INVESTIGATION ON ENGINE PERFORMANCE TEST ON COMPRESSION IGNITION ENGINE WITH HYBRID METAL MATRIX COMPOSITE PISTON

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The increase in demand and introduction of stringent emission regulations resulted in the need to develop and implement innovative technologies towards improving the emission and performance characteristics of compression ignition engines. A hybrid metal matrix composite piston (HMMC) of Al7075 reinforced with 6% of 100 μm Silicon Carbide (SiC) and 4% of 100 μm Aluminium oxide (Al_2O_3) was fabricated. The HMMC piston was mounted on a compression ignition (CI) four stroke single-cylinder constant speed engine and the test was carried out with eddy current dynamometer attached with computerized data acquisition system. This paper is focused on the study of performance of Al7075-SiC-Alumina composite piston for compression ignition engine application. Experimental investigations were performed at injection pressure of 200 and 220 bar on both standard piston and HMMC piston and analysed the performance, combustion and emission behaviour of CI engine. From the results it was found that the HMMC piston exhibits an improved efficiency and thereby improving the lifetime of the engine. Though a little compromise in performance and emissions has been accepted, the implementation of HMMC pistons will reduce the carbon foot print of running an internal combustion engine.

Keywords: Al7075 (SiC, Al_2O_3), HMMC Piston, CI Engine, Performance, Emission.

1. Introduction

The rapid growth of energy demands and energy usage of the industrial world has pushed researchers to invent various methods to improve the performance of existing energy conversion systems available [1-2]. Of the world's energy demand, fossil fuels support around 80 percent, among which diesel, distilled and separated from crude oil plays a major role in providing transportation, heat and electricity, along with nursing processes that produces enormous product range from plastics to steel [3-4]. Day to day researchers are developing performance improvement methods to implement in compression ignition engines for increasing energy conversion ratio as well as the efficiency of compression ignition engines [5].

Emission standards are being set and continuously revised by all governments in order to control the total emission associated with internal combustion engines considering environmental safety. Implementation of these standards resulted in the development of various active and passive methods to decrease the emission for improving the IC engine efficiency including compression ignition engines [6-7]. Narciso et al. [8]. Investigated the thermal and flexural strength of graphite particle reinforced in Al-12wt%Si towards suitable for usage in compression ignition engines and concluded that Griffith criterion was the reason behind the strength of composites when size of defect is acknowledged with particulate diameter. Also, they suggested that the strength of the composite increases drastically with infiltration pressure. Yesilyurt [9]. Has studied the influence of injection pressure of fuel on the emission and performance measures of waste cooking oil-based bio-diesel blends on the diesel engine. Experiments were performed at different injection pressures of fuel (170–220 bars) and at various speed of engine (1000–3000 rpm) at peak load conditions to identify the ideal pressure that produces better results for different fuel blends. From experimental results, the author has concluded that the increasing the pressure of injection increases the torque of the engine, brake thermal efficiency and brake power until 210 bar.

Piston present in an internal combustion engine are more frequently replaced since they are continuously subjected to thermal and mechanical load conditions during engine operations. There is a high demand in development of new piston materials that can provide increased lifetime for internal combustion engines, thereby reducing the operating cost and also with reduced carbon footprint.

In this present study, a hybrid metal matrix composite piston is fabricated with Al7075 aluminium alloy as base metal, mixed with 6% of 100 µm Silicon Carbide and 4% of 100 µm Aluminium oxide based on the authors previous work, using stir casting technique and machined in a CNC turning center to the desired shape of a piston. The piston is fitted in a vertically mounted constant speed single cylinder compression engine. Experiments are conducted at different pressures of fuel injection and the emission, combustion and performance were measured and evaluated.

2. Materials and Methods

2.1. HMMC piston fabrication

Table 1. Composition information of Al7075 Aluminium alloy

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Other, each	Other, total
Weight %	87.1 - 91.4	0.18 - 0.28	1.2 - 2	Max 0.5	2.1 - 2.9	Max 0.3	Max 0.4	Max 0.2	5.1 - 6.1	Max 0.05	Max 0.15

Table 2. Physical properties of Al 7075 Aluminium alloy

Physical Properties	Density g/cc	Hardness, Brinell (BHN)	Ultimate Tensile Strength	Tensile Yield Strength (Mpa)	Elongation at Break	Modulus of Elasticity (Gpa)	Modulus of Elasticity (Gpa)	Poisson's Ratio	Fatigue Strength (Mpa)	Shear Modulus (Gpa)	Shear Strength (Mpa)
Values (Metric)	2.81	150	572	503	11%	71.7	0.33	0.33	159	26.9	331

Alloys based on aluminium were extensile used for fabrication of various automotive and aerospace parts, due to their high formability, stiffness and specific strength [10-11]. Yet, both aluminium at its different alloys hold deprived resistance to wear, which directly affects the component's lifetime and performance especially in fatigue loaded components such as pistons, compressor blades etc., [12-13].

In this work, a composite material piston is fabricated into a piston with desirable physical and material properties like improved Poisson ratio, high temperature stability and higher coefficient of linear thermal expansion [14-15]. The composition information of aluminium alloy Al7075 is presented in Table 1 and its physical properties are displayed in Table 2.

The HMMC material is produced by following all standards in the foundry technique. The quality of the material produced is improved by proper selection of molten temperature, stirrer speed and preheating temperature of the reinforcement as standardized by ASTM standard. The raw Al7075 (90% by wt.) is initially heated and melted in an electric furnace heated to a temperature exactly 900^oC. A three-blade stainless steel stirrer connected with a variable speed electric motor is employed in the material making process to continuously stir the molten material and a steady vortex has been created by adjusting and gradually increasing the stirrer rotation speed. After obtaining stability in the vortex, 6% weight fraction of SiC and 4% weight fraction of Al_2O_3 reinforcement are added into the vortex of the melt and the stirring was continued involved in the rate of 600rpm for 15 minutes time maintain the temperature steadily at 850^oC.

The molten composite is brought to a temperature of 600^oC suitable for casting and then poured into a cylindrical casting mould in the shape of the piston as shown in Figure 1. The stirrer is employed for proper mixing of and settlement of melt inside the mould for 15 minutes time.

Figure 1. The cylindrical casting of the piston

The reinforcements of the mould are pre-heated prior to the addition of melt for proper and quality casting process. The casting process is completed in the greensand mould pattern and HMMC piston is obtained. The raw mould piston is further machined in CNC lathe and milling machine for proper dimensions to be used in the Kirloskar TV1 CI engine. The machined HMMC piston is further finished using buffing wheels and the dimensional homogeneity and symmetry of the piston are also checked. Various views of the fabricated HMMC piston is shown in Figure 2.

Figure 2. Fabricated HMMC piston

The amount of porosity present in the composite materials will lead to lower strength and other properties. Therefore, the evaluation of porosity in the fabricated composite materials is acts as the predominant role to achieve the required mechanical and thermal properties. In this work, the porosity of hybrid metal matrix composite piston has been evaluated by Archimedes' principle. The density of the hybrid metal matrix piston theoretically evaluated using the rule of mixtures. From the results, it is observed that the difference between theoretical and experimental densities of the hybrid metal matrix composite piston is negligible and porosity is very minimal.

2.2. Microstructural Examination

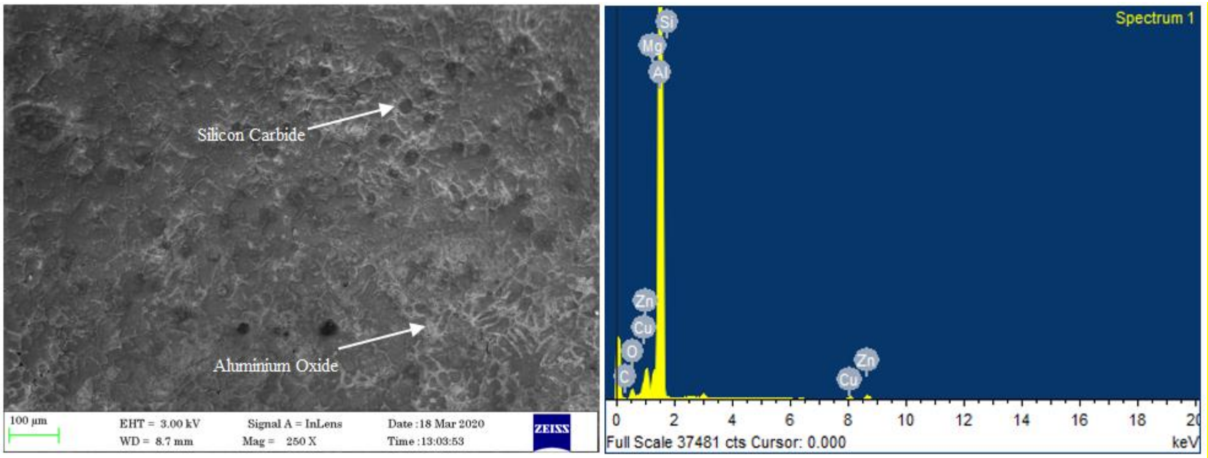


Figure 3. SEM image and EDX of hybrid composite

The SEM image of the hybrid composite is shown in Figure 3. The reinforcement particles were observed as, dark colored particles are Al_2O_3 and grey colored particles are SiC. With higher reinforcement of SiC particles in the matrix, higher amount of grey colored particles were observed and Al_2O_3 were observed less than the former. Fine grains were visualized with dentric structure. The EDX spectrum of the hybrid composite shows the presence of alloying elements such as aluminium, magnesium and silicon in major amounts and copper, zinc, carbon and oxygen atoms in smaller quantities, which confirms the alloying constituents of the hybrid composite.

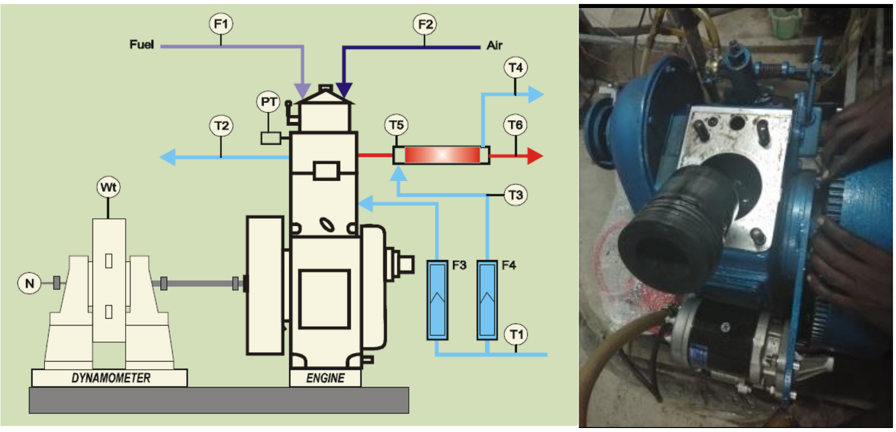
2.3. Engine experimental setup

The hybrid metal matrix composite material made piston is fitted in a single cylinder four-stroke constant speed CI engine fueled with diesel. The engine is attached with a dynamometer (eddy current) to apply the variable load at different operating conditions. Table 3 shows the detailed specification of engine used in the experimentation.

Table 3. Specifications of Engine used in this work

Specification	No. of Cylinders	Fuel Used	Model and Make	Engine Power	Cylinder Dimension	Compression Ratio	Mechanism of Loading	Crank angle sensor
Value	1	Diesel	TV1 - Kirloskar	5.2 kW at 1500 RPM	Stroke 110 mm; Bore 87.5 mm; Volume 661 cubic centimeter	17.5:1	Eddy current dynamometer; 0-50 kg range	1 Degree resolution; Speed 5500 RPM with TDC pulse.

A data acquisition system (computerized) was connected with the engine for measuring various performance and combustion related parameters like airflow rate, rate of fuel flow, rate of cooling water flow, angle of crank, in-cylinder pressure, in-cylinder temperature, exhaust gas temperature, inlet and outlet cooling water temperatures along with the speed and applied load on the engine [16 - 17]. The schematic view of the engine setup used in this experiment is shown in Figure 4. The implementation of HHMC piston will vary the thermal conductivity of the piston, which in turn will affect the amount of heat conducted through the piston. The surface property will alter the convective heat transfer coefficient between gases and piston surfaces which also will affect the engines performance, emission and combustion characteristics [18].



N – Engine speed, Wt – Load, F1– Fuel flow rate, F2 – Air flow rate, PT – Cylinder pressure, T1 – Inlet water temperature for cooling the engine, T2 – Temperature of engine cooling water at outlet, T3 – Temperature at calorimeter inlet water, T4 – Outlet water temperature of Calorimeter, T5 – Inlet exhaust gas temperature of Calorimeter, T6 – Outlet exhaust gas temperature of Calorimeter

Figure 4. Schematic illustration of engine setup

Experimental trials were performed on the engine for standard CI piston and the fabricated hybrid MMC piston and the results are compared at two different injection pressures, one at 200 bar and another at 220 bar and various performance and combustion parameters such as indicated power, brake power, frictional power, indicated mean effective pressure, brake mean effective pressure, indicated and brake thermal efficiency, specific fuel consumption, volumetric and mechanical efficiency, ratio of air-fuel mixture and heat balance were determined [19-20]. These results are compared with the results obtained from experiments with standard piston in the same engine which is also operated at 200 bar and 220 bar injection pressures. Also, the engine emissions like HC, CO_2, CO, O_2, HC, smoke opacity and NOx are also measured at different conditions of experiment using AVL Digas 444N gas analyzer and AVL 437C smoke measurement meter [21-22]. From the previous study, the injection pressure selected for this study is 200 and 220 bar. Now a day's diesel engine fuel injection systems are designed to obtain higher injection pressure. The objective of the design is to minimize exhaust emissions thereby increasing the efficiency of the engines. If the fuel injection pressure is low, the diameters of the fuel particle will enlarge, and the ignition delay period increases during the combustion. Therefore the injection pressure is maintained between 200-220 bar.

3. Results and Discussion

3.1. The effect of HMMC engine performance

Performance tests are conducted in compression engine with standard CI piston and the fabricated HMMC piston at 200 bar and 220 bar injection pressures. Results are acquired using data acquisition system connected with the engine and they are discussed in the upcoming section. Readings are recorded by altering the load on the engine using the dynamometer (eddy current) and different set of readings are identified as S200 (Standard piston operated an injection pressure of 200 bar), H200 (piston made of HMMC being operated at an injection pressure of 200 bar), S220 (Standard piston run at 220 bar) and H220 (piston made of HMMC run at 220 bar) are deliberated over combustion emission and performance point of view as follows.

3.1.1 Comparison of mean effective pressure

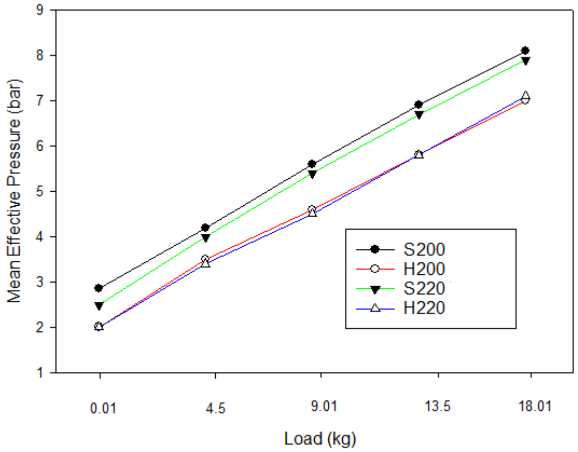


Figure 5. Comparison of mean effective pressure with Load

The change in mean effective pressure for varying load on the engine obtained for different pistons are shown in Figure 5. The mean effective pressure is measured as the values of average pressure that acts on the piston over the complete four strokes. It is inferred from results that, mean effective pressures of engine operated with the standard piston at injection pressures of 200 and 220 bar are higher irrespective of the loads compared with HMMC piston [23]. A minor reduction in mean effective pressure during HMMC piston usage and for maximum load condition, 13.8% reduction at fuel injection at 200 bar and 10.2% lower mean effective pressure at fuel injection at 220 bar. Various factors contribute to this pressure drop but the main reason is understood to be the frictional losses.

The fabricated HMMC piston has limitations in mechanical advantages due to the process followed in fabrication compared with perfectly fabricated original piston available in the engine. These losses can be effectively improved by adopting modern fabrication techniques in piston manufacturing.

3.1.2 Variation of indicated power

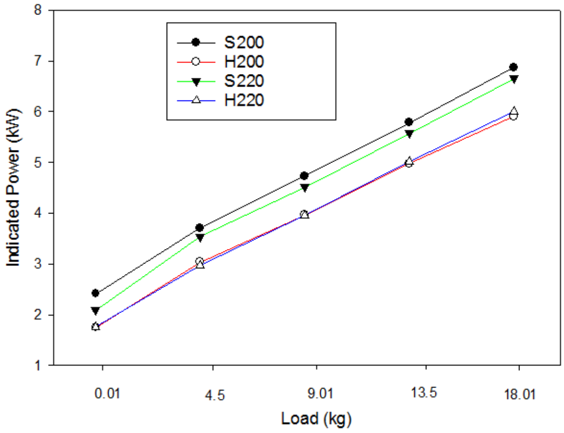


Figure 6. Variation of indicated power with load

Figure 6 presents the indicated power variation of engine at various load conditions operated with different piston and injection pressure combinations. The indicated power of the engine increases with load however, for any load the indicated power is low for the experiment conducted using HMMC piston. An engine indicated power is the product of mean effective pressure, stroke volume and engine speed. Even though different pistons are used, care has been taken to keep the stroke volume the same while using both the pistons.

The deviation in indicated power is mainly due to the loss in mean effective pressure as described earlier. Considering 13.5 kg load condition for HMMC piston engine operated at 200 bar pressure of fuel injection, a reduction of indicated power of 14% was attained against 9.9% reduction with 220 bar pressure of fuel injection when compared with standard piston operation [24].

3.1.3 Specific fuel consumption

A CI engine specific fuel consumption (SFC) is a measure of the fuel efficiency of the engine by comparing the power produced per kg of fuel that is burnt in combustion chamber. Figure 7compares the variation of SFC for different piston and fuel injection pressure experiments conducted with different engine load. A gradual reduction in SFC was obtained with increasing load conditions. Observation from results show that, during partial load operation, the specific fuel consumption is high around 8.5% for HMMC piston operated at 200 bar and around 15.7% for HMMC piston operated at 220 bars.

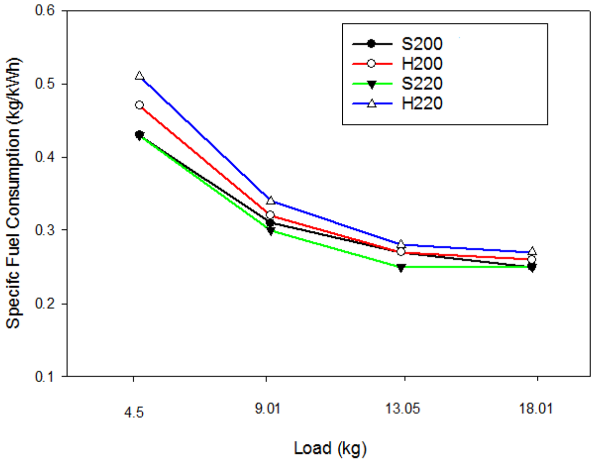


Figure 7. Specific fuel consumption with load

This is because piston friction dominates during low speed and low load operations. But during maximum load (18.01 kg), the specific fuel consumption for all four experiments remains close to each other, i.e., 0.25, 0.26, 0.25and 0.27 kg/kW.hr for S200, H200, S220 and H220 engine operations. The increase in specific fuel consumption is very little around 3.7% which is within the tolerance limit of the engine.

3.1.4 Variation of indicated thermal efficiency

Figure 8 presents the indicated thermal efficiency values of diesel engine operated with different pistons and different pressures of fuel injection at various conditions of load. An engine indicated thermal efficiency is the proportion of heat equivalent of indicated power considered per unit time to the supply of heat to engine in unit time [25]. From the results, the engine indicated thermal efficiency does not change much with variation in injection pressure.

At maximum load condition of 18.01 kg, the indicated thermal efficiencies of S200 and S220 are 46.19% and 44.78% (1.41% deviation) and for H200 and H220, the indicated thermal efficiencies are 38.19% and 37.4% (0.78% deviation). But when comparing the efficiencies of engines operated with a standard piston and HMMC piston, the efficiencies are 46.19% and 38.19% with an8% efficiency reduction, which is mostly because of decrease in indicated power due to friction available in the engine when using the HMMC piston. Although the efficiency loss in the no-load condition is 15.78% during no-load operation, the efficiency loss is reduced during full load operation to a minimum of only 8%.

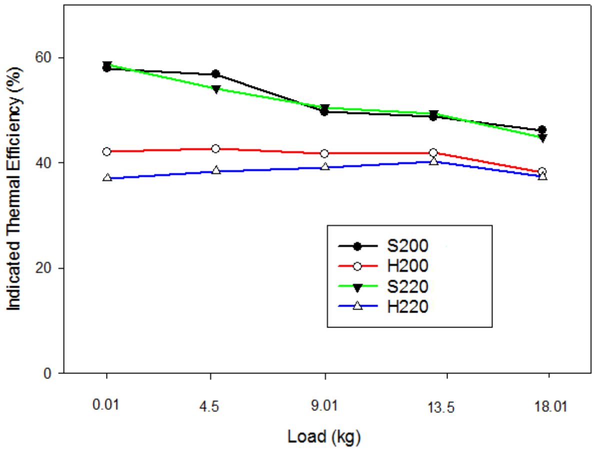


Figure 8. Variation of indicated thermal efficiency with load

3.1.5 Variation of mechanical efficiency

The variation of CI engine mechanical efficiency with load is illustrated in Figure 9. In CI engine generally, mechanical efficiency increases with a decrease in frictional power [26-27]. The usage of HMMC piston enhanced the engine mechanical efficiency drastically when compared to a standard piston engine.

From outcomes, it was concluded that the mechanical efficiency of H200 and H220 at full load operation are 84.24% and 83.07% respectively, whereas for S200 and S220, the mechanical efficiencies are 73.22% and 75.54%, which is 11.02% and 7.53 lesser than HMMC engine. Hence proved the implementation of HMMC piston inside the CI engine has improved the mechanical efficiency.

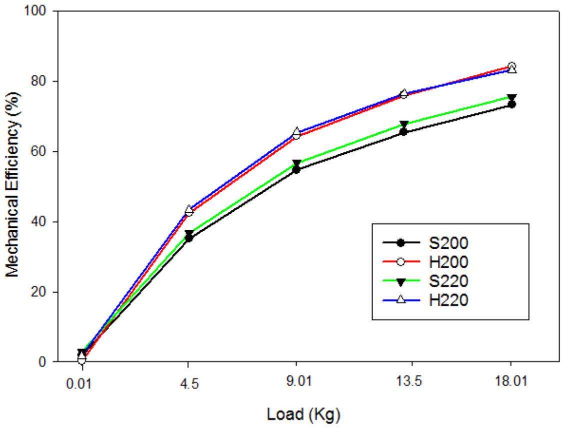


Figure 9. Variation of mechanical efficiency with load

3.1.6 Variation of volumetric efficiency for different pistons

Figure 10 shows the volumetric efficiency variation trend with engine load for four sets of experiments conducted in the CI engine. An engine volumetric efficiency specifies the capability of the engine to transfer the charge of fuel and air into and out of its cylinders [28]. The flow resistance of the manifold and piston plays a vital part in governing the engine volumetric efficiency. In this experimental work, it can be understood from the results that the HMMC piston volumetric efficiency operated engine has slightly decreased (83.67%) when compared to a standard piston operated engine (84.28%).

This reduction in efficiency is due to the fact that the HMMC piston has more wear and surface resistance which increased the drag in airflow inside the cylinder, thereby reducing the engines volumetric efficiency. However, increasing the injection pressure has increased the volumetric efficiency along with which the reduction can be compensated perfectly.

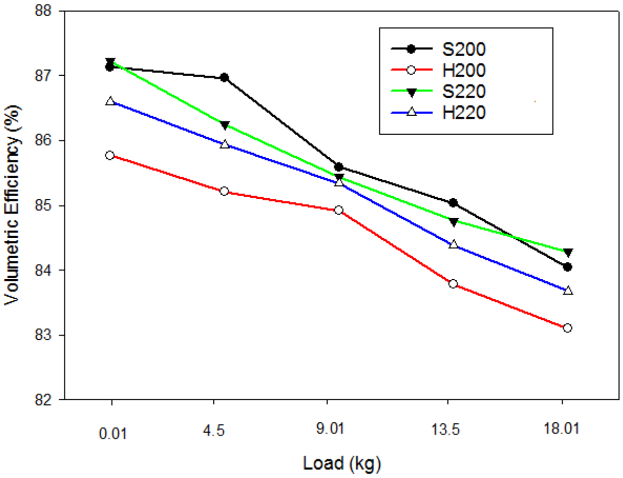


Figure 10. Variation of volumetric efficiency with load

3.1.7 In-cylinder pressure with crank angle for different pistons

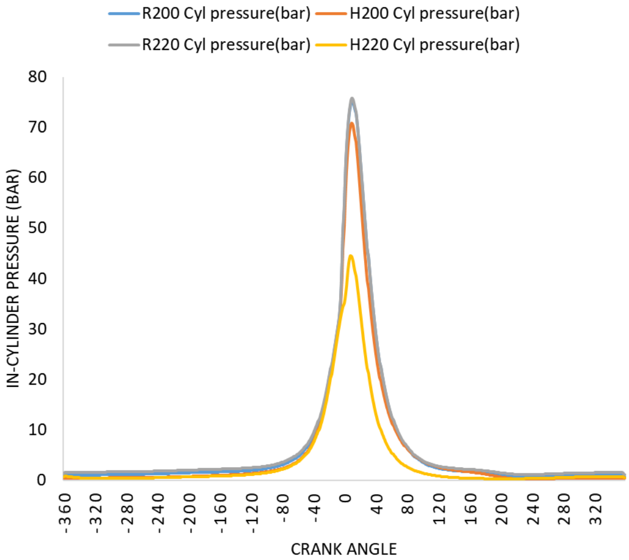


Figure 11. In-cylinder pressure with crank angle for maximum load at (18.01) kg load

The CI engine combustion aspects can be evaluated by studying the heat release and peak pressure happening inside the cylinder during combustion [29]. Figure 11displays the in-cylinder pressure variations for different angle of crank for the engine operated at maximum load (18.01 kg) for different injection pressures and pistons. The peak pressure occurrences are recorded at the crank angle of 9^{o} after TDC for all four experimental cases. But the peak pressure increased with injection pressure in both pistons. The introduction of HMMC piston has improved the combustion process by thermally insulating the piston which resulted in peak pressure increase compared with the standard piston. For H200 the peak pressure is 70.8 bar which is very near to the peak pressure of S220 which is 75.45 bar. The little variation in in-cylinder pressure is compensated by increasing the pressure at which fuel is injected in the engine.

3.1.8 Analysis of CO emission

The emission features of CI engine that was functional at 200 and 220 bar injection pressures with different pistons are discussed in the following section. The engine is loaded in 5 stages (0%, 25%, 50%, 75%, and 100%) of load and emissions are measured and recorded. Figure 12 presents the emission of CO related to the various conditions of load for CI engine at different injection pressures operated with different pistons. At no-load conditions, the CO emissions of all experiments are similar without much variation. When the load increases, the CO emission remains constant and a peak rise is noted after 75% load. This is due to the scavenging of the engine trying to produce more power at less rpm which results in poor combustion and directly increasing the CO percentage in the emission. The emission of CO at the condition of no-load of HMMC engine at both 200 bar and 220 bar injection pressure remained lesser than standard piston engine and the trend continued till 35% engine load, above which the CO percentage started raising.

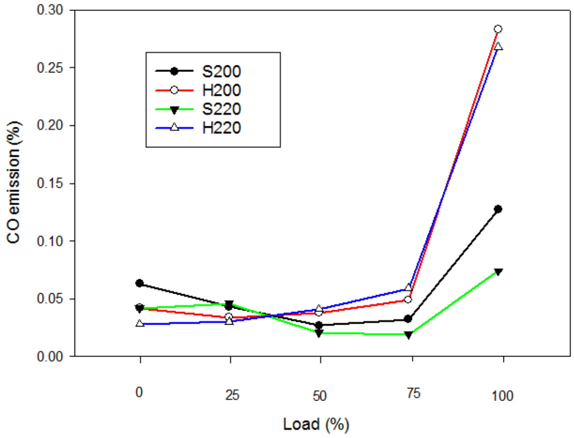


Figure 12. Comparison of CO emission with different load

3.1.9 Analysis of CO_2 emission

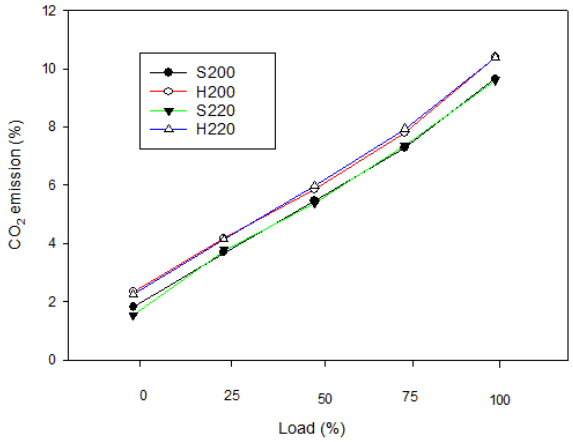


Figure 13. Comparison of CO_2 emission with different load

The emission of carbon dioxide is unavoidable in diesel fuel operated compression ignition engines [30-31]. With increase in load on the engine, CO_2 emissions intensifies because of the higher fuel burning. Figure 13 indicates the variation of emission of $CO_2$for different load conditions for various pistons and injection pressure. Observation made infers that, pressure at which the fuel is injected has no major effect on CO_2 emission increase. At peak load (100% load), the CO_2 emission levels are 9.65%, 10.4%, 9.61% and 10.4% for S200, H200, S220 and H220 respectively. Comparing HMMC piston with a standard piston, The CO_2 emissions have increased slightly about 0.75% for 200 bar and 0.79% for 220 bar injection pressures.

3.1.10 Analysis of HC emission

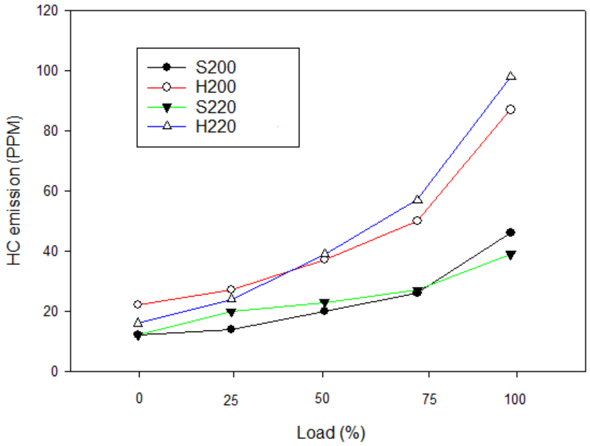


Figure 14. Comparison of HC emission with different load

The increase in hydrocarbon emission with different load conditions on engine is illustrated in Figure 14. Hydrocarbon emissions are comprised of unburned diesel fuel as a result of deficient temperature which happens nearer to the surface of the cylinder walls and subsequently, the air-fuel blend temperature is substantially less than the middle of the cylinder. From the figure, it is clear that the HC emission tends to increase with increasing load conditions. By increasing the pressure of fuel injection, initially lower HC emissions were obtained during moderate load conditions up to 25% load and with further increase in load on the engine, the trend reverses and HC emissions shoot up.

For HMMC piston, the HC emission level is acceptable for partial load operations up to 50% of maximum load, beyond which the HC emission quantity increases by double quantity compared to the standard piston.

3.1.11 Analysis of NOx emission

Figure 15 describes the trends of emission of oxides of nitrogen with conditions of increasing load in CI engine under different injection pressures and piston materials. NOx emissions are formed during extremely high-temperature combustion inside compression ignition engines [32-33]. The NOx emissions of all four experiments are measured in ppm. From the obtained outputs, it was revealed that, emission of NOx for H220 is much lower compared to other experiments. The reason for this reduction is due to the controlled combustion while using HMMC piston, which reduced the peak pressure and heat release in the cylinder chamber during combustion, thus reducing the chamber temperature. For peak load (100% load), the NOx emission of HMMC piston fitted engine at 200 bar and 220 bar injection pressure is 1748 parts per million (ppm) and 1740ppm respectively, whereas for standard piston it is 2151ppmand 2166ppm.The NOx has drastically reduced for about 18.7% for 200 bar and 19.7% for 220 bar injection pressure in using HMMC piston.

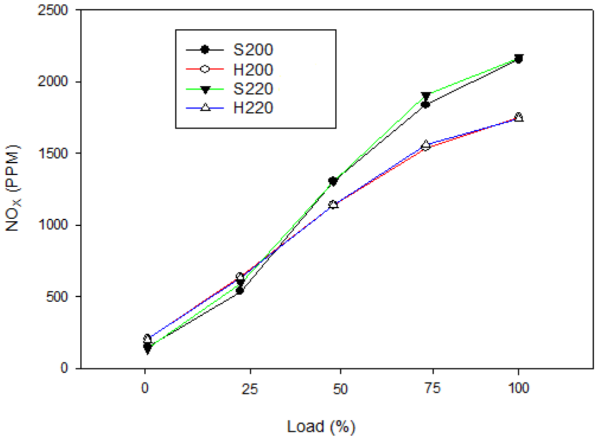


Figure 15. Comparison of NOx emission with different load

3.1.12 Analysis of Smoke opacity

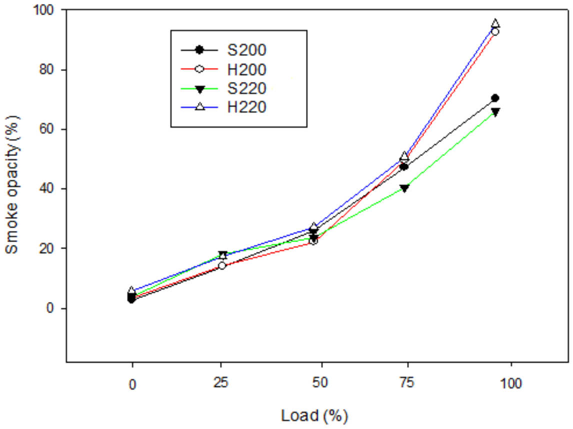


Figure 16. Comparison of smoke opacity with different load

The smoke opacity of exhaust gases is measured for various pistons operated at various injection pressures, which is shown in Figure 16. The degree of soot particles presence in emission gases of an IC engine is known as smoke opacity [34]. From the trends presented in the figure, it was inferred that, with increasing the load, smoke opacity tends to increase and it is highest for H220 (HMMC piston – 220 bar injection pressure). The second highest is for H200 and the reason behind this phenomenon is that the reduced combustion temperature has increased the percentage of soot particles.

The intensification in smoke opacity becomes drastic after 75% load operation of the engine. When operated at a 50% load, there is not much difference in smoke opacity of HMMC piston when compared to the standard piston.

4. Error Analysis

Experimental error was observed improper calibration of equipment. Uncertainty analysis proved accuracy of experiments. Table.9 showed uncertainty values. In the present study, propagation of error techniques determined the total uncertainty.

Total uncertainty $_{\text{(Expt)}} = \sqrt{(A_1)^2 + (A_2)^2 + (A_3)^2 + (A_4)^2 + (A_5)^2 + \ldots..}$

Total uncertainty $_{\text{(Expt)}} = \sqrt{(1)^2 + (0.18)^2 + (0.15)^2 + (0.12)^2 + (0.2)^2 + (0.1)^2 + (0.21)^2 + (1)^2 + (0.2)^2 + (1)^2}$

$= \pm 1.789\%$

Where, A1- Uncertainty of total fuel consumption, A2- Uncertainty of BP, A3- Uncertainty of BSFC, A4- Uncertainty of BTE, A5- Uncertainty of Carbon monoxide, A6- Uncertainty of Hydrocarbon and so on.

Table 9. The experimental uncertainty varies according to the measuring instruments and parameters used.

Sl.no	Parameters	Measuring technique	Accuracy	Errors (±)
1	Load (N)	Strain - gauge type load cell	±10	±0.15
2	Speed (rpm)	inductive sensor principle	±10	±0.11
3	Fuel flow measurement (cc)	Volumetric flow measurement	±0.1	±1
4	Temperature (^{0}C)	Thermocouple	±1	±0.2
5	Crank angle encoder (deg)	Magnetic pickup concept	±1	±0.18
6	Pressure (kg)	Magnetic pickup concept	±0.1	±0.12
7	Time (s)	Stop watch (Manual Method)	±0.1	±0.15
8	Manometer deflection (mm)	Balancing of column of fluid	±1	±1
9	CO (%)	Non-dispersive infrared technique	±0.02	±0.2
10	HC (ppm)	Non-dispersive infrared technique	±10	±0.1
11	NOx (ppm)	Non-dispersive infrared technique	±12	±0.21
12	Smoke (HSU)	Opacimeter	±1	±1

5. Conclusions

In the present study, hybrid metal matrix composite piston was casted and machined as per the dimensions of a standard piston and was tested on a constant speed diesel fuel operated experimental compression ignition engine run at 200 bar and 220 bar injection pressures. The fabricated piston was tested for structural rigidity was studied. Experiments were conducted by installing the HMMC piston and the following conclusions were drawn:

- The usage of HMMC piston in CI engine has affected the engine performance but any loss in performance attributes were compensated by increasing the fuel injection pressure.
- The HMMC piston has slightly affected the combustion process, but the effect is ignored since there were not many variations in peak in-cylinder pressure and rate of heat release.
- The HMMC piston during its operation has slightly elevated the emissions of HC, CO_2 and CO but lowered the emission of NOx to a larger extend because of controlling the peak temperature during combustion process.
- The specific fuel consumption is high around 8.5% for HMMC piston operated at 200 bar and around 15.7% for HMMC piston operated at 220 bars and by comparing the indicated thermal efficiencies of engines operated with a standard piston and HMMC piston, the efficiencies are 46.19% and 38.19% with a 8% efficiency reduction.
- Mechanical efficiency of H200 and H220 at full load operation are 84.24% and 83.07% respectively, whereas for S200 and S220, the mechanical efficiencies are 73.22% and 75.54%, which is 11.02% and 7.53 lesser than HMMC engine.
- The reduction in volumetric efficiency is due to the high wear and surface resistance of HMMC piston which increased the drag in airflow inside the cylinder, thereby reducing the engines volumetric efficiency.
- The emission of CO of HMMC engine at both 200 bar and 220 bar injection pressure remained lesser than standard piston engine and the trend continued till 35% engine load, above which the CO percentage started raising.
- The CO_2 emissions have increased slightly about 0.75% for 200 bar and 0.79% for 220 bar injection pressures. HC emission tends to increase with increasing load conditions. By increasing the pressure of fuel injection, initially lower HC emissions were obtained during moderate load conditions up to 25% load and with further increase in load on the engine, the trend reverses and HC emissions shoot up.
- For peak load (100% load), the NOx emission of HMMC piston fitted engine at 200 bar and 220 bar injection pressure is 1748 parts per million (ppm) and 1740ppm respectively, whereas for standard piston it is 2151ppm and 2166ppm. The NOx has drastically reduced for about 18.7% for 200 bar and 19.7% for 220 bar injection pressure in using HMMC piston. When operated at a 50% load, there is not much difference in smoke opacity of HMMC piston when compared to the standard piston.

Overall, it is concluded that the implementation and usage of HMMC (Hybrid Metal Matrix Composite) piston in CI engine improves the overall lifetime of the engine, with minor compromises in performance, combustion and emission parameters, which might be adjusted with increase in injecting pressure in the combustion process and it will help to reduce pollution as well as global warming.

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Nomenclature

HMMC : Hybrid metal matrix composite piston
MEP : Mean effective pressure
IP : Indicated power
SFC : Specific fuel consumption
ITE : Indicated thermal efficiency
ME : Mechanical efficiency
VE : Volumetric Efficiency
CA : Crank angle
CO : Carbon monoxide
CO_2 : Carbon dioxide
HC : Hydrocarbon

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