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EXPERIMENTAL INVESTIGATIONS ON CI ENGINE WITH VARYING AIR GAP AND YTTRIUM OXIDE AS HEAT RESISTING MATERIAL

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ABSTRACT

In the present day to day life each and every work involves travelling and transportation as a result of this usage of automobile vehicles increases day by day rapidly for heavy duty works and for heavy transportation. DI Diesel Engine is used because of its higher power outputs. But in this Diesel Engine in the suction stroke, inlet air which is entering in to the engine cylinder is compressed to higher pressure and temperature, which sometimes is not sufficient to mix with the fuel injected, and some of the fuel particles are burnt incompletely in this process and it gets released into atmosphere from exhaust stroke. Due to these circumstances there is a loss of fuel and also it produces less power output than the required. Improving engine performance and reducing the exhaust emissions are the most important issues. The thermal efficiency of an engine increases by the amount of heat present in the combustion chamber which mainly depends on heat transfer rate through the piston. Thermal efficiency is increased by reducing heat loss through piston by providing air insulations between the piston crown and skirt. In the present work, three different strategies of air insulation (air gap) of 1.5mm, 2mm, 2.5mm between the aluminium piston skirt and conical brass crown which is of low thermal conductivity and low specific heat are attempted on the test engine, with an objective to identify the best one in terms of performance and emissions. Among them 2mm air gap insulated piston has the better performance characteristics. And then it is coated with yttrium oxide as heat resisting material and the engine tests are carried out and the performance and emissions are evaluated and compared with the performance of other pistons.

Keywords: single cylinder four stroke diesel engine, brass crown, air gap, insulated piston, bowl, conical, circular, exhaust emissions.

INTRODUCTION

Engineers always strive to achieve great heights in the fields of Thermal efficiency and energy conservation with internal combustion engines. In present days, the usage of diesel engines has been increasing tremendously for different purposes like electricity generation and transportation. These engines consume in heavy quantity of fuel per hour, this may be resulted in a great scarcity of fuel for internal combustion engines and also produces various toxic gases that are harmful to human beings and environment. By weighing the pros and cons of combustion chamber temperatures, ic engines are developed. In cylinder temperature has a major impact on efficiency. The quantity of heat present in the combustion chamber depends mostly on heat transfer rate through the piston. Many researchers in India and abroad are working in this area with a solo idea of improving the efficiency of a Diesel Engine. From the day of invention of the Engine, maximum thermal efficiency obtained so far is not greatly enhanced. Hence, the research is very much needed to develop an efficient Diesel Engine.

The motivation of insulation to piston is proposed to decrease heat transfer rate from top portion of piston to bottom surface and insulating the maximum surface area of the crown to decrease the heat transfer. Low thermal conductivity and low specific heat material brass crown along with insulated piston implemented with air gap will be used in this study to investigate the performance of engine. During expansion process piston crown absorbs rate of heat transfer from combustion gases and releases to the fresh charge that enters in to the engine cylinder just like heat reservoir because of low thermal conductivity of brass material. According literature survey the conical shaped brass crowned piston has the better performance when compared to the other shapes such as cylindrical and circular shapes. Also there was increase in brake thermal efficiency and reduction in specific fuel consumption.

It is also observed that due to high temperatures the levels of unburned hydro carbons and carbon monoxide are decreased and where as nitrogen oxide NOx is increased. Increase in weight of the crown piston is not a major problem in diesel engines when compared to the engine performance. The other survey concludes that thermal coatings on pistons can be very effective. According to one of those previous works the engine with piston coated with yttrium oxide is giving better performance in terms of brake thermal efficiency and specific fuel consumption when compared to the baseline engine. In this work it is proposed to focus on the emission and performance characteristics of single cylinder four strokes direct injection diesel engine by incorporating different conical shaped air insulations such as 1.5mm, 2.5mm and 2mm. and then by comparing the performance of above three insulated pistons, the piston with best performance characteristics is coated with yttrium oxide and the performance of the engine is studied.

MATERIALS AND METHODS

Design of Insulated Air Gap Piston:

The combustion chamber shape and the dynamics of fluid inside the chamber are important in combustion of diesel. The fuel is pushed into the piston bowl when it moves upward. The geometry of the bowl can be designed such that it improves the formation of fuel and air mixture. Here a conical shaped brass crown is designed and fabricated with the aluminum alloy piston skirt. Three different types of air insulations are provided between the brass crown and aluminum alloy skirt. The properties of brass are stated below.

Table 1: Properties of Brass Crown

Properties	Value
Melting point(^{0}c)	885-900
Poisson's ratio	0.331
Thermal conductivity(w/m-k)	90-110
Thermal expansion(x10^{-6} m/m^{0}c)	18.7
Tensile strength(MPa)	338-469
Compressive strength(MPa)	147-180
Yield strength(MPa)	124-310
Creep strength(MPa)	12
Rupture strength(MPa)	85
Fatigue strength(MPa)	42
Density (g/cc)	8.49
Modulus of elasticity(GPa)	96-110
Bulk modulus(GPa)	140
Shear modulus(GPa)	37
Brinnel hardness	130

Initially the brass crown and aluminum skirts are designed in PRO-E tool as per our required dimensions. The brass crown is prepared by performing various mechanical operations on 80mm diameter brass rod such as milling, facing, turning and drilling on the lathe and milling machines. The aluminum alloy piston skirts are manufactured by inward turning operations on the lathe machine. Three different air insulations 2.5mm, 2mm, 1.5mm are provided between the brass crown and aluminum alloy piston skirt. The piston crown and skirt are fixed by using M4 screws of length 10mm. The design of piston crown and skirt in PRO-E and the manufactured brass crowns and aluminum piston skirts are shown below.

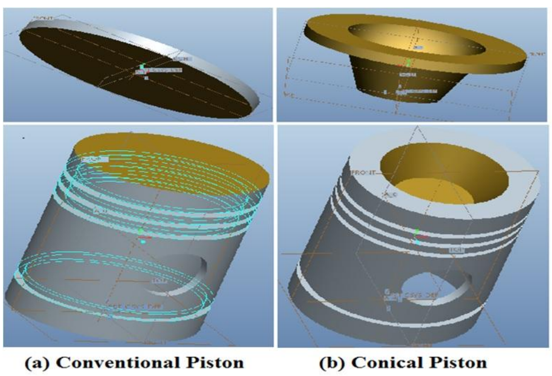

Figure 1: Modeling of Piston

Figure 2: Manufactured Piston

Thermal Barrier Coating:

The internal engine rejects around 2/3rd of the heat energy of the fuel in the form of coolants and burnout. TBC increases the power available and reduces the thermal stresses. Normally TBC is deposited on the crown of the piston to increase performance of the engine. Here the modified piston with the better performance characteristics is selected and it is coated with yttrium oxide. Thermal barrier coatings can be done using several techniques. Among them plasma spray technique is used for coating the piston and yttrium oxide Y_2O_3. Yttrium oxide is sprayed in powder form in ionized gas continuously on the piston brass crown surface until it results in a 150μm thin thermal barrier coating.

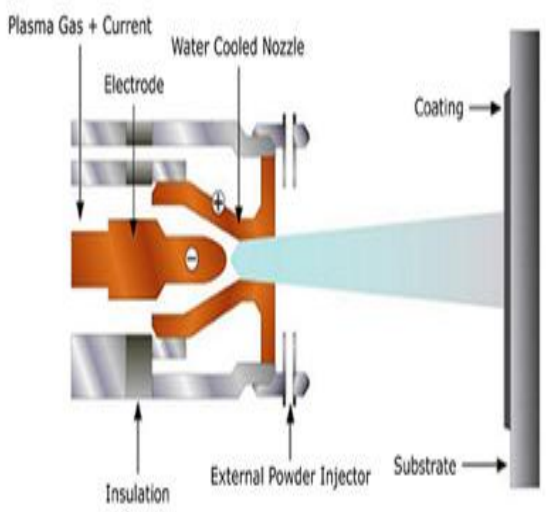

Figure 3: Plasma Spray Coating

Figure 4: Yttrium Oxide Coated Piston

EXPERIMENTAL SETUP

A stationary single cylinder four stroke direct injection (DI) water cooled kirloskar AV1 diesel engine is used to conduct experiments. The pistons are air insulated as explained above and the experiments are conducted at rated speed of 1500rpm. For measuring the emissions, the exhaust gas analyzer is used. Diesel is used as the fuel in the present work. The lubricating oil level in the sump is checked periodically. To prevent overheating, constant water flow is maintained through the engine. All the readings are taken at steady running conditions.

Table 2: Test Engine Specifications

Particulates	Specification
Engine make and model	Kirloskar (India) AV1
Rated Power	5Hp
Bore × stroke	80 mm × 110 mm
Method of cooling	water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
Dynamometer	Rope break dynamometer

Table 3: Fuel Properties

Property	Diesel
Density(kg/m^3)	831
Colour	Reddish
Flash point(^0c)	51
Calorific value(kJ/kg)	42000

RESULTS AND DISCUSSIONS

The performance of engine is evaluated based on the brake thermal efficiency and brake specific fuel consumption. The emission characteristics of the engine are studied in terms of concentration of HC, CO, CO_2 and NO_x. The result obtained from three different air gaps are studied and the air gap with better performance among the three is selected and coated with yttrium oxide and the performance is studied and compared.

1. Brake Thermal Efficiency:

The temperature in the combustion chamber is the main factor for complete combustion of the fuel in the combustion chamber. The insulated air gap piston reduces the heat transfer rate from crown to skirt of the piston. The preheated air provides homogeneous mixture in combustion chamber which further increases the combustion efficiency. Figure four shows the variation of brake thermal efficiencies for different insulations at various loads. Due to the reduction of heat loss, the efficiency is increasing with increase in loads. The brake thermal efficiency of the 2mm air gap piston is increased by 1.32% when compared to conventional aluminum piston at rated loads. Similarly the brake thermal efficiency is increased by 0.66% and 0.99% respectively for 2.5mm and 1.5mm brass crowned pistons when compared with aluminum conventional piston at rated loads. And for the piston coated with yttrium oxide the brake thermal efficiency is increased by 1.98% when compared to the conventional aluminum piston at rated loads.

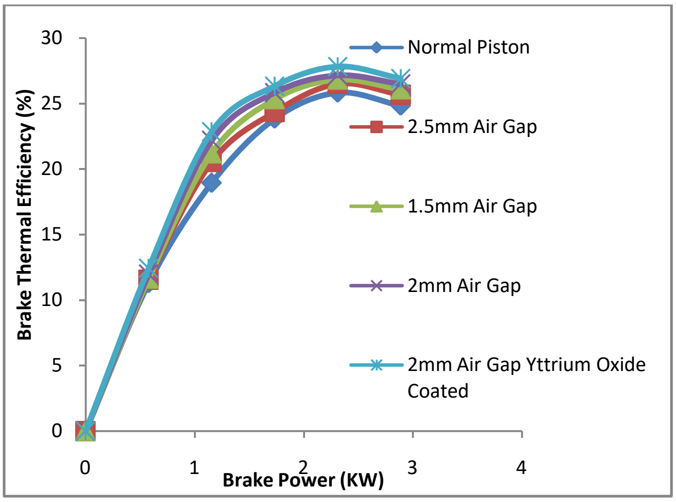

Figure 5: Brake Thermal Efficiency

2. Brake Specific Fuel Consumption:

The result for variation of brake specific fuel consumption (BSFC) with load is presented in figure 5. The brake specific fuel consumption is decreased slightly for all brass crown insulated and brass crown yttrium oxide coated piston when compared with aluminum base piston for pure diesel.

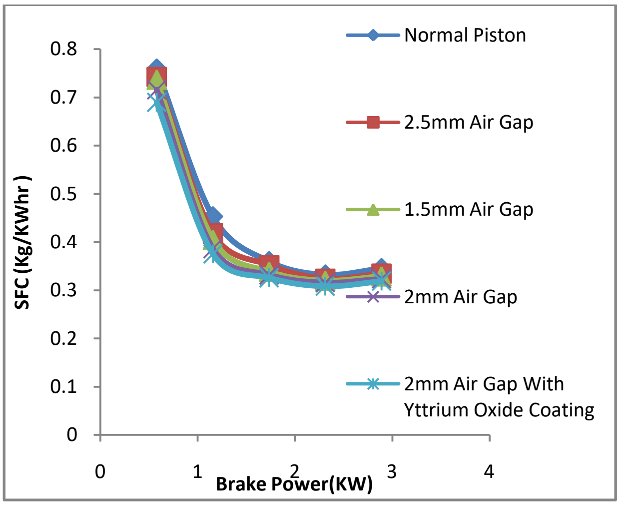

Figure 6: Brake Specific Fuel Consumption

From the above figure we can observe that bsfc for 2mm air gap piston with yttrium oxide coating is reduced by 7.1% when compared with normal piston for pure diesel and 4.8%, 3.7%, 2.5% for 2mm air gap. 1.5mm air gap, 2.5mm air gap brass crowned pistons respectively. This is due to proper combustion of fuel at high temperatures generated in the combustion chamber due to thermal insulations.

3. Hydrocarbon Emissions (HC):

In the figure 7 the variation of hydro carbons at various loads for different insulated pistons are presented. Lean mixing of fuel, burning of lubricating oil and wall quenching are the main source of these emissions. The HC emissions are reduced considerably due to complete combustion of the fuel due to hot combustion chamber. As the load is increased, it would increase the temperature and this could increase oxygen content, reduce the density, leading to improved spray and atomization, better combustion and lower HC emissions.

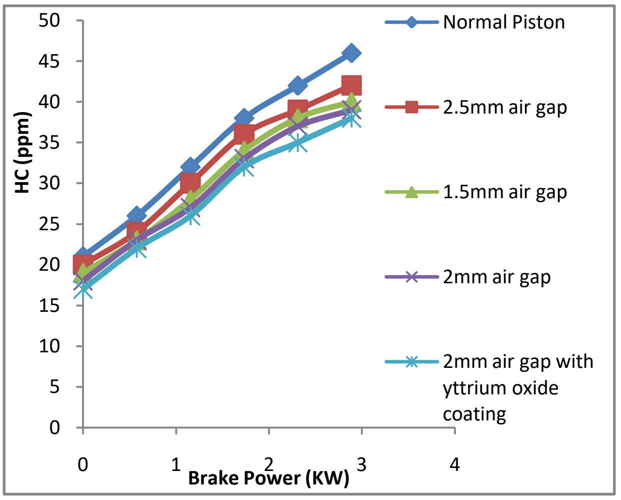

Figure 7: Hydrocarbon emissions

4. Carbon monoxide (CO):

In the figure 8 the variation of hydro carbons at various loads for different insulated pistons are presented. The CO emissions are reduced considerably due to complete combustion of the fuel due to hot combustion chamber. It clearly shows that CO is decreased after using different air gap insulations in brass crown piston due to complete combustion. At high temperature carbon easily combines with oxygen and reduces CO emission. The results show that CO emission of standard engine is slightly higher than three different air insulation air gap brass crown pistons and 2mm air gap yttrium oxide coated piston at full load condition.

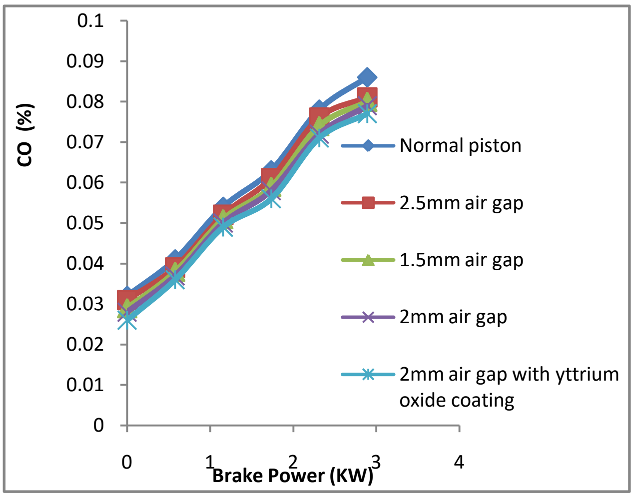

Figure 8: Carbon monoxide emissions

5. Nitrogen Oxide (NO_x):

The formation of nitrogen oxide emissions depends mainly on heat transfer rate and evaporation of fuel. It also increases further with the availability of oxygen and higher prevailing temperatures.

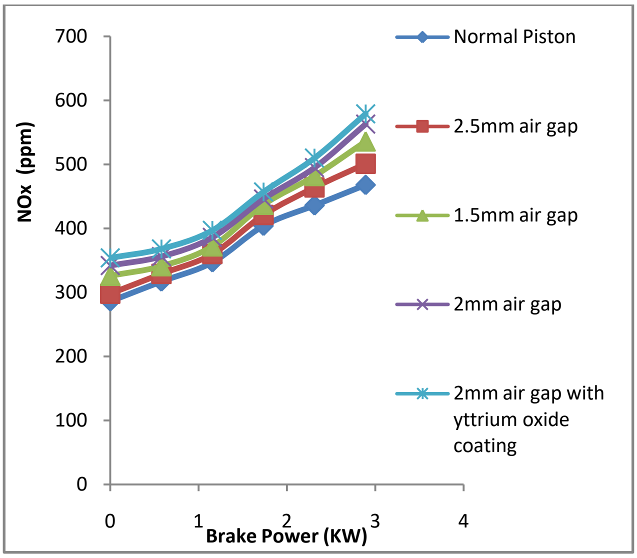

Figure 9: Nitrogen Oxide Emissions

Figure illustrates the variation of NO_x emissions with different air insulated pistons. With the brass piston material the temperature in the chamber is slightly higher which further increases the evaporation rate of the fuel. This increases the combustion efficiency due to availability of oxygen levels in the fuel. So the NOx emission tendency also increases. The increase in 2mm air insulated piston is increased slightly when compared to aluminum piston at rated load. The other pistons also show significant rise in the NOx levels.

6. Carbon dioxide (CO_2):

From the results present in the figure, it is observed that the amount of CO_2 is higher in the insulated pistons and yttrium oxide coated piston when compared with the base aluminum piston. the formation of carbon dioxide is a sign for complete combustion of the fuel. As a general rule, higher the CO_2 reading, the more efficient the engine is running.

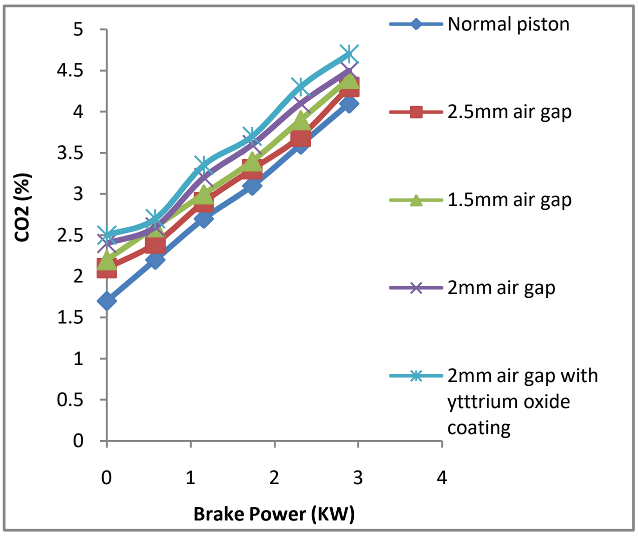

Figure 10: Carbon dioxide Emissions

CONCLUSION

Based on the experimental results with brass crown piston with different air gap insulations and 2mm air gap insulated piston with yttrium oxide coating, the following conclusions are drawn:

- The brake thermal efficiency of 2mmair gap insulated brass crowned piston is increased by about 1.32% compared to conventional piston at rated loads. And for the 2mm air gap insulated piston with yttrium oxide coating the brake thermal efficiency is increased by 1.98% when compared to conventional piston.
- The brake specific fuel consumption of 2mmair gap insulated brass crowned piston is slightly reduced by 4.8% when compared to conventional piston. And for the 2mm air gap insulated piston with yttrium oxide coating the brake specific fuel consumption is decreased by 7.1% when compared to conventional piston.
- Due to the higher operating temperatures and with the oxygen present in the combustion chamber, will be used for reducing CO emissions by 7.7% for 2mmair gap insulated brass crowned piston when compared to conventional piston at rated load. And for the 2mm air gap insulated piston with yttrium oxide coating the CO emissions are reduced by 8.9% when compared to conventional piston.
- Due to the higher operating temperatures, HC emissions are decreased by 11.9% for 2mmair gap insulated brass crowned piston when compared to conventional piston at rated load. And for the 2mm air gap insulated piston with yttrium oxide coating the HC emissions are reduced by 16.6% when compared to conventional piston.
- Increases of the temperatures in the combustion chamber leads to the higher emissions of NOx. The NOx formation is 13.5% higher for 2mmair gap insulated brass crowned piston when compared to conventional piston at rated load. And for the 2mm air gap insulated piston with yttrium oxide coating the NOx emissions are increased by 16.9% when compared to conventional piston.

From the above analysis, It is concluded that out of three different air insulations of conical shaped brass crown piston configurations tested, Brass piston with 2mm air gap insulation is proved to be good performance wise and same yttrium oxide coated piston with 2mm air gap is proved to give better performance characteristics than the one without coating. Hence the conical shaped brass crown with 2mm air gap insulated piston with yttrium oxide coating is a suitable substitute for conventional aluminum piston as it has satisfactory performance and emission characteristics.

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