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ORIGINAL PAPER

Numerical simulation of heat transfer and design optimization of IC engine fins geometry using Finite Element analysis

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Abstract

A major amount of fuel energy is lost in the form of heat is one of the major concern in an internal combustion (IC) engine, which can be avoided by providing the engines with better cooling systems in automobiles. Due to weight constraints, air cooling is the only way to cool the small engine in motorcycles. The fins significantly increases the heat transfer rate, but by changing their parameters, the rate of heat transfer of these fins can be increased even further. The majority of previous research has been done on small displacement engines ranging from 50 cc to 150 cc, and no research work has been reported beyond that. The majority of previous work has been carried out on fin shape and design rather than its thickness and count. These concerns have been addressed in this study, where an analysis of the heat transfer of air-cooled IC engines with a displacement of 373 cc has been taken into consideration. The design modelling of the engine body has been done with different fin thicknesses. In the first phase, computational fluid dynamics (CFD) analysis of the engine body has been done by SOLIDWORKS Flow Simulation. Airstream passing over the engine body has been studied at variable speeds. Thermal analysis of the engine body was carried out by varying the vehicle speed, fin thickness, and materials. Properties like temperature on the fin, temperature on the engine head, and heat loss from the engine were analysed for different vehicle speeds, fin thickness, and materials. Lastly, the results obtained by using those boundary conditions were compared with previous research and reported. It was found that fins with a thickness of 5 mm performed better with Aluminium Alloy as their material as compared to other fin thicknesses and materials. This will help with optimum cooling of the engine, which makes the motorcycle engine perform well and increase its life.

Keywords Aluminium Alloy · CFD · Fin thickness · Heat loss · IC engine

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Nomenclature

Q	Heat flux (W/m^2)
k	Thermal conductivity of the material ($W\ m^{-1}\ K^{-1}$)
H	Heat transfer coefficient of air ($W/(m^2K)$)
θ	Temp difference at a distance x from the base of the fin
θ°	Difference b/w base and ambient temperature
A	Area of cross section of fin (m^2)
l	Length of fin (m)
t	Thickness of the fin (m)
P	Perimeter of fin (m)
x	Distance measured from base of fin (m)

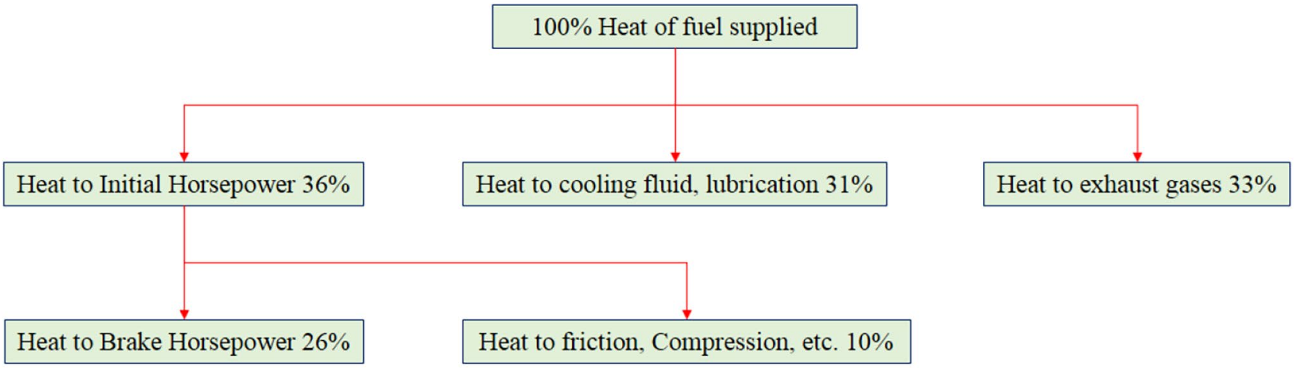

Fig. 1 Heat dissipation of an IC engine

1 Introduction

The combustion of air and fuel occurs within the IC engine cylinder, resulting in the production of hot gases. The chemical energy of the fuel is transformed into mechanical energy in these engines. During the fuel combustion in an IC engine, the heat generated is of the order of 2100°C to 2200°C inside the combustion chamber. This may result in burning the lubricant film between the parts of the engine, thereby causing the engine to cease. To prevent this malfunction and to maintain a healthy working temperature, we have to bring down the generated temperature to about 230°C. In order to achieve optimum cooling, fins are used. They provide exterior, extended cooling surfaces. These fins are designed to reduce and optimise the temperature inside an IC engine such that the temperature is optimum and there is no increase in the weight of the IC engine [1]. It should also be recognized that around 30–35% of total heat created is utilised to generate break power, 20–25% of total heat is decreased by the cooling system, and the remaining heat is lost through friction and taken away by exhaust fumes (Fig. 1).

Modern engines use technologies like increased compression ratios, variable valve timing, computerization, and liquid cooling to make lighter engines more powerful and achieve thermal efficiency of up to 50%. It does, however, increase cost, regular maintenance, and the possibility of engine failure while the engines are running. Due to economic considerations, tiny displacement engines used in two-wheelers often do not have as many technologies; so, over the years, researchers have attempted to improve the heat transfer rate of such engines through modifications in design and cheaper materials. Overheating of the I.C. has numerous negative consequences. The piston crown has a risk of being burned. Thermal stresses will accumulate in the cylinder, cylinder head, and piston, potentially resulting in cracking, burning, and warping of the exhaust valve.

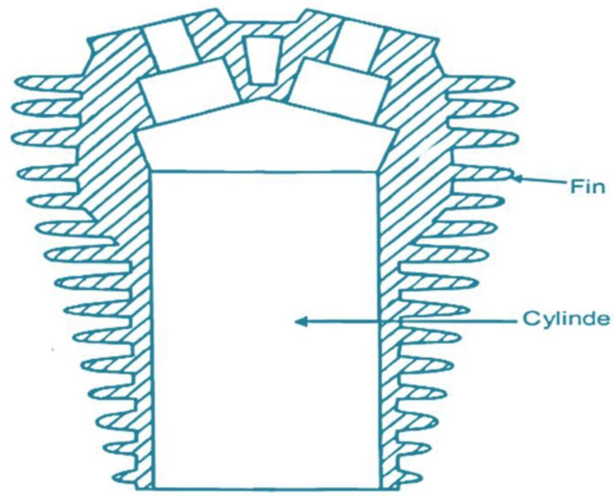

Fig. 2 Cylinder with fins

Due to carbonization from the increased blow, the piston ring may stick in the ring grooves. Reduction in volumetric efficiency heat transferred to an engine component should be removed into the atmosphere after a certain level to avoid engine overheating [2]. The temperature in the engine is regulated by the cooling system, and in other words, we can say that the cooling system acts as a temperature regulating system. Excessive cooling has a number of negative consequences, including decreased thermal efficiency, decreased mechanical efficiency, increased corrosion of engine components, and inappropriate fuel vaporisation. Excessive cooling is also undesirable since it affects thermal efficiency. As a result, if high thermal efficiency is sought, the amount of heat drained should not be greater than that required to prevent overheating [3].

Small-displacement engines use air-cooled systems. Extended surfaces or fins are supplied on the cylinder walls and head in air-cooled systems. Heat from the engine is transferred to these fins, and as air rushes over the fins, the heat is dispersed into the atmosphere (Fig. 2). The quantity of heat lost into the environment is determined by the fins' surface area, the air volume moving over the fins, and the thermal conductivity of the fin material [4]. Its effective surface area should be big in order to quickly remove heat from the engine. The arrangement is mounted over the engine to do this. These are referred to as fins. Most modern smaller-displacement internal combustion engines are air-cooled. Heat created by an air-cooled engine, on the other hand, is discharged straight into the environment. This is typically aided by metal fins covering the exterior of the cylinder head and cylinders, thereby increasing the acting area of air. They provide a larger surface area for heat dissipation without significantly increasing engine weight. Fins may be forged, casted, shrink-fitted, or welded on the engine cylinder. They can be arranged circumferentially or longitudinally. Force-fed air can be used with a fan and shroud to accomplish effective cooling with large volumes of air, or natural air flow can be achieved with well-designed and angled fins. The capacity of fins to dissipate heat is determined by their cross-section & length. The temperature stays highest at the fins base, dropping through their lengths to the lowest at the tips. Fins are best suited for enhancing the heat transfer rate in an air cooling system [3]. Fins are long, flat surfaces. These are used to round the cylinder or cylinder head. Fins are often categorised as follows:

(1) Longitudinal Fins: These fins run the length of the body.
(2) Circumferential Fins: These are discs that wrap around the tubes.
(3) Triangular Fins: Pin fins are formed in the shape of cylindrical rods with a small diameter.

The capacity of fins to dissipate heat is determined by their cross section and length. The temperature of the fin drops from its root to its tip as heat is gradually removed from the fin surface. As a result, the fin surface closer to the tip dissipates heat more slowly and is less efficient. The thickness of the fin, on the other hand, may be reduced as the quality of the heat flowing towards the tip steadily lowers. If the temperature decrease from the root to the tip is constant per unit length, the material of the fin is used most efficiently [5]. The rectangular cross section has the smallest temperature decrease, whereas the triangle cross section has the most. When the motorcycle runs, the engine cylinder's heat is transmitted to the engine fins, which store the heat and blast it into the atmosphere as the air passes over them. When determining and analysing the fin's heat transfer rate, the air velocity must be taken into account. Due to space limits, air-cooled engines are the only practical alternative for two-wheelers and other applications. Although the fins considerably boost heat transmission from the cylinder, the number of fins might still be increased significantly. Aside from that, the dimensions and shape of the fins play a significant effect in heat transfer rate.

Interactive design processes for internal combustion (IC) engines involve various stages and considerations to create efficient, reliable, and high-performance engines like:

- Conceptualization and requirements gathering, where the purpose and application of the engine are determined along with the required power output, efficiency, emissions targets, and other performance criteria.
- System Architecture and Engine Layout.
- Thermodynamic analysis and simulation to optimise compression ratio, combustion process, and efficiency; use of computational fluid dynamics (CFD) simulations to analyse airflow, combustion, and heat transfer.
- Optimised design of engine components.
- Material selection and manufacturing process.
- Emissions and Combustion Optimisation.
- Integration and assembly of engine components for ensuring proper alignment, clearances, and functionality of all parts.
- Prototype testing to validate design assumptions and optimise performance.
- Safety and reliability considerations.

Throughout these stages, the design process is highly interactive, with engineers and specialists collaborating and iterating to achieve the desired performance, efficiency, emissions, and reliability goals for the IC engine. Modern design tools, simulations, and testing methods play a crucial role in facilitating this interactive and iterative design process. The present work deals with numerical simulation of the engine, where thermal analysis and the CFD process have been piloted to study the behaviour of the engine running at different speed in actual conditions, which is an important and integral part of the interactive design process of an IC engine.

Distinguished researchers have investigated the behaviour of fins made of different materials, different shapes, and different thicknesses. Srinivas et al. [1] reported better heat transfer in rectangular fins with 2 mm thickness for engines. Also, they compared the performances of both Al and Mg Alloys and reported the superiority of both materials. Tiwari et al. [2] optimised the Cylinder Head Fins design using FEA and reported better heat transfer from the modified design using Cast Iron as a material. Using FEA, Rupesh et al. [3] shown that an annular fin made of Alusil material may improve heat transmission from the engine cylinder to the environment at a much quicker pace. According to Sonawane et al. [4], Aluminium Alloy 6061 outperformed Aluminium Alloy 204, with considerable gains in both heat transfer rate and power to weight ratio. Bhayana et al. [5]

reported the superiority of Magnesium Alloy ZC63A by 14.91% in terms of heat dissipation over Aluminium Alloy 6061 with a modified fin design of an engine. Subbiah et al. [6] reported AA6061 as the best material for fabrication of the fin due to its better thermal conductivity as compared to Magnesium Alloy AZ31. Varma and Gautam [7] presented numerous results in the realm of heat transfer, employing fins for various applications in order to get the highest heat transfer rate. Kore and Pappula [8] projected the behaviour of finned tube evaporators using R134a and R407C on all fin shape designs, as well as Aluminium Alloy 7475 and copper, and reported higher material and refrigerant performance. Abdullah and Ali [9] analysed a 3P induction motor and designed a frame using the thermal network method and reported Aluminium as the superior material as compared to Cast Iron. Raja et al. [10] plasma coated 4-stroke IC engine fins with silicon carbide nanoparticles and reported improvement in heat transfer. It was also validated by the Finite Element Method. Using Ansys Fluent, Dasore et al. [11] investigated the thermal properties of rectangular and elliptical fins and discovered a 5% surge in heat transfer rate through the elliptical fin. Padmanabhan et al. [12] used MATLAB to perform numerical analysis on rectangular and triangular fins constructed of copper and Aluminium, and compared the consequences of the fin's temperature distribution at various spatial positions. Abbood et al. [13] investigated heat transfer on a modified Aluminium Alloy cylinder for a motorbike engine with addition of various shapes of fins and found that the square fin was the most excellent material. Aluminium Alloy 6061 with a circular shape and 1.5 mm thickness was described by Kumar et al. [14] as the best combination for creating engine fins between Grey Cast Iron and Magnesium Alloy AZ31B due to superior heat dissipation among all. Lisowski and Lisowski [15] investigated the number and length of fins in Aluminium finned tubes of LNG ambient air vaporizers and discovered that the fin count and length had a significant influence on the quantity of heat transmitted via fins. Real-Ramirez et al. [16] compared the results of CFD analysis of finned tubes using OpenFOAM, SALOME Meca and Fluent and reported open-source platforms' superiority for easy investigation of airflow around fin surfaces. Patil and Shetty [17] reported a wavy-design fin with 3 mm thickness that dissipated a greater amount of heat and Aluminium Alloy A319 as a material for cylinder fins. Prasad et al. [18] used Cast Iron for investigating the heat-transfer engine fins and reported enhanced heat transfer by increasing the slots and fin pitch. Senthilkumar et al. [19] reported triangle fins as the most superior among rectangular and elliptical fins for better heat transfer from small displacement engines. Padmanabhan et al. [20] reported that rectangular fin geometry has a higher heat transfer rate compared to triangular fins while conducting numerical analysis of an IC engine with Aluminium material. Their results were also validated with CFD analysis. Shareef et al. [21] reported that Al6082-made IC engine angular fins provided better heat transfer as compared to other materials and designs. Charan et al. [22] reported that a triangular perforated Aluminium fin provided better heat transfer as compared to other fin designs. Rinawa et al. [23] reported that AA319 round dimple fins provided better heat transfer as compared to standard and step fin designs. Akhtar et al. [24] found that heat transfer increases when circular holes are increased in rectangular fins made of Aluminium Alloy. Risal et al. [25] optimised annular fin arrangement and design using GA and reported enhanced heat transfer rate. A similar kind of result was also reported by Varghese et al. [26] using the NSGA II method. Sachar et al. [27] stated that fin design and count play a crucial role in heat transfer, and Aluminium alloy is the most suitable material for fins. Alam et al. [28] reported that Berylium oxide fins provided better heat flux as compared to Aluminium alloy for 125 cc engines. Agarwal and Letsatsi [29] investigated the heat transfer in engine fins and reported some useful modifications in fin design for better heat dissipation.

Sahoo et al. [30] reported that the heat transfer rate in the 100-cc engine fin can be increased with proper design modifications in the fin geometry and a lower pitch.

Thiagarajan et al. [31] found that Titanium alloy provided better heat transfer as compared Magnesium alloy and Cast Iron when fin thickness was reduced to 0.5 mm.

According to Angamuthu et al. [32], cast iron fins with a 2.5 mm groove and a hole diameter of 4 mm generated a higher heat transfer rate than different materials and designs. Sharma et al. [33] found that an angular fin made of AlC443 performs better with more significant heat transfer as compared to other fin designs and Aluminium alloy.

Karthick et al. [34] found that Titanium alloy can be an alternative material for truck radiator fins made of aluminium alloy or copper since it has better heat transfer and is lighter. Mohankumar et al. [35] reported that the AA6061 fin can perform better when the fin design can be optimised and weight is reduced. Madani et al. [36] investigated the underwater FSW of the AA2217 butt joint both experimentally and in FEA. They optimized the welding parameters using the Taguchi technique and reported that welding velocity is the most influential factor for achieving greater tensile strength. Boukraa et al. [37] conducted transient thermal analysis of FSW-welded AA2195-T8 plates to study the thermal cycle and the temperature distribution of the nugget zone. They reported a decrease in HAZ after using optimal parameters [38]. Dissolution time and HAZ temperature were significantly reduced [39] after using Taguchi-Grey

Relational Analysis, where axial force was found to be the most influential parameter [40].

For any research work to be academically contributing, it is necessary to find out the literature gap from the previous work, address it correctly, and suggest some future scope that is not addressed by any investigator. Much research has been carried out on the heat transfer of the air-cooled engine. The majority of the work has been done on small displacement engines with displacements ranging from 50 cc to 150 cc. No research work has been reported on two-wheeler engines above 150 cc. Since lightweight engines are being used nowadays, lighter materials need to be harnessed more. Very little work on Aluminium Alloy 6061, Magnesium Alloy and their comparative evaluation with Cast Iron has been reported. Majority of previous work has been carried out on fin shape and design rather than its thickness and count. In addition, most of the researchers have conducted thermal analysis on their designed fin. Less attention has been given to the CFD analysis of the engine fins and the heat transfer investigation of the combination of the engine block and head. These concerns have been addressed in this study with a bigger volume engine with 373 cc (which also falls under the small displacement category since it is used in two-wheelers) for the present work. The engine specification is equivalent to the DOMINOR 400 (Make: Bajaj Auto Ltd., India) which is popular street legal motorcycle. Regardless of the material utilised in engine construction, such engines are often supplied with liquid cooling systems. However, they have several significant drawbacks, including the fact that they are expensive, the installation of such systems is quite difficult, and they require periodic maintenance to avoid failure. As a result, a simple solution to such a problem is to replace conventional engine materials with any other alternative material with a higher heat dissipation rate, which not only eliminates the use of liquid cooling systems in such engines but also reduces the cost and weight of the engine. To address all of these difficulties, Aluminium alloy and Magnesium alloy have the potential to be breakthrough materials that can easily replace the old Cast Iron.

In this investigation, the design modelling of the engine body has been carried out in SOLIDWORKS 3D CAD platform with different fin thicknesses. In the first phase, computational fluid dynamics (CFD) analysis of the engine body has been done using SOLIDWORKS Flow Simulation. Airstream passing over the engine body has been studied at variable speeds. Thermal analysis of the engine body was carried out by varying the vehicle speed, fin thickness, and materials. Properties like temperature on the fin, temperature on the engine head, and heat loss from the engine were analysed for different vehicle speeds, fin thickness, and materials. Lastly, the results obtained by using those boundary conditions were compared with previous research and reported.

2 Experimental methodology

Fins are used to boost the rate of thermal dissipation from or to the surrounding by increasing convection. The rate at which heat is transmitted is determined by the total of the effects of convection, conduction, and radiation on an item. It grows in proportion to the temperature differential between the surroundings and the item, increasing the convection coefficient of heat exchange or widening the surface region. However, increasing the area also increases the resistance to heat flow. As a result, the coefficient of heat transmission is dependent on the total area, which is smaller than the base. Fins of various shapes and sizes are used in engineering applications to maximise heat transfer rate. Different forms and designs of fins are employed in various settings.

Different materials and their qualities that may be employed for the specific project were extensively researched, and materials were chosen accordingly. The fins, their combinations, and geometries were designed in SOLIDWORKS 3D CAD. Fin characteristics (geometry, material, and thickness) were taken into consideration to measure the variation in the quantity of heat removed by different model of fin and the temperature of the fins and cylinder head.

2.1 Material for engine

The heat transmission rate is greatly influenced by the material qualities. To ensure maximal heat transmission in the engine block, numerous materials are considered. All of the material under examination is also readily available. For this investigation, three different materials are chosen i.e. Cast Iron, Aluminium Alloy (AA6061) and Magnesium Alloy (AZ31B). The mechanical properties of the material are shown in Table 1.

2.1.1 Cast iron

Cast iron (Table 1) is prominent owing to its affordability as well as its capacity to be cast into complicated shapes while still molten. It also has greater machining ease, compressive strength, vibration dampening, corrosion and wear resistance than cast steel. Minor elements such as chromium, silicon, molybdenum, nickel, and copper increase Cast Iron's corrosion resistance. Graphitic microstructures can be seen in Cast Iron. Cast Iron has a carbon content of 2.5 wt%-4.0 wt% and a silicon content of 1.0 wt%-3.0 wt%. Engine

Table 1 Material properties of Cast Iron, Aluminium Alloy and Magnesium Alloy [14]

	Cast Iron	Aluminium Alloy (AA6061)	Magnesium Alloy (AZ31B)
Density (kg/m^3)	7150	2700	1770
Young's modulus (GPa)	80	68.9	44.8
Poisson's ratio	0.25	0.33	0.35
Tensile strength (MPa)	100	310	260 MPa
Shear strength (MPa)	304	207	130 MPa
Hardness, Brinell (BHN)	200	95	49
thermal conductivity (W/mK)	40	167	96
thermal expansion co-efficient at 0-100 °C (μm/m°C)	11	23.2	26

cylinder blocks, manifolds, flywheels, disc brake rotors, gearbox cases, and cookware all benefit from its machinability, high thermal conductivity, vibration dampening, high rigidity along with high heat capacity [13].

2.1.2 Aluminium alloy (AA6061)

Aluminium Alloys are temperature sensitive. When exposed to high temperatures of around 200–250 °C, they tend to lose part of their strength. They are also resistant to corrosion. It is the most widely used and heat-treatable Alloy. In tougher T4 and T6 tempers, AA6061 Alloy (Table 1) offers high machinability. It is machineable to an annealed temper. It is readily produced and worked in the annealed state. Bending, stamping, deep drawing, and spinning operations are carried out using established procedures. AA6061 is used in the production of truck and marine components, pipelines, heavy-duty constructions, tank fittings, furniture, general structural and high-pressure applications, train carriages, and other similar products [14].

2.1.3 Magnesium alloy (AZ31B)

Magnesium Alloys are extremely light and simple to machine. They are frequently anodised to increase corrosion resistance. The ASTM and SAE systems are used to name them, with the first component indicating the two primary alloying elements in the Alloy and the second portion representing their percentages. It comes in a variety of shapes and sizes, including plate, sheet, and bar. Because of its excellent strength-to-weight ratio, it is an alternative to Aluminium Alloys. When compared to other Magnesium grades, it is more commonly accessible. AZ31B (Table 1) is easily machined. Because it is combustible, considerable caution should be exercised when carrying out this procedure. A lubricant is utilised throughout the machining process. A Magnesium fire arresting equipment is essential for the machinist to continually watch the process. It is possible to shape it by preheating it at 260 °C. Metal arc and gas tungsten arc welding procedures can be used to join it. AZ31B is mostly utilised in aircraft and broad commercial applications [14].

Table 2 Engine specification

Max Torque	35 Nm @ 6,500 rpm
Emission Standard	Bharat Stage-VI / Euro VI
Max Power	39.42 bhp @ 8,800 rpm
Compression Ratio	12:1
Bore	89 mm
Displacement	373 cc
Stroke	60 mm
Cylinders	1
Valves Per Cylinder	4
Valve timing• • •	Intake opens 20° Before Top Dead Centre Intake closes 40° After Bottom Dead Centre Exhaust opens 50° Before Bottom Dead Centre Exhaust closes 15° After Top Dead Centre
Fuel System	Throttle Body Injection

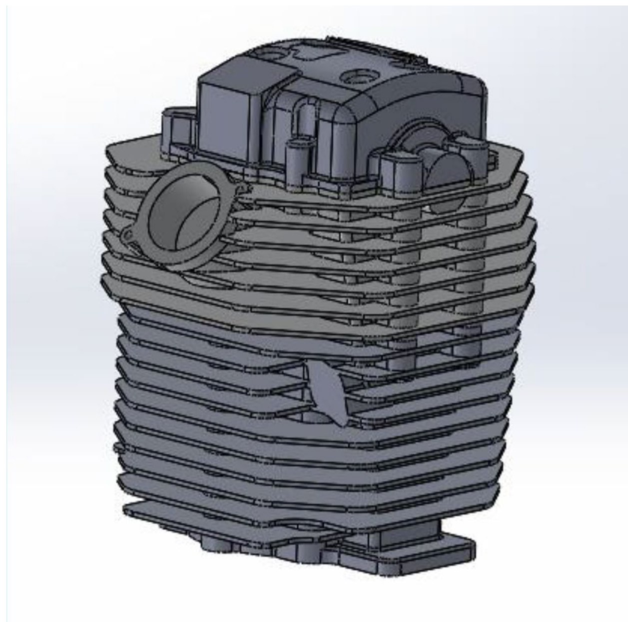

Fig. 3 CAD model of engine

2.2 CAD modelling

A 373 cc single-cylinder twin-spark ignition engine (Table 2) is modelled using SOLIDWORKS 3D CAD. A total of 17 fins were designed for the cylinder body. The fin thickness was taken as 2 mm, 3 mm, 4 mm, and 5 mm, along with a fin pitch of 10 mm. A longitudinal or rectangular-type fin has been designed on the cylinder body. Table 2 shows the engine specification. Figure 3 shows the CAD model of the engine body.

2.3 Governing equations

Steady-state heat conduction equations, temperature-independent material characteristics, fin thickness minimal in comparison to fin length, homogeneous cross-sectional area, and so on. While calculating the heat flow from the fins, the following assumptions were taken. It was supposed that convection had occurred at the ends of longitudinal fins, and that the ends of circular fins were entirely insulated. The governing equation used to compute the heat flow extracted by longitudinal fins was based on Fourier's law steady-state heat conduction equation, i.e. [13]

$$q = \frac{\left(tanh\,tanh\,ml + \frac{h}{mk}\right)}{1 + \left(\frac{h}{mk}\right) tanh\,tanh\,ml} \tag{1}$$

$$m = \sqrt{\left(\frac{hP}{KA}\right)} \tag{2}$$

The temperature fluctuation along the fin's length may be computed as follows [14]:

$$\theta = \theta^{\circ} \frac{cosh\,cosh\,m\,(l-x) + \left(\frac{h}{mk}\right) sinh\,sinh\,m\,(l-x)}{cosh\,cosh\,ml + \left(\frac{h}{mk}\right) sinh\,sinh\,ml} \tag{3}$$

The modified Bessel's equation was used for computing the amount of heat loss haul out by fins [14]:

$$Q = KAm\theta^{\circ} \frac{h\cosh(ml) + k\,sinh\,(ml)}{mk\cos\text{h}\,(ml) + h\,sinh\,(ml)} \tag{4}$$

When the entire fin is at base temperature, the maximum heat transferred by fin is [13]:

$$Q_{max} = h\,(Pl)\,\theta^{\circ} \tag{5}$$

2.4 Boundary conditions

Based on the previous studies conducted by the previous researchers, boundary conditions were chosen. The longitudinal/rectangular fin geometry was analysed using SOLIDWORKS Flow Simulation, a CFD platform. The SOLIDWORKS 3D CAD model was used to create the CAD model, which was then imported into Flow Simulation for heat analysis. The fin and cylinder surfaces were combined and designed as a single part for better investigation. The velocity at which the wind flows through the engine is varied and analyzed. The velocity is taken to be 20kmph, 40kph, 60kmph and 80kmph respectively. Three materials for engine fins are Cast Iron, AA6061 and AZ31B. The inner surface of the engine cylinder is 473 °K hot. The convective region of the model is represented by the fin area in the geometry. The temperature outside is 35 degrees Celsius. Convection is the only heat transfer mode used [14].

3 Results and discussion

Figures 4, 5 and 6, and 7 show an isometric view of an engine cylinder using coloured path lines, which depict the flow characteristics happening at different speeds. To

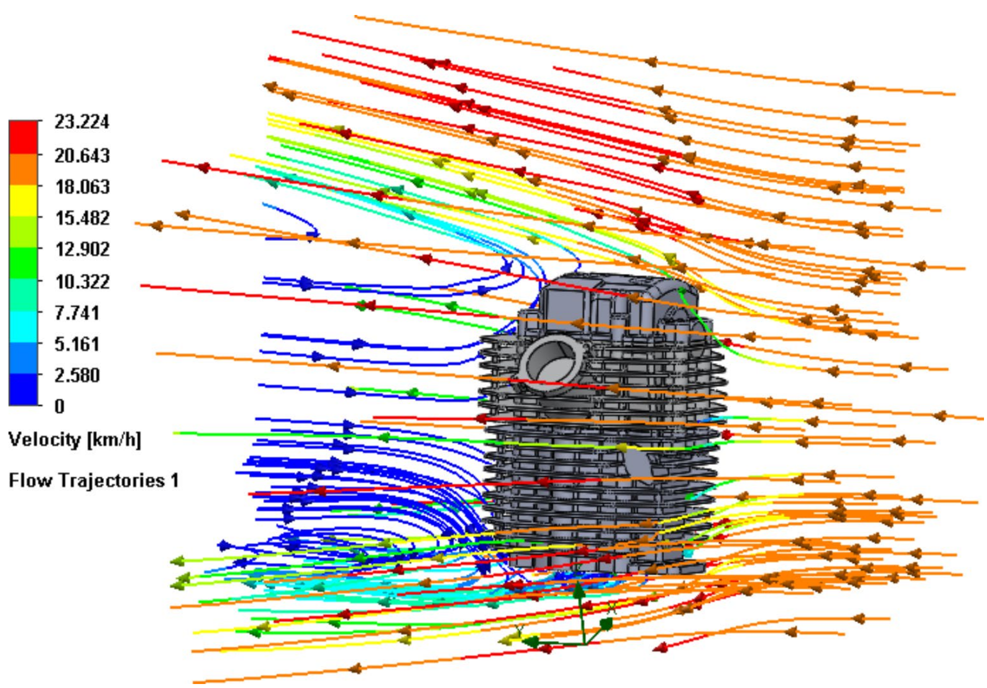

Fig. 4 Flow trajectories of the air stream passing over the cylinder at 20 km/h vehicle speed

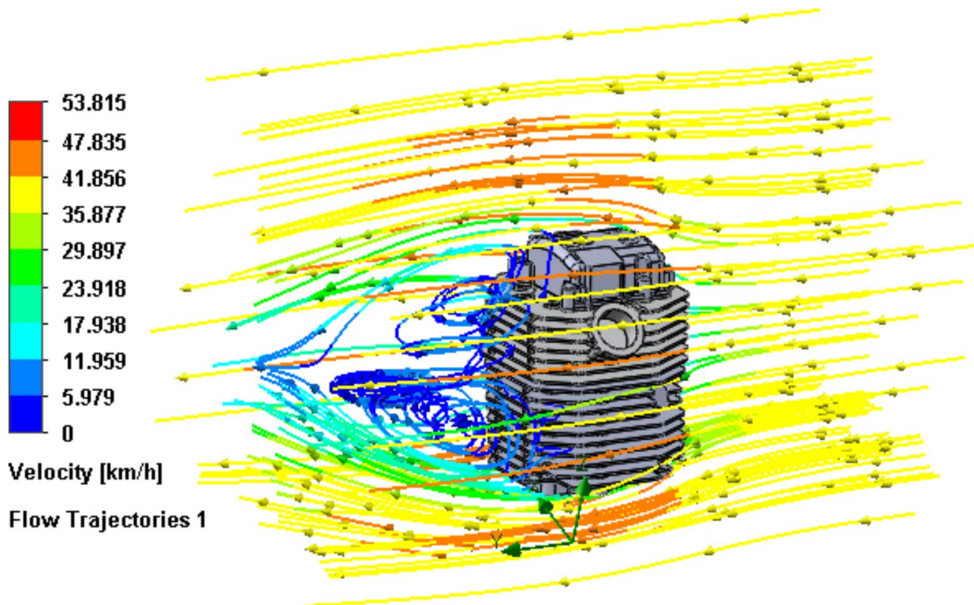

Fig. 5 Flow trajectories of the air stream passing over the cylinder at 40 km/h vehicle speed

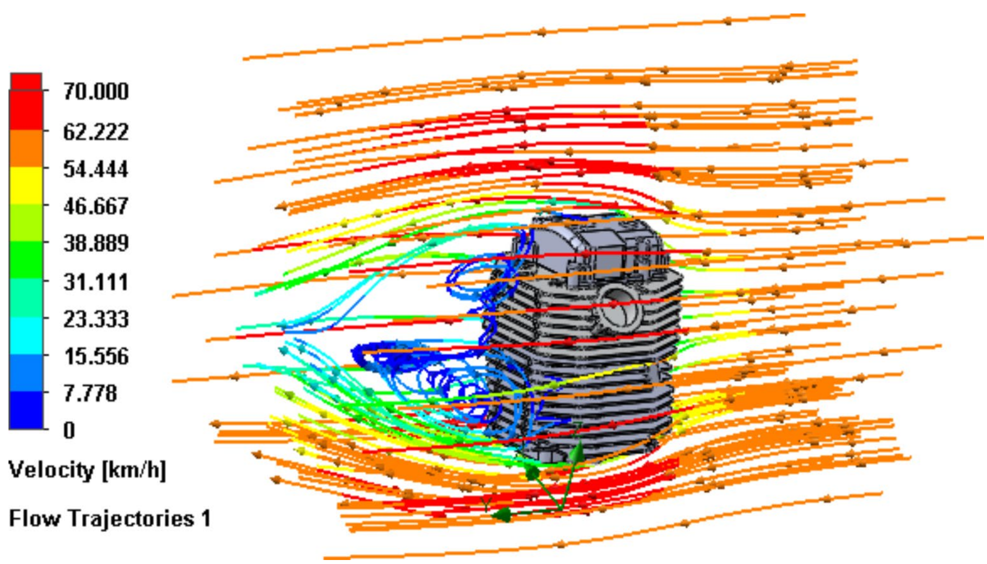

Fig. 6 Flow trajectories of the air stream passing over the cylinder at 60 km/h vehicle speed

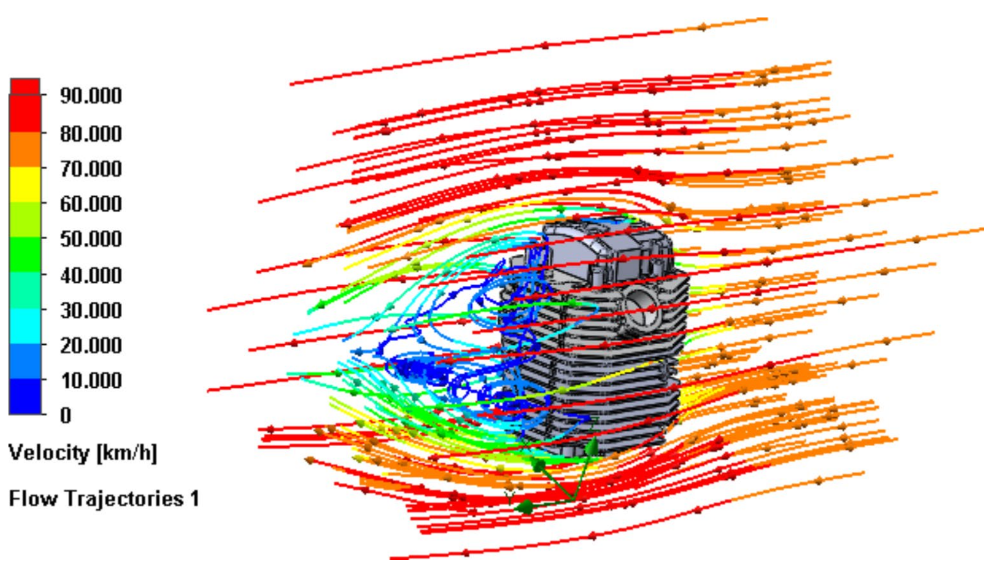

Fig. 7 Flow trajectories of the air stream passing over the cylinder at 80 km/h vehicle speed

contrast with the shades of the lines and increase visibility of the details, the finned cylinder was tinted grey. Lines were utilised to depict the association among air flowing and the engine at the outermost portion of the fins, as well as the flow behaviour. Several lines flow across the finned arrangement at the geometry's middle, while others were deflected. The flow then generates eddies of varying magnitudes towards the backside of the finned block. The fin surfaces are coloured by the magnitude of the velocity of the flow, which leads to a non-uniform circulation alongside the surface. Similarly, the colour variations on the cylinder and fin indicate sites where the flow separates from the fin surface. The airflow passes in, interacts with the finned cylinder block, and produces turbulence at the rear, followed by a change in direction of the stream flowing, which produces oscillations that are detected throughout the simulations. The main reason behind this is the fin angle and the vertical cylinder walls.

The finned cylinder block is followed by a turbulent wake, which constantly changes due to the turbulence that surrounds the fins. A symmetric flow pattern was identified from this perspective. The flow passes around the finned cylinder, forming the wake with lateral flow streams, with an approximately larger flow velocity magnitude. Horseshoe vortices were also observed, where the airflows in the swirling motion advance in the wake. As the finned cylinder block is placed vertically, the flow stream passes between the channel of fins and splits into different lateral streams. The flow swirls and produces the high-velocity separator, causing an increased localised zone of turbulence. The unsteady vortices formation leads to the high-velocity separator at the front side of the cylinder. Stream-wise streaks and turbulent structures are also developed due to the interaction of streams behind the cylinder block, which pass between fins at the end of the control volume. Real-Ramirez et al. [16] reported similar phenomena in which airflow was visualised, identified the horseshoe vortex system formed around the finned cylinder that separated from the fins edge, and corroborated the symmetry of flow behaviour over the fin surfaces as well as the flow patterns at the wake.

Table 3 Temperature on fins for different materials with various thicknesses at different vehicle speeds

Vehicle Speed in kmph	Fins Thickness in mm	Temperature on Fins in °C		
		Cast Iron	Aluminium Alloy (AA 6061)	Magnesium Alloy (AZ31B)
20	2	154.76	165.91	163.7
	3	161.24	173.01	170.96
	4	163.86	174.56	172.46
	5	166.01	174.87	172.86
40	2	149.91	161.06	158.85
	3	156.39	168.16	166.11
	4	159.01	169.71	167.61
	5	161.16	170.02	168.01
60	2	146.25	157.4	155.19
	3	147.07	158.84	156.79
	4	149.99	160.39	158.29
	5	152.04	160.7	158.69
80	2	131.66	142.81	140.6
	3	132.48	144.25	142.2
	4	135.4	145.8	143.7
	5	137.45	146.11	144.1

The air from the cylinder head flows downward; meanwhile, the air from the downward portion of the cylinder block tends to move upward. This leads to turbulence, which occupies the volume remaining at the back side of the cylinder block. The illustrations also show how the horseshoe vortex breaks from the fin surface edge and how its shape is preserved as it moves through the air stream. As the velocity of the vehicle increases, the vortex concentration also increases. The different velocity distributions on each fin can help in comparing the hydrodynamics in the respective channel. It is worth noting that during numerical modelling, to prevent the turbulence fin channel's edges present in the first and last of the array, the fin and cylinder surfaces were combined, which usually does not happen when any experiments are piloted in a wind tunnel.

Flow simulation Analysis is done by taking the thickness of the fin (2 mm, 3 mm, 4 mm, and 5 mm). The materials considered for the engine cylinder are Cast Iron, Aluminium Alloy (AA6061), and Magnesium Alloy (AZ31B). The vehicle velocity is considered to be 20 km/h, 40 km/h, 60 km/h, and 80 km/h. The fin pitch is 10 mm among the 17 numbers of fins on the engine cylinder. Finally, maximum temperatures on the fins, and the cylinder head, along with the heat loss from the cylinder, were recorded for different materials, with different fin sizes, and running at different vehicle speeds.

Table 3 represent the temperature on fins with respect to the vehicle speed for different materials with fin thicknesses of 2 mm, 3 mm, 4 mm, and 5 mm, respectively. It can be seen in each plot that all three materials (Cast Iron, Aluminium Alloy and Magnesium Alloy) behave in similar manners. As the speed of the vehicle gradually increases, so does the temperature on the fins, which also decreases progressively. Interestingly, the temperature of the fins for all materials is initially higher than 160 ^{O}C in the majority of cases of fin thickness. It drops drastically beyond 140 ^{O}C for all materials and all thicknesses, which is required for optimal cooling of the engine cylinder and thus maintaining the thermal efficiency of the engine. Fin thicknesses of 5 mm displayed better results as compared to other fin thicknesses. It can also be observed that both Aluminium Alloy and Magnesium Alloy behave similarly, as the temperatures recorded were equivalent and higher as compared to Cast

Iron. Kumar et al. [14] reported similar results where the temperature of the Magnesium Alloy fin is very near that of the Aluminium Alloy fin and higher as compared to cast iron.

Table 4 represent the temperature on engine head with respect to the vehicle speed for different materials with fin thicknesses of 2 mm, 3 mm, 4 mm, and 5 mm, respectively. It can be seen that all three materials (Cast Iron, Aluminium Alloy and Magnesium Alloy) behave abnormally for a fin thickness of 2 mm. This is due to the large difference in the thermal conductivity of the respective materials. As the thickness increases, this problem is solved, and the behaviour of the material gets uniform at larger fin thicknesses. In Table 4, the engine head temperature for Cast Iron is near 140 ^{O}C, which drops drastically beyond 120 ^{O}C as the vehicle speed increases. While the temperature for Aluminium Alloy and Magnesium Alloy is nearly equivalent and above 150 ^{O}C at low speed, it drops beyond 130 ^{O}C as the speed of the vehicle increases. Fin thicknesses of 5 mm displayed better results as compared to other fin thicknesses. It can be stated that the engine head doesn’t have any fins on its body, and it gets cooled either by the lubricant used in the engine or by the atmospheric air drafted towards the head’s outer body while the vehicle is moving. Overall, the temperature on the engine head of Aluminium Alloy materials remains high as compared to Cast Iron and Magnesium Alloy. Subbiah et al. [6] and Kumar et al. [14] also reported similar results, where they reported that Aluminium Alloy 6061 fetched the highest temperature followed by Magnesium Alloy as compared to Cast Iron engine.

Table 5 represent the heat loss from the engine cylinder with respect to the vehicle speed for different materials with fin thicknesses of 2 mm, 3 mm, 4 mm, and 5 mm, respectively. In all, the Table 5 indicate that the heat loss in the Cast Iron engine is nearly 1500 W at lower speeds and gradually increases above 3500 W as the vehicle speed increases. But, in the case of Aluminium Alloy and Magnesium Alloy, heat loss is nearly equal, i.e., heat loss is nearly 2500 W at lower speeds and gradually increases above 4000 W. Fin thicknesses of 5 mm displayed superior outcomes as compared to other fin thicknesses. It can be concluded that the percentage of heat loss is higher in both Aluminium Alloy and Magnesium Alloy as compared to Cast Iron. At a constant heat flux, the rate of heat transfer rises, and the temperatures of the cylinder and fins decline even more. It is interesting to notice that the thermal conductivity of Aluminium Alloy is four times that of cast iron and twice that of Magnesium Alloy. In spite of this quality, both Aluminium Alloy and Magnesium Alloy can warm up quickly, retain an ample amount of heat energy for engine operation, and cool quickly as compared to Cast Iron during high-speed operation. Cast Iron engines are more bulky as compared to Aluminium Alloy and Magnesium Alloy. In addition, the strengths of Aluminium Alloy and Magnesium Alloy are equivalent to Cast Iron, which makes them more suitable materials for high-speed engines with small displacement. Srinivas et al. [1], Subbiah et al. [6], and Kumar et al. [14] also reported that the cooling rate of Aluminium Alloy was higher than Magnesium Alloy along with better corrosive strength and a lower weight.

Table 4 Temperature on engine head for different materials with various thicknesses at different vehicle speeds

Vehicle Speed in kmph	Fins Thickness in mm	Temperature on engine head in °C		
		Cast Iron	Aluminium Alloy (AA 6061)	Magnesium Alloy (AZ31B)
20	2	138.99	143.75	142.11
	3	140.47	156.12	150.91
	4	142.19	157.11	155.17
	5	145.88	157.85	155.85
40	2	130.1	140.23	139.77
	3	131.29	148.35	145.77
	4	133.8	149.88	147.26
	5	135.7	151.14	148.11
60	2	115.4	134.93	131.17
	3	118.93	137.55	134.11
	4	121.88	140.11	137.21
	5	126.1	141.28	137.55
80	2	110.1	126.1	125.79
	3	113.1	127.88	125.99
	4	115.1	128.11	126.25
	5	118.57	129.91	127.05

Table 5 Heat loss from engine cylinder different materials with various thicknesses at different vehicle speeds

Vehicle Speed in kmph	Fins Thickness in mm	Heat loss in W		
		Cast Iron	Aluminium Alloy (AA 6061)	Magnesium Alloy (AZ31B)
20	2	1635	2388	2383
	3	1759	2512	2508
	4	1783	2537	2533
	5	1807	2564	2556
40	2	2560	3313	3308
	3	2684	3437	3433
	4	2708	3462	3458
	5	2732	3489	3481
60	2	2918	3671	3666
	3	3167	3795	3791
	4	3191	3820	3816
	5	3215	3847	3839
80	2	3315	4068	4063
	3	3525	4192	4188
	4	3549	4217	4213
	5	3573	4244	4236

When the numerical simulation undertaken in this research is compared to earlier work, the convergence of the findings produced is in good accord. Srinivas et al. [1] stated Aluminium Alloy with rectangular fins as the best combination for heat transfer in place of Magnesium Alloy due to its corrosive resistant nature and light weight. Sonawane et al. [4] reported Aluminium Alloy 6061 made cylinder fins' performance was much better as compared to Aluminium Alloy 204 as it provided better heat transfer in addition to power to weight ratio. The analysis was done in Ansys in steady state environment. Subbiah et al. [6] also reported AA6061 as the most suitable material among Cast Iron and Magnesium Alloy AZ31 for cylinder fin due to its better heat transfer and light weight. This analysis was also done in Ansys in steady state environment. Abbood et al. [12] conducted CFD analysis on cylinder fin using Fluent platform and obtained best performance in heat transfer Aluminium Alloy cylinder fin with square shape and 5 mm thickness. Kumar et al. [13] performed steady state thermal analysis on engine cylinder fin and reported Aluminium Alloy 6061 with fin geometry as circular and 1.5 mm thickness as the best due to its better heat dissipation among other material (Grey Cast Iron and Magnesium Alloy AZ31B), longitudinal geometry and fin thickness (2.5 and 3 mm). Patil and Shetty [16] performed steady state thermal analysis on engine cylinder fin and reported Aluminium Alloy (A319) with step design fin geometry and 3 mm thickness as the best due to its better heat dissipation.

All the stated work has been done fin mainly reported Aluminium Alloy as the better material due to its ability to dissipate heat in a better manner. Majority of the researcher also stated that rectangular/longitudinal shaped fins are more suitable for engine Cylinder. This work is also done using CFD package provided a better interaction of atmospheric air stream with the engine fins. It also helped in investigating the heat loss and temperature of the fin and engine head clearly.

4 Conclusion

In this research, the heat transfer rate of air-cooled IC engines on a motorcycle was investigated. Engine displacement of 373 cc has been taken into consideration. Design modelling of the engine body has been carried out in the SOLIDWORKS 3D CAD platform with different fin thicknesses, and CFD analysis of the engine body has been done using SOLIDWORKS Flow Simulation. Airstream passing over the engine body has been studied at variable speeds. Thermal analysis of the engine body was carried out by varying the vehicle speed, fin thickness and materials. From the above studies, it can be concluded that the material of the fins and the thickness of the fins play an important role in heat transfer from the engine cylinder, thereby resulting in the cooling of the engine. The summary of the study is as follows:

(1) The change in thickness of the fins altered the heat transfer rate. As thickness increases, the heat loss from the cylinder also increases, thereby resulting in faster cooling of the engines. From the study, it was found that by taking the fin thickness as 5 mm, the value of heat transfer is high as compared to others.
(2) It was noted that all the three materials (Cast Iron, Aluminium Alloy and Magnesium Alloy) behave in a similar manner, i.e., when the speed of the vehicle gradually increases, the temperature on the fins also decreases progressively for all three materials. It can also be observed that both Aluminium Alloy and Magnesium Alloy behave similarly, as the temperatures recorded were equivalent and higher as compared to Cast Iron.
(3) Temperature on engine head with respect to the vehicle speed for Aluminium Alloy was higher as compared to Cast Iron and Magnesium Alloy.
(4) The percentage of heat loss is higher in both Aluminium Alloy and Magnesium Alloy as compared to Cast Iron. At a steady heat flux, the rate of heat transfer rises while the temperatures of the cylinder and fins drop.
(5) As the thermal conductivity of Aluminium Alloy is four times that of cast iron and twice that of Magnesium Alloy, both Aluminium Alloy and Magnesium Alloy can warm up quickly, retain an ample amount of heat energy for engine operation, and cool quickly as compared to Cast Iron during high-speed operation.
(6) In all cases, fins with a thickness of 5 mm performed better with Aluminium Alloy as their material as compared to other fin thicknesses and materials.

Cast Iron engines are more bulky as compared to Aluminium Alloy and Magnesium Alloy. In addition, the strength of Aluminium Alloy and Magnesium Alloy are equivalent to Cast Iron which makes them more suitable materials for high-speed small displacement engines. Hence, the results obtained can be used to design a better engine that can compete with liquid-cooled engines, help in cutting costs, and avoid any unwanted failures that an engine equipped with a liquid cooling system can face while running. The study opens up a vast area of research that can be conducted on the geometry of the fins to enhance their heat dissipation rate. Combinations of various suitable parameters can also be introduced to attain maximum efficiency of heat transfer in cylinder fins. Studies based on different alloy compositions of either Aluminium or Magnesium can be conducted since they show better heat transfer. A comparative thermal analysis based on different platforms and experiments can also be piloted, which can provide truthfulness in the numerical modelling. Apart from that, to get more convergent results, physical experiments can also be performed in the wind tunnel to investigate the performance of the fins.

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Declarations

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