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EXPERIMENTAL EVALUATION WITH COMPARATIVE STEADY-STATE THERMAL ANALYSIS OF TWO-WHEELER ENGINE CYLINDER BY VARYING ITS MATERIAL

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Abstract- *In this study, the surface temperature distribution and average surface temperature for different bore temperature of a two-wheeler engine cylinder were analyzed experimentally and numerically in a steady-state condition. For the experiment, the "Hero-Splendor" bike engine cylinder was used. The cylinder of this bike was experimented for various bore temperature. Then the bike engine cylinder was modeled and analyzed in a steady-state condition, using a CFD simulation software. A comparative study was done among the experimented engine cylinder and the modified model of that engine cylinder. The analysis results show that the aluminum alloy made cylinder gave better surface temperature and total heat flux than the gray cast iron made cylinder. The average surface temperature was found to be maximum for aluminum made modified cylinders. Also, the average heat flux was found to be maximum for aluminum made "Hero-Splendor" two-wheeler engine cylinder.*

Keywords: Engine cylinder, Steady-state, CFD, Heat flux

1. INTRODUCTION

Engine performance of a vehicle depends on numerous parameters such as types of material used for making the engine, numbers of fins used, type of fins used, the thickness of fins and fins profile, which escort thermal effect on it. Combustion of IC engines can best convert about 25 to 35 percentage of the chemical energy of the fuel used into mechanical energy. About 35 percent of the heat produced is lost into the atmosphere and the remaining heat is removed through exhaust and radiation from the engine [1]. Inside the core of the IC Engine cylinder, the burning temperature of gases is about almost 2000ºC-2500ºC. In IC engines, very high-temperature and pressure gases produced by combustion apply direct forces to some parts of the engine, such as pistons, cylinder wall, or the valves. The parts of the engine, like cylinder head, cylinder wall, piston, and the valves absorb this heat from hot gases of the combustion [1]. Only some part of heat formed during the combustion of used fuel in the IC engine cylinders is transformed into mechanical energy at the crankshaft. These loses may arise due to the thermal stresses set up in the parts of the engine, Engine valves twist because of overheating, reduces the strength of the materials used for piston and piston rings and many more factors that leads heat loses in the IC Engine [2]. The objective of this paper is to show the comparative study between the engine cylinders made of different materials both experimentally and numerically.

2. MATHEMATICAL EQUATIONS

As the solver in FLUENT software works on Finite Volume Method (FVM) and in this case solved the standard Navier – Stokes equations of the fluid flow in three dimensions for attainment the required pressure and the velocity at domain points. The following momentum conservation equation was used accompanied by the continuity equation [3]:

$$\frac{\partial(\rho\upsilon)}{\partial t} + \upsilon\nabla.(\rho\upsilon) = -\nabla P + \nabla.\tau + F + \rho g \qquad (1)$$

For modeling of the heat transfer in the engine cylinder, the energy equation is solved in the following form:

$$\frac{\partial(\rho E)}{\partial t} + \nabla.(\upsilon(\rho E + P)) = \nabla.(K_{eff}\nabla T - \sum_j h_j J_j + (\tau\upsilon)) + S\hbar \qquad (2)$$

Eq. 2 is utilized to measure the temperature at various focuses in the liquid district. The 3D differential condition can be understood as a scalar vehicle condition to compute the temperature at the blade surface and cylinder surface for which the above condition reduces to the accompanying:

$$\nabla^2 T + \frac{\dot{q}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (3)$$

Also, in this case $\frac{\partial T}{\partial t}$ = 0, owing to steady-state assumption [3].

3. METHODOLOGY

In this analysis firstly a two-wheeler engine cylinder model was experimented for getting the temperature distribution profile at different temperatures. Then the model was generated using CAD software. The model will be studied and simulated for desire results in ANSYS software. Thermal properties were evaluated from the simulation. In this analysis, the engine cylinder of “Hero Splendor Pro, model- 2015” is selected. Figure 1 shows the drawing of the designed two-wheeler engine cylinder model of Hero Splendor Pro. All dimensions are in inches. The total flow chart of the working process is shown below in Figures 1 and 2 sequentially. The material used in this study were cast iron and aluminum 2014-T4 alloy whose mechanical properties are listed in Tables 1 and 2 respectively.

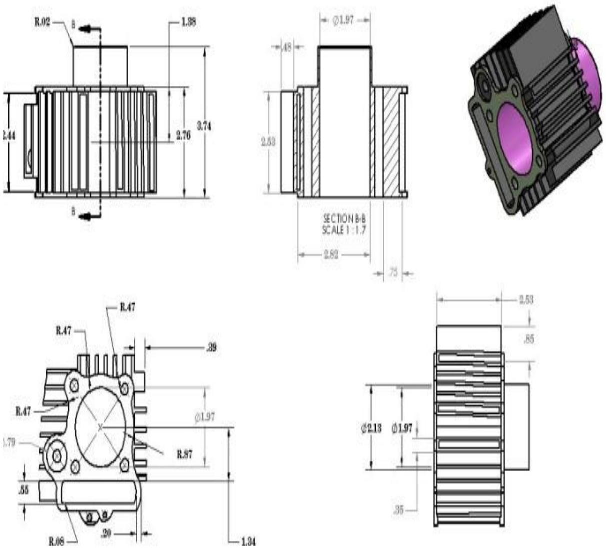


Figure 1: Hero Splendor Pro Two-Wheeler Engine Cylinder Model Drawing

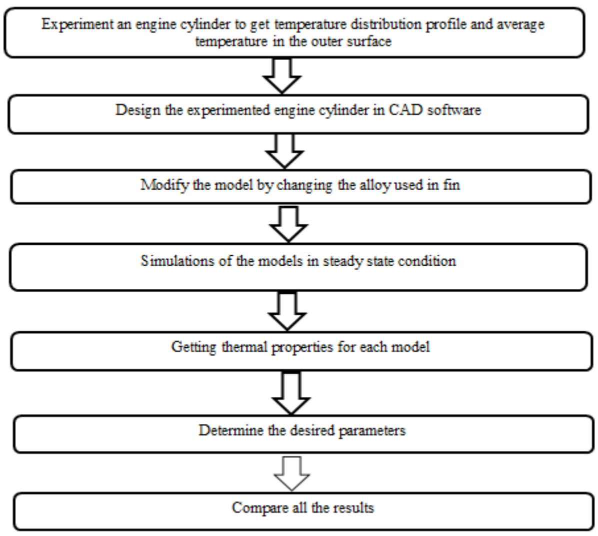


Figure 2: Flow Chart of the Total Working Process

Table 1: Mechanical Properties of Gray-Cast Iron Used [4]

Material Properties	Unit	Values
Density	Kg/m^2	7200
Young’s modulus	GPa	110
Poisson’s ratio		0.28
Bulk modulus	Pa	8.33×10^{10}
Shear modulus	Pa	4.2969×10^{10}
Tensile ultimate strength	Pa	2.4×10^{8}
Compressive ultimate strength	Pa	8.2×10^{8}
Thermal conductivity	W/m-k	52
Specific heat	J/Kg-°C	447
Coefficient of thermal expansion	1/K	11×10^{-8}

Table 2: Mechanical Properties of Aluminum 2024-T4 Used [4]

Material Properties	Unit	Values
Tensile ultimate strength	MPa	469
Modulus of elasticity	GPa	73.1
Poisson’s ratio		0.33
Thermal conductivity	W/m-k	121
Specific heat	J/g-k	0.875
Density	g/cc	2.78

4. EXPERIMENTAL AND SIMULATION SETUP

4.1 Experimental setup

A Hero motorcycle engine cylinder was used which is of Splendor pro 2015 model of the Hero two-wheeler company, which is shown in Figure 3. Firstly the engine cylinder bore was heated by cartridge heater. Cartridge heater is a tube-shaped, heavy-duty, industrial Joule heating element used in the process heating industry, usually custom manufactured to a specific watt density, based on its intended application [5] shown in Figure 4.

Figure 3: Hero Splendor Pro Two-Wheeler Engine Cylinder

Figure 4: Cartridge Heater [5]

The surface temperature of the cylinder at different locations was measured by a digital k-type thermocouple.

Figure 5 shows the whole experimental set-up.

Figure 5: Experimental Set-Up (Engine Cylinder and Cartridge Heater)

In this experiment, the engine cylinder bore is heated with a cartridge heater inserted in the bore with the help of cylindrical shaped metal. And the temperature distribution at the outer surface of the cylinder is determined with digital thermocouple meter for different bore temperatures under steady-state conditions. In Figure 5, the experimental set-up is shown, where a cartridge heater is inserted into the bore o the engine cylinder to generate heat energy. A core metal is tightly inserted into the cylinder bore to propagate the heat generated in the cylinder surface. In Figure 6 the used voltage regulator and digital k-type thermocouple are shown. With the help of the voltage regulator, different voltages were generated and thus different temperature was generated at the core metal with the help of heater. In the experiment, the data for different voltage and temperature in the core was measured with the help of digital thermocouple meter as shown in Figure 6

Figure 6: Experimental Set-Up (Voltage Regulator and Digital k-type Thermocouple)

Four different voltage of 200V, 180V, 160V, and 150V was generated and four different core temp. was found for these voltages such as 150°C, 130°C, 110°C and 90°C. The surface temp. distribution for four different core temp. and voltages were collected. For collecting data different location temp. of the engine, cylinder surface was measured to get the average temp. of the engine cylinder surface for each core temp. of the cylinder.

4.2 Simulation Setup

A HERO SPLENDOR engine cylinder model was created in CAD software and then the simulation was done for the exact model and the modified others. The simulation was done by the following parameters:

- The simulation was done in a steady-state condition.
- Ambient fluid: Air and temperature 31°C.
- Ambient Temperature was set according to experimental data.
- Cylinder inner wall temperature was set to different temperatures to see the variations in the surface temperature distribution, average surface temperature, and total heat flux as well.
- The simulation was done for gray cast iron and aluminum 2024-T4 alloy to have comparative data sets from the analysis.

Meshing is very important as the accuracy of the simulation depends on it. In the present study 3D unstructured tetrahedral mesh was generated because it is suitable for a complex model. It increases the computational accuracy. The inflation layer was created to construct a structured grid. The number of layers was 4 with a growth rate of 1.2. The minimum thickness was 0.0002. Figure 7 shows the mesh generated for the engine cylinder model.

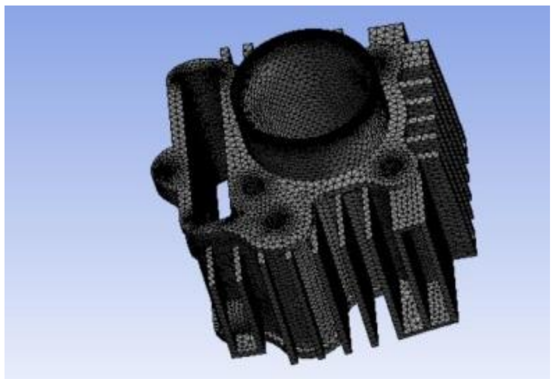


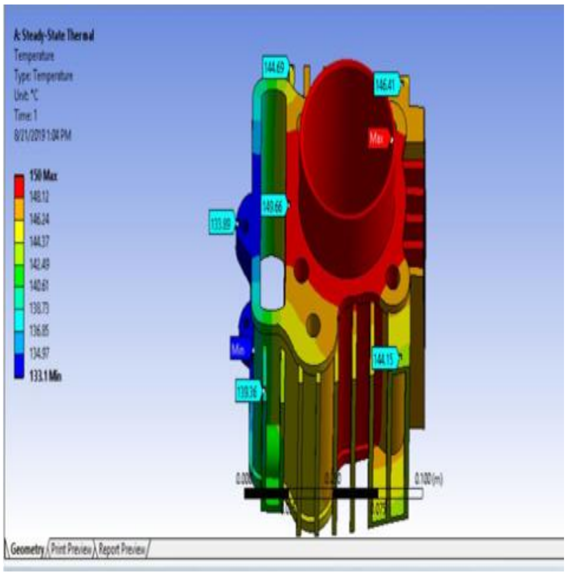
Figure 7: Meshing in ANSYS

The experimented engine cylinder of Hero Splendor at different bore temperature gave different average surface temperature. To vary the bore temperature a voltage regulator and a cartridge-type heater were used. After completing the meshing process the quality of mesh was checked by skewness and orthogonal quality. Both showed acceptable values. The element number was 16260, and the node number was 29976. The nodes and elements number was restricted under 32000, as the student version of the software was used.

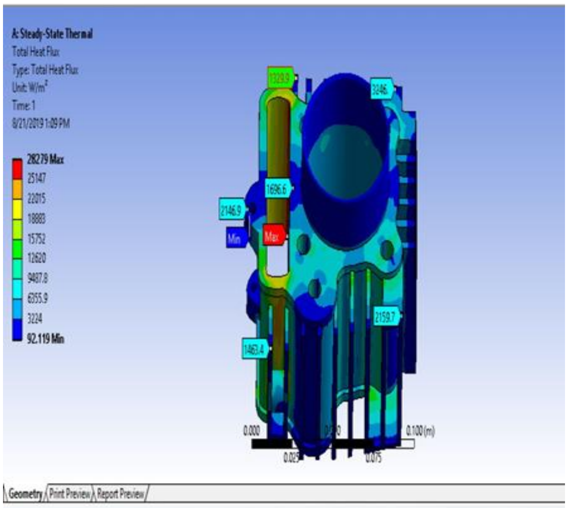
4.2.1 Simulation Results

Temperature Conditioning and Simulation of Hero Splendor Engine Cylinder with Gray Cast Iron

After the meshing procedure was done, then the core temp. of the engine cylinder was set to different temperatures like the experiment (150°C, 130°C, 110°C and 90°C). The temperature of ambient was selected 31°C, as the experimental ambient temp. was 31°C. After selecting the core temperature of the engine cylinder and ambient convection temp. the simulation was done for both temperature distribution and total heat flux. And metals were selected both gray cast iron and aluminum alloy.



(a)



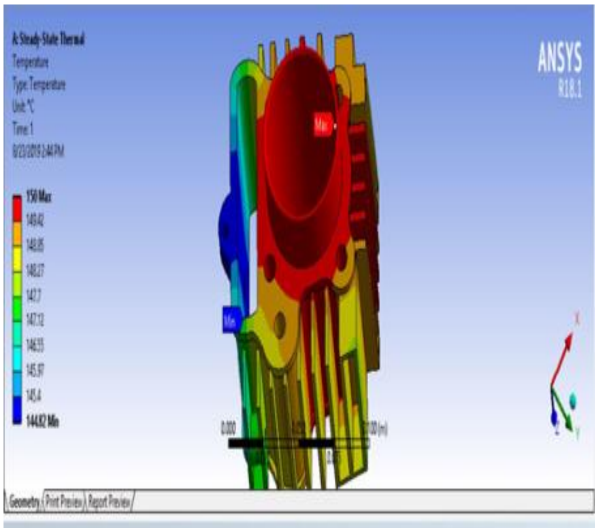
(b)

Figure 8: Simulation of Hero Splendor Engine Cylinder (Gray Cast Iron) For 150°C Core Temperature. (a) Temp. Distribution, (b) Total Heat Flux

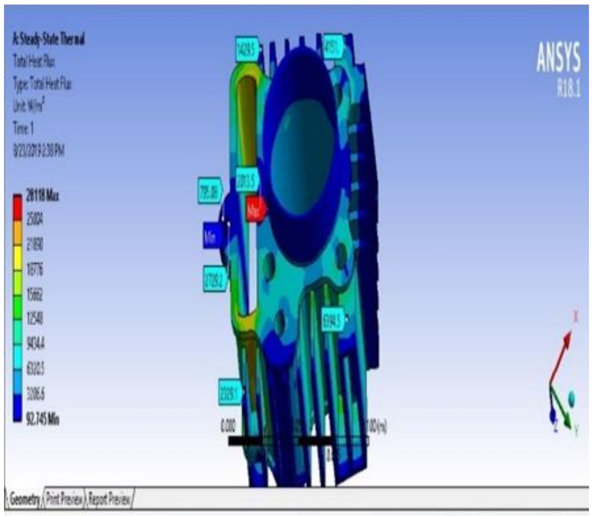
Figure 8 shows the simulation of the Hero-Splendor engine cylinder of gray cast iron metal for both total heat flux and temp. distribution profile at 150°C core temperature inside the bore.

Simulation of Hero Splendor Engine Cylinder with Aluminum Alloy

For aluminum 2024-T4 alloy the simulations are done again at the previous set of core temperatures which are shown. Figure 9 shows the simulation of the Hero Splendor engine cylinder of Aluminum 2024-T4 alloy for both total heat flux and temp. distribution profile at 150°C core temperature inside the bore:



(a)



(b)

Figure 9: Simulation of Hero Splendor Engine Cylinder (Aluminum Alloy) For 150°C Core Temperature. (a) Temp. Distribution, (b) Total Heat Flux

Now, the simulation was also done for 130°C, 110°C, and 90°C core temperatures. For all the bore temperatures the aluminum alloy gave higher average surface temp. and higher heat flux. The value and comparison of gray cast iron and aluminum alloy are given in the result section of this report. So, from the above simulations, we can say, we found improvement by using aluminum alloy as material from the thermal point of view.

4.2.2 Comparative Results

At 200V from the voltage regulator, a temperature of 150°C was generated at the core of the engine cylinder. Then temp. data from some fixed location was measured through a digital k-type thermocouple meter. Those temps. data at different locations are shown in Table 3.

Table 3: Average Temp. from Experiment and Simulation at 150°C Bore Temp. and 200V

Location points	Temp. from Experiment (°C)	Temp. from Simulation (°C)
1	120	144.15
2	128	146.41
3	100	133.89
4	139	149.66
5	107	139.36
6	115.5	144.69
Av. Temperature (°C)	118.25	143.03

From Table 3, we can see the average temp. of the cylinder surface for 150°, C bore temperature when the voltage regulator was operating at 200V. The data from experiment and simulation were both taken at a similar steady-state condition and hence the result shows they are pretty close.

6. RESULTs AND DISCUSSION

Hero splendor engine cylinder with changed material (Aluminum Alloy) gave higher average temperature and higher total heat flux than the gray cast iron used as material. Because of higher heat transfer through the Aluminum alloy, it gave better results than gray cast iron. Table 4 shows the comparison between the two metals with respect to average temperature and average heat flux.

Table 4: Hero Splendor Average Temperature and Heat Flux from Simulation at Different Bore Temperature and materials

Core Temp. (°C)	Av. Temp. for Gray Cast Iron as Material (°C)	Av. Heat Flux for Gray Cast Iron as Material (W/m^2)	Av. Temp. for Aluminum Alloy as Material (°C)	Av. Heat Flux for Aluminum Alloy as Material (W/m^2)
150	143.03	10828.16	147.41	14105.22
130	124.62	10971.64	127.822	11729.97
110	105.69	8755.35	108.243	9356.65

Now, Figure 10 shows the Hero-Splendor engine cylinder average temperature from the simulation at different bore temperature for gray cast iron and modified Aluminum 2024-T4 alloy. From Figure 10, we can see the average temperature is higher for Aluminum alloy than Gray cast iron at different bore temperature.

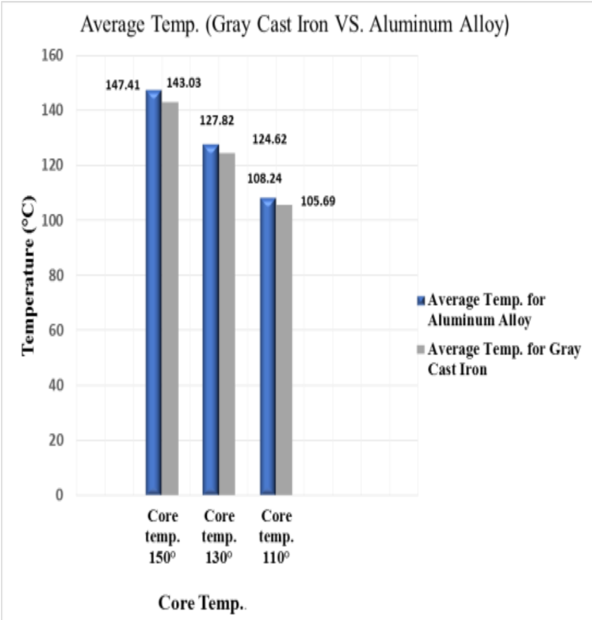


Figure 10: Hero Splendor Engine Cylinder Average Temperature from Simulation at Different Core Temperature

Now, Figure 11 shows the Hero-Splendor engine cylinder average heat flux from the simulation at different bore temperature for gray cast iron and modified Aluminum 2024-T4 alloy. From Figure 11 we can see the average heat flux is higher for Aluminum alloy than Gray cast iron in case of all different bore temperatures.

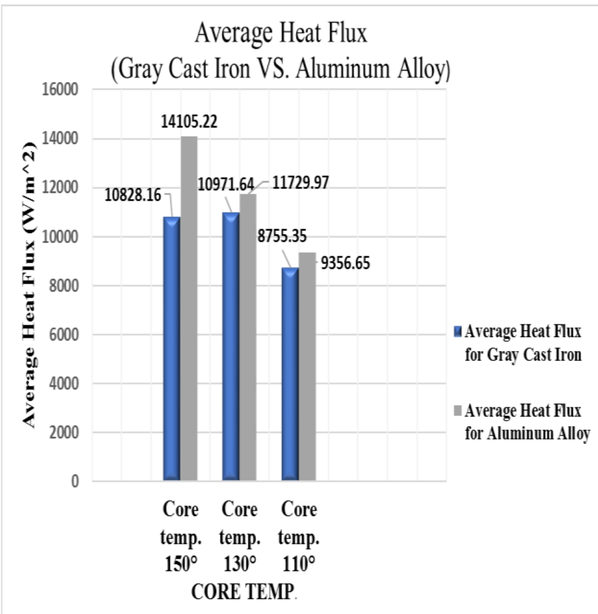


Figure 11: Hero Splendor Engine Cylinder Average Heat Flux from Simulation at Different Core Temperature

In Figure 11, we can see the average heat flux is higher for Aluminum alloy than Gray cast iron in case of all different bore temperature.

6.CONCLUSION

In this analysis, the main concern was to study a practical engine cylinder and experiment with the model to get the temperature profile and average surface temperature. Then create the CAD model and simulate to study its thermal parameters under steady-state condition. Then compared the data found, with the experimental value. As aluminum alloy possesses better thermal properties, we modified the engine model with aluminum alloy. We focused these points and compared all the data collected to see the amount of higher and better heat flux and average temp. provided by our modified engine cylinder. Because if there is a sufficient amount of enhanced cooling done, the engine will give more mileage and less fuel consumption. Finally, from all the analysis and study it can be concluded that:

- The experimented engine cylinder has vertical types of the fin, which gave lower average surface temperature but higher heat flux.
- The experimented engine cylinder simulation gave an almost close value of data set as the simulation. Some differences occurred due to surroundings and heat loss.
- The experimented engine cylinder simulated with aluminum alloy gave a better average temp. and heat flux.

So, from the study, it can be said that we experimented Hero Splendor Engine cylinder and then modified the engine material with aluminum 2024-T4 alloy, and found sufficient growth in average surface temp. and heat flux.

7. REFERENCES

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(K)
t	Time	(s)
P	Pressure	(Pa)
ρ	Density	(kg/m^2)
G	Gravity acceleration	(m/s^2)
F	Force	(N)