal analysis using CFD software gives the results of temperature and heat flux distribution of cylinder block assembly attached with fins made of cast iron. Fig. 3 shows temperature distribution and heat flux distribution for grey cast iron fin material. From the Fig. 3(a) temperature distribution plot gives the maximum temperature of 300 \(^{\circ}\)C and minimum temperature of 291.2 \(^{\circ}\)C. The heat flux distribution plot shown in Fig. 3(b) shows the minimum heat flux value of 1069 W/m\(^2\) K and the maximum value of 24838 W/m\(^2\) K. It is observed that the maximum values of both the temperature and heat flux occurs in the inside of the cylinder wall.
In second case fins of Aluminium alloy 6061 over the cylinder block are considered. Fig. 4 shows temperature distribution and heat flux distribution for aluminum alloy 6061 as fin material.

**Figure 4.** Temperature and heat flux distribution for aluminum alloy 6061 as fin material

Fig. 5 shows temperature distribution and heat flux distribution for aluminum alloy 356 as fin material.

**Figure 5.** Temperature and heat flux distribution for aluminum alloy 356 as fin material

Fig. 6 temperature distribution and heat flux distribution for Brass C37700 as fin material.
7. CFD Results
Table 2 gives data of results from ANSYS simulation. The maximum and minimum temperature in each case is mentioned. The minimum temperature is clearly a function of thermal conductivity ($k$) and thermal diffusivity ($\alpha$). The materials which have higher value of minimum temperature is a clear indicator of better material in terms of its thermal properties. So from the data aluminum alloy 356 is best material among the four materials which we have chosen. The average heat flux value also give idea about, which material is to be chosen; by this criterion also aluminum alloy 356 is better among all. The weight which is the function of density of material is also an important parameter which influence the selection of the material. The aluminum alloy 356 is having lowest density among the four materials considered in this study. So from above analysis aluminum alloy 356 seems to be a better material among the four materials to be used as material for manufacturing of fins. The simulation software results are compared with the weighted point method to find the better material.

Table 2. Temperature and heat flux distribution along with weight of fins for various materials from ANSYS report

| Materials       | Temperature °C | Average heat flux, h, W/m² | Weight of fins, kg |
|-----------------|----------------|----------------------------|-------------------|
|                 | Maximum        | Minimum                    |                   |
| Grey cast iron  | 300            | 291.2                      | 12352             | 0.99755          |
| Al alloy 6061   | 300            | 294.6                      | 132785            | 0.3758           |
| Al alloy 356    | 300            | 294.6                      | 14072             | 0.372            |
| Brass C37700    | 300            | 294.1                      | 13824             | 1.1454           |

8. Weighted point method
The weighted point method is a recent technique developed for selection of material. The method consist of different steps; first step consist of study of application and preparing list of material for that application. So we have chosen four different materials for comparison. The desirable properties then assigned some values according to their importance. We have selected five properties as influencers and their value is mentioned in respective bracket.

(i) Thermal conductivity, $k$ (5)
(ii) Thermal diffusivity, $\alpha$ (4)

(iii) Cost (3)

(iv) Density, $\rho$ (2)

(v) Ultimate tensile strength (UTS) (1)

The thermal conductivity and thermal diffusivity have given more weighted (value) that is 5 and 4 respectively because fins should be made up of materials having better thermal properties. Cost is also a main influencer in material selection; so it has given value 3. The fins should be of lighter weight so we have given some importance to density also. Similarly we have calculated the value of each material and the materials which have higher weight (value) is to be selected and other materials should be given priorities according to their total value. Table 3 gives data of total points for each material by using weighted point method.

### Table 3. Total points for each material by using weighted point method

| Material         | Material properties contribution as per weighted point method | Total |
|------------------|---------------------------------------------------------------|-------|
|                  | $k$  | $\alpha$ | Cost | Density, $\rho$ | UTS |
| Cast iron        | 0.54907 | 0.36041 | 1.54639 | 0.31153 | 0.18436 | 2.95176 |
| Al alloy 6061    | 1.63791 | 1.39434 | 0.41237 | 0.82677 | 0.24051 | 4.51190 |
| Al alloy 356     | 1.67624 | 1.47491 | 0.78298 | 0.83539 | 0.18951 | 4.95903 |
| Brass C37700     | 1.13678 | 0.77034 | 0.25773 | 0.26631 | 0.38562 | 2.57678 |
| Sum              | 5    | 4      | 3    | 2   | 1   | 15   |

9. Conclusions

The studies on thermal analysis of engine cylinder having fins of different materials for heat transfer enhancement, and to find out the best material among the selected materials following conclusions were made. From the five main parameters which influence the selection of the material and by comparing this parameters we came to the final conclusion. From the thermal analysis which is done by using ANSYS it is clear that Aluminum alloys are better compared to the Gray cast iron and copper alloys. We also used weighted point method to select the best material among them. By doing the calculations according to weighted point method we made the final table which clearly depicts that Aluminum alloy 356 is best among the 4 materials. This method also gives us the selection preferences of the materials to be chosen. The results obtained from ANSYS analysis and weighted point method are complementary to each other and both shows us that Aluminum alloy 356 has better combination of required properties to be chosen as fin material.

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