CFD Transient Thermal Analysis of Cylinder Fins by Using Different Materials

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Abstract- **The cylinder block is an integrated structure comprising the cylinder of a reciprocating engine and often some or all of their associated surrounding structures (coolant passages, intake and exhaust passages and ports, and crankcase). The term engine block is often used synonymously with "cylinder block" (although technically distinctions can be made between engine block cylinders as a discrete unit versus engine block designs with yet more integration that comprise the crankcase as well).**

The energy is transit is termed Heat and Heat is a form of energy. The molecules of a substance are in parallel motion. The mean kinetic energy per molecule of the substance is proportional to its absolute temperature. The transmission of energy from one region to another as a result of temperature gradient. In heat transfer the driving potential is temperature difference. The aim of this study to optimized the better material for engine cylinder block for maximum heat transfer. The main focus on the study are to make as fast as heat transfer from the cylinder block.

In this work the model of engine cylinder block has been design in ANSYS 14.5.The designed model has been meshed and the transient analysis of engine cylinder block done. The transient thermal analysis ware performed using an analytical software package ANSYS worktable supported finite volume analysis. Within the present work transient thermal analysis is performed for various material for engine cylinder fin. The subsequent points are recognized within the variety of conclusive statements that are as follows. From the results it is clearly shows that the fin which is made up of Aluminum alloy 6061 attain maximum temperature of 793.1 °C at 10 seconds in comparison to other where aluminum alloy 795.71°C, Al metal matrix composition alloys (Al-MMC) 793.67°C.Aluminum alloy 6061 dissipates more heat as compare to other material. Aluminum alloy 6061 attain maximum heat flux of 2.1013e+005 W/m2 at 10 seconds in comparison to other where aluminum alloy 1.1832e+005 W/m2.Aluminum alloy 6061 attain maximum directional heat flux of 1.6841e+005 W/m2 at 10 seconds in comparison to other where aluminum alloy 95063 W/m2.

Index terms- Heat flux, temperature distribution, directional heat flux, heat transfer, ANSYS, Transient analysis, fins.

I. INTRODUCTION

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine, the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle. This force moves the component over a distance, generating useful mechanical energy.

In internal combustion engine, combustion of air and fuel take place inside the engine cylinder and hot gases are produced. The temperature of gases will be around 2300 - 2500°C. This is very high temperature and may result into burning of oil firm between the moving parts and may results it seizing of same so, this temperature must be reduced to about 150-200°C at which the engine will work most efficiency.All the heat produced by the combustion of fuel in the engine cylinders is not converted into useful power at the crankshaft. A typical distribution for the fuel energy is given below:

Useful work at the crank shaft = 25 %
Loss to the cylinders walls = 30 %
Loss in exhaust gases = 35 %
Loss in friction = 10 %

It is seen that the quantity of heat given to the cylinder walls is considerable and if this heat is not removed from the cylinders it would result in the preignition of the charge. In addition, the lubricant would also burn away, thereby causing the seizing of the piston. Excess heating will also damage the cylinder material. Keeping the above factors in view, it is observed that suitable means must be provided to dissipate the excess heat from the cylinder walls, so as to maintain the temperature below certain limits.

However, cooling beyond optimum limits is not desirable, because it decreases the overall efficiency due to the following reasons:

1. Thermal efficiency is decreased due to more loss of heat to the cylinder walls.
2. The vaporization of fuel is less; this results in fall of combustion efficiency.
3. Low temperatures increase the viscosity of lubrication and hence more piston friction is encountered, thus decreasing the mechanical efficiency.

Though more cooling improves the volumetric efficiency, yet the factors mentioned above result in the decrease of overall efficiency. Thus it may be observed that only sufficient cooling is desirable and any deviation from the optimum limits will result in the deterioration of the engine performance.

Indian two-wheeler market is the world’s second biggest market. Among the three segments (motorcycles, scooters and mopeds) of the Indian two wheeler market, major growth trends have been seen in the motorcycle segment over the last four to five years due to its resistance and balance even on bad road conditions. In Indian motorcycles, Air-cooling is used due to reduced weight and simple in construction of engine cylinder block. As the air-cooled engine builds heat, the cooling fins allow the wind and air to move the heat away from the engine. Low rate of heat transfer through cooling fins is the main problem in this type of cooling. The Engine cylinder is one of the major automobile components, which is subjected to high temperature variations and thermal stresses.

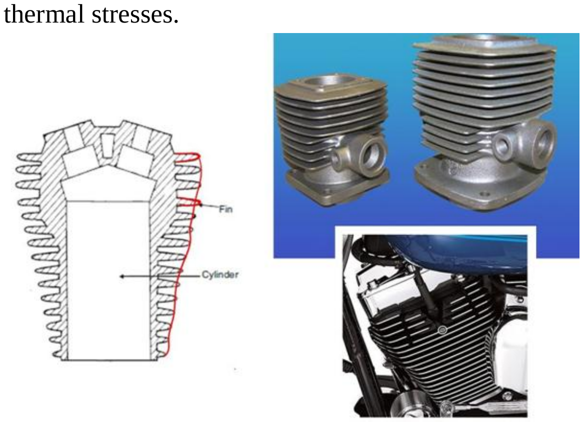

Figure 1 Finned engine cylinder

In order to cool the cylinder, fins are provided on the surface of the cylinder to increase the rate of heat transfer. By doing thermal analysis on the engine cylinder fins, it is helpful to know the heat dissipation inside the cylinder. The principle implemented in the project is to increase the heat dissipation rate by using the invisible working fluid, nothing but air. We know that, by increasing the surface area we can increase the heat dissipation rate, so designing such a large complex engine is very difficult. The main purpose of using these cooling fins is to cool the engine cylinder by air. The main aim of the project is to analyze the thermal properties by varying material of cylinder fins.

Heat Transfer Mechanism

Heat transfer mechanisms are simply ways by which thermal energy can be transferred between objects, and they all rely on the basic principle that kinetic energy or heat wants to be at equilibrium or at equal energy states. There are three different ways for heat transfer to occur: conduction, convection, and radiant heat (often referred to as radiation, but that's a more general term that includes many other phenomena). There is a related phenomenon that transfers latent heat called evapotranspiration.

Simultaneous Heat Transfer Mechanism

We mentioned that there are three mechanisms of heat transfer, but not all three can exist simultaneously in a medium. For example, heat transfer is only by conduction in opaque solids, but by conduction and radiation in semi-transparent solids. Thus, a solid may involve conduction and radiation but not convection. However, a solid may involve heat transfer by convection and/or radiation on its surfaces exposed to a fluid or other surfaces. For example, the outer surfaces of a cold piece of rock will warm up in a warmer environment as a result of heat gain by convection (from the air) and radiation (from the sun or the warmer surrounding surfaces). But the inner parts of the rock will warm up as this heat is transferred to the inner region of the rock by conduction.

Heat transfer is by conduction and possibly by radiation in a still fluid (no bulk fluid motion) and by convection and radiation in a flowing fluid. In the absence of radiation, heat transfer through a fluid is either by conduction or convection, depending on the presence of any bulk fluid motion. Convection can be viewed as combined conduction and fluid motion, and conduction in a fluid can be viewed as a special case of convection in the absence of any fluid motion.

Thus, when we deal with heat transfer through a fluid, we have either conduction or convection, but not both. Also, gases are practically transparent to radiation, except that some gases are known to absorb radiation strongly at certain wavelengths. Ozone, for example, strongly absorbs ultraviolet radiation. But in most cases, a gas between two solid surfaces does not interfere with radiation and acts effectively as a vacuum. Liquids, on the other hand, are usually strong absorbers of radiation.

Finally, heat transfer through a vacuum is by radiation only since conduction or convection requires the presence of a material medium.

Extended Surfaces (Fins)

Extended Surfaces It is most common approach to enhance the Heat transfer by using the extended surfaces. A plain fin may increases the surface area but a special shape extended surface may increase heat transfer coefficient in addition to the heat exchanger. The extended surfaces for liquids typically use much smaller fin heights than that used for gases because of the higher heat transfer coefficient for liquids. Use of high fins with liquids would result in low fin efficiency and result in poor material utilization. Externally finned tube and internally finned tube are the examples of extended surfaces for liquids. The temperature distribution, rate of heat transfer and fin effectiveness for six common profiles of longitudinal fins are given below.

The analytical expressions given for these profiles are based on the following assumptions:

1. The heat conduction in the fin is steady and one dimensional.
2. The fin material is homogeneous and isotropic.
3. There is no energy generation in the fin.
4. The convective environment is characterized by a uniform and constant heat transfer coefficient and temperatures.
5. The fin has a constant thermal conductivity.
6. The contact between the base of the fin and the primary surface is perfect.
7. The fin has a constant base temperature.

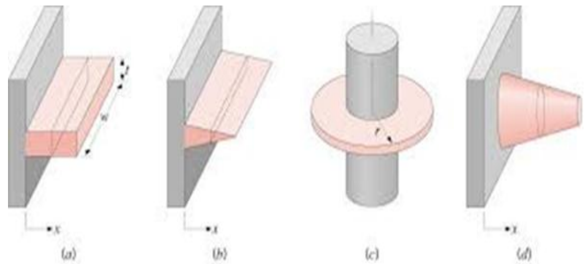

Figure 2 Type of Fins

Working Principle of fins

As fins are mainly works on principle of heat transfer through convection .In convection type heat transfer, heat is transfer from one portion of fluid to another. As fluid is heated by wasted heat energy, its heated molecule will going to rise up and the colder molecules will go down and gradually heat is distributed throughout the volume.

Mathematical equation of convection heat transfer,

$Q_{Convection} = h\ A_s\ (T_s - T_\infty)$

Here, h= Heat transfer coefficient in W/ m^2-^{0}C

As= exposed surface area of fin (m^2)

T_s= surface temperature of engine (^{0}C

T_∞= temperature of surrounding (^{0}C)

From equation, it is clear that rate of convective heat transfer is directly depend upon coefficient of convective heat transfer and surface area of engine exposed to surrounding. It is not feasible to increase surface area of engine, so we can increase coefficient of heat transfer to increase convective heat transfer. Heat transfer coefficient is depending upon following aspects:

- Geometry of exposed surface
- Temperature difference between engine surface and surrounding
- Convective velocity of fluid
- By extending the surface area of engine, which is called fins.

II. LITERATURE REVIEW

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

Munukuntla Vidya Sagar et. al. [2017] simulated a cylinder fin body using SOLIDWORKS and transient thermal analysis done on ANSYS. These fins are used for air cooling systems for two wheelers. In present study, Aluminium alloy is compared with Magnesium alloy. The various parameters (i.e., geometry and thickness of the fin) are considered, 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 there by increasing the heat transfer rate and efficiency of the fin. The results shows, By using circular fin with material Aluminium Alloy 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.

Sahu [2018] According to researcher, to overcome the problem of overheating, especially in thermal systems, fins are usually provided. Fins can be analyzed in design phase only using Computational Fluid Dynamics as tool and assuming uniform heat transfer coefficient model on its surface. However, research investigators prove that heat dissipation is not constant, however varies along the fin length. It is mostly due to non-uniform resistance experienced by the fluid flow in the inter fin region. In order to dissipate high heat flux densities, the specified heat sink have to be larger than device. Consequently, the heat sink overall performance is decreased. The inter fin resistance can be decreased with the aid of adding the perforation to the fins. Adding a pass-fin in the middle enables to increase the heat dissipation area, but it forms the stagnant layer of hot air at the fin bottom. The fluid drift motion at the underside of the fin array may be improved by adding perforation to the fins. Also we can develop a model for the values of total heat flux and temperature distribution by using ANSYS.

Tekhre [2017] in this research studied to investigate heat dissipative effect of fins made up of different materials and different geometries. It's necessary to analyze the heat transfer rate of fins. Study will lead to the different experiments which have been made to increase fin efficiency by changing fin material properties, climatic condition around fins, using perforations and notches in fins and fin geometry. The main thermal analysis tool is CFD analysis with the help of computer modeling software. The main study is focused on a two wheeler engine (Honda unicorn 150cc). It also founded that change in environmental condition causes great change in heat transfer coefficient and in its efficiency.

Laad et al. [2016] According to researcher, the impact of the pin-fin shapes on the general performance of the heat sink with inline and staggered arrangement is studied during this research. Six totally different shapes of fins square, trapezoidal, rectangular interrupted, rectangle, circular inline and staggered are subjected to study during this research. The optimization processes are allotted using computer simulations performed using ANSYS bench 14.0. Heat transfer was analyzed in natural air and aluminum 6063 as a pin fin material. to review of thermal performance of different heat sink of fin profile at different velocities 5, 10 & 12 m/s and simulation is completed at totally different heat load of 15W, 20W & 25 W and air inlet temperature is taken as 295 K. the aim of this study is to look at the effects of the configurations of the various pin-fins design. It is determined from the results that optimum cooling is achieved by the heat sink design that contains Circular pin fins. After the choice of correct heat sink by CFD simulations the steady state thermal performance is allotted at different fin height of circular pin fin heat sink. The result shows that the temperature is increasing by reducing the fin height. At totally different loads the performance of all chosen fin profiles is allotted and located that at & 25 W load the maximum temperature is maximum for interrupted rectangular fin and minimum for circular pin fin. And therefore the price of Nusselt number is additionally maximum for circular pin fin design.

Indian two-wheeler market is the world's second biggest market. Among the 3 segments (motorcycles, scooters and mopeds) of the Indian two wheeler market, major growth trends have been seen in the motorcycle segment (125-150 CC) over the last four to five years due to its resistance and balance even on bad road conditions. In Indian motor-cycles, Air-cooling is used due to reduced weight and simplicity in construction of engine cylinder block. As the air-cooled engine builds heat, the cooling fins allow the wind and air to move the heat away from the engine. Low rate of heat transfer through cooling fins is the main problem in this type of cooling. About 35% of heat generated in engine cylinder is lost to the cooling medium. In case of air cooling larger heat transfer area is needed. This can be possible by providing fins on cylinder block. So it demands an urgent need to carry out research work to find out the viable-effective fin design for fast removal of heat. Very less research work has been carried out on fins. It is found that heat transfer rate through fins can be augmented by changing fins geometry, materials, fins parameter like thickness, pitch and wind velocity etc. Therefore, there will be wide importance of the research to be carried out in area of fins materials effect on heat transfer rate.

Based on above mentioned research gaps, following objectives of the new research are being formulated. Following are the objectives of the research:

- To generate 3-D model of cylinder block model and carry out Transient Thermal analysis and test heat transfer performance, Temperature distribution, Heat Flux and Directional heat flux.
- To analyze the effect of material changes on thermal characteristics of IC engine.
- To validate results with previous research done.

III. METHODOLOGY

The ANSYS Design Modeler provides the following approaches for model generation: Creating a surface model within ANSYS Design Modeler. The engine cylinder setup the geometry of engine cylinder fin performing the simulation study is taken form one of the research scholar's Mulukuntala Vidya Sagar et.al. (2017) paper with exact dimension .The part of model was designed in ANSYS (Fluent) workbench14.5 software. The geometric dimension of the cylindrical block having circular fins is shown in the Figure 3. For simulating the cylindrical block have circular fins ANSYS 14.5 finite element control volume approach has been used.

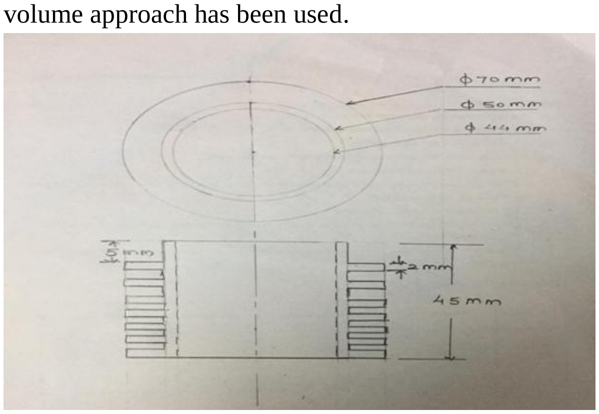

Figure 3 Geometrical dimensions of cylindrical block having circular fins with holes.

By, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular faces at the boundaries.

Number of nodes-717718

Number of elements-461906

Curvature- On

Smooth – Medium

Table 1 Model Description

Object Name	Transient Thermal (A5)
State	Solved
Definition	
Physics Type	Thermal
Analysis Type	Transient
Solver Target	Mechanical APDL
Options	
Generate Input Only	No

Table 2 Mechanical Properties

Material Name	Density (Kg/m^3)	Specific Heat (J/Kg-K)	Thermal Conductivity (W/m-K)
Aluminum alloy	2770	875	202
Aluminum alloy 6061	2700	1256	167
Al metal matrix composition alloys (Al-MMC)	2760	842	124

Table 3 Boundary conditions

Load	Unit	Value
Inlet Temperature	K	1073
Film coefficient	W/m^2-K	5
Ambient Temperature	K	303
Material	---------	Aluminum Alloy, Al metal matrix composition alloys (Al-MMC) and Aluminum alloy 6061

IV. RESULTS AND DISCISSIONS

After applying all boundary condition we have obtained the fallowing results which are shown in figure:

Contours for Aluminum Alloy

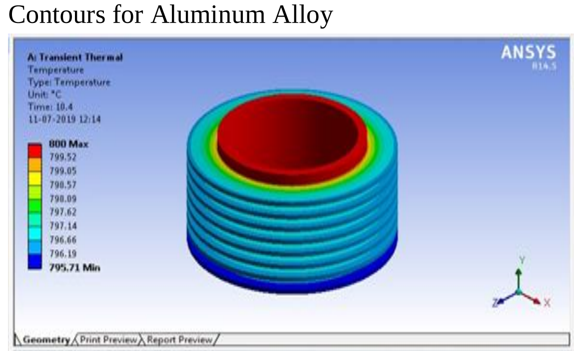

Figure 4 Temperature contour Aluminum Alloy

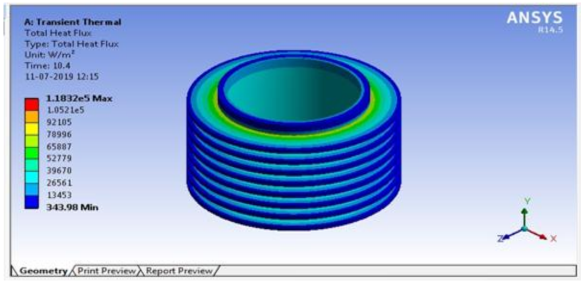

Figure 5 Total Heat Flux contour Aluminium Alloy

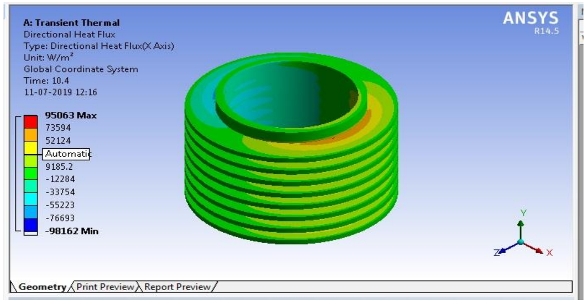

Figure 6 Directional Heat Flux contour Aluminium Alloy

Contours for Aluminium Alloy 6061

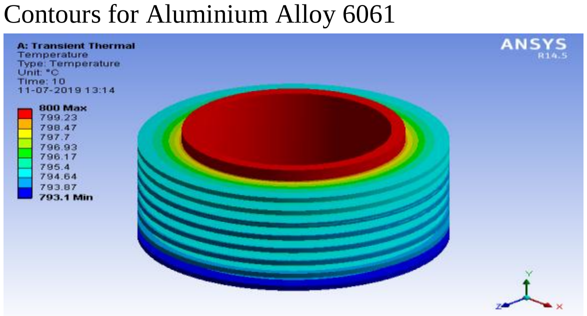

Figure 7 Temperature contour Aluminium Alloy 6061

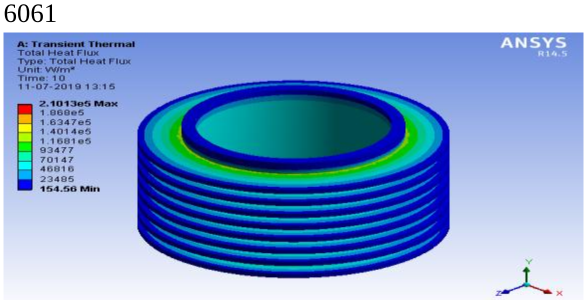

Figure 8 Total Heat Flux contour Aluminium Alloy 6061

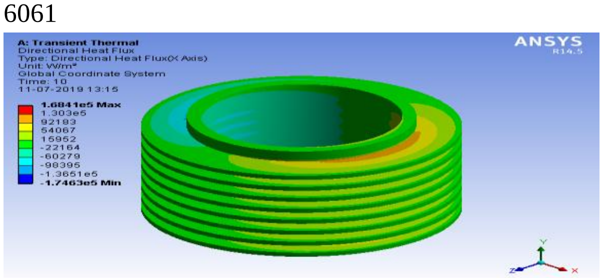

Figure 9 Directional Heat Flux contour Aluminium Alloy 6061

Contours for Al metal matrix composition alloys (Al-MMC)

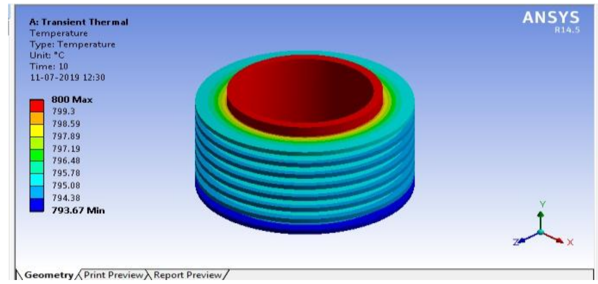

Figure 10 Temperature contour Al metal matrix composition alloys (Al-MMC)

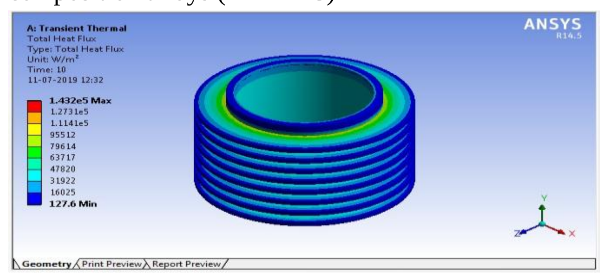

Figure 11 Total Heat Flux contour Al metal matrix composition alloys (Al-MMC)

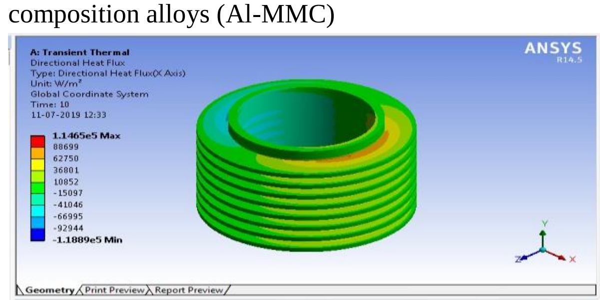

Figure 12 Directional Heat Flux contour Al metal matrix composition alloys (Al-MMC)

Comparison for different material over time

Table 4 Comparison of Temperature Distribution for different material over time

Time [s]	Temperature [°C]		
	Aluminium Alloy	Aluminium Alloy 6061	Al metal matrix composition alloys (Al-MMC)
1.	303	256.9	273.69
2.	522.07	465.45	486.68
3.	649.35	600.82	619.43
4.	718.47	682.13	696.29
5.	755.43	730.03	740.
6.	775.12	758.12	764.76
7.	785.6	774.56	778.76
8.	791.17	784.18	786.67
9.	794.13	789.81	791.15
10.	795.71	793.1	793.67

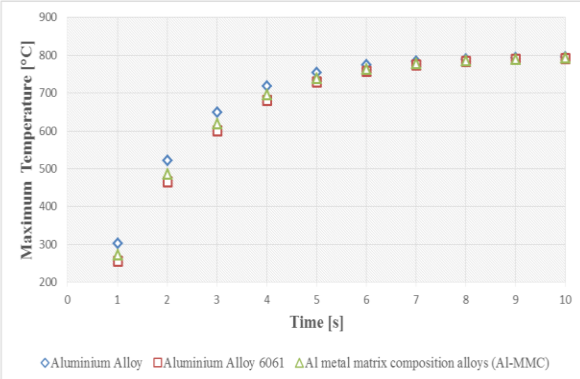

Figure 13 Comparison of Temperature Distribution. For different materials over time.

Table 5 Comparison of Heat flux Distribution for different material over time

Time [s]	Heat Flux [W/m²]		
	Aluminium Alloy	Aluminium Alloy 6061	Al metal matrix composition alloys (Al-MMC)
1.	1.4348e+007	1.7404e+007	1.7404e+007
2.	7.7825e+006	1.0417e+007	1.0417e+007
3.	4.1322e+006	6.0516e+006	6.0516e+006
4.	2.2288e+006	3.5624e+006	3.5624e+006
5.	1.2197e+006	2.1154e+006	2.1154e+006
6.	6.8218e+005	1.2683e+006	1.2683e+006
7.	3.9564e+005	7.7171e+005	7.7171e+005
8.	2.4295e+005	4.8062e+005	4.8062e+005
9.	1.6162e+005	3.1005e+005	3.1005e+005
10.	1.1832e+005	2.1013e+005	2.1013e+005

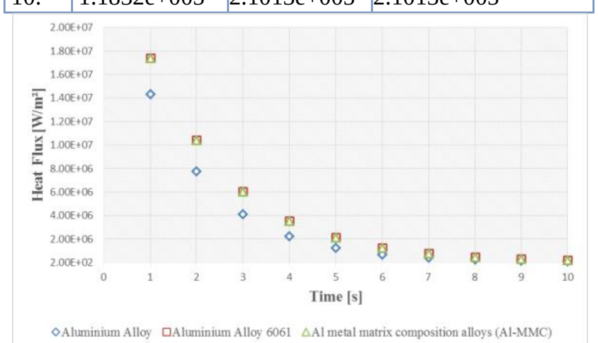

Figure 14 Comparison of Heat Flux Distribution. For different materials over time.

V.CONCLUSIONS

The transient thermal analysis ware performed using an analytical software package ANSYS worktable supported finite volume analysis. Within the present work transient thermal analysis is performed for various material for engine cylinder fin. The subsequent points are recognized within the variety of conclusive statements that are as follows.

- From the above results it is clearly shows that the fin which is made up of Aluminum alloy 6061 attain maximum temperature of 793.1 °C at 10 seconds in comparison to other where aluminum alloy 795.71°C, Al metal matrix composition alloys (Al-MMC) 793.67°C.
- So above values clearly shows that Aluminum alloy 6061 dissipates more heat as compare to other material.
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