A Technical Review on Piston Ring Coating of Single Cylinder Four Stroke SI Engine Fuelled with Compressed Natural Gas

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Abstract— Now a day's various methods are in use on cylinder piston group for improving service life of IC Engine for reducing exhaust emission and improving engine performance. The wear resistance of thermal sprayed molybdenum applicable to the piston ring will be studied in this review. Wear resistance of molybdenum coated piston ring is high as compared to ordinary cast iron rings. Experiments on life cycle is to be performed on the compressed natural gas engine as per IS Standard for specified operating parameters. Oil lubricity test done on oil sample would give measure of wear. And wear effect on piston ring is investigated based on performance parameters like Brake specific fuel consumption, Brake power, exhaust gas temperature, Brake thermal efficiency and exhaust emissions like NOx, CO, CO2, HC, and O2. Results will be compared for both coating and non-coating condition. So by reviewing research on effect of piston ring coating, we can improve the performance of SI Engine Fuelled with Compressed Natural Gas.

Key words: Piston Ring Coating, Compressed Natural Gas, SI Engine, Performance of SI engine

I. INTRODUCTION

Internal Combustion Engine is a device in which heat is generated as a result of combustion process .This heat of combustion product is used to produce the work. To produce the work, the combustion is carried out in such a way that high pressure combustion product would be expanded through the piston. So engine life depends mainly on the part of the engine. So consequently service life of the engine can be increased by considering the part which dominates its major role in the working condition of the engine.

The split piston ring was invented by John Ramsbottom who reported the benefits to the Institution of Mechanical Engineers in 1854. It soon replaced the hemp packing hitherto used in steam engines. The use of piston rings at once dramatically reduced the frictional resistance, the leakage of stream, and the mass of the piston, leading to significant increase in power and efficiency and longer maintenance intervals.

Most automotive pistons have three rings: The top two while also controlling oil are primarily for compression sealing (compression rings); the lower ring is for controlling the supply of oil to the liner which lubricates the piston skirt and the compression rings (oil control rings). At least two piston rings are found on most piston and cylinder combination. Typical compression ring designs will have an essentially rectangular cross section or a keystone (right angled trapezoidal) cross section. The periphery will then have either a barrel profile (top compression rings) or a taper napier form (second compression rings or scraper rings). There are some taper faced top rings and on some old engines simple plain faced rings were used.

The piston might be a fairly loose fit in the cylinder. If it were a tight fit, it would expand as it got hot and might stick tight in the cylinder. If a piston sticks (seizes) it could cause serious damage to the engine. On the other hand, if there is too much clearance between the piston and cylinder walls, much of the pressure from the burning gasoline vapour will leak past the piston (a condition known as blow-by) and into the crankcase, and the push on the piston from combustion will be much less effective in delivering power.[3]

Piston rings for current internal combustion engines have to meet all the requirements of a dynamic seal for linear motion that operates under demanding thermal and chemical conditions. In short, the following requirements for piston rings can be identified:

Low friction for supporting the high power efficiency rate. Low wear of the ring, for ensuring a long operational lifetime. Low wear of the cylinder liner, for retaining the desired surface texture of the liner. Emission suppression, by limiting the flow of engine oil to the combustion chamber. Good sealing capability and low blow-by for supporting the power efficiency rate. Good resistance against mechanothermal fatigue, chemical attacks and hot erosion. Reliable operation and cost effectiveness for a significantly long time.

II. REVIEW ON PISTON RING COATING

A. *Marcus Kennedy (2012)[3]*

studied on Piston ring coating reduces gasoline engine friction and developed a coating system for piston rings under the name of Carboglide which decreases wear in highly charged gasoline engines and further reduces friction losses which occur between the ring pack and the cylinder running surface. The tailored composition of the specific layer structure of the carbon-based Carboglide coating in combination with corresponding modified piston ring designs yields a potential to improve fuel efficiency by up to 1.5 %.

Piston Ring coating combines extremely low friction values with high strength and durability of piston rings and cylinder running surfaces. By using this coating, the ring pack's frictional losses can be reduced by up to 20 %. It signifi cantly protects the cylinder run- ning surface against scoring, increased wear and scuffi ng during inadequate lubrication. Carboglide makes a substan- tial contribution to the development of high performance gasoline engines with even better fuel economy by up to 1.5 % with consequently lowering CO2 emissions.

B. *Yucong Wang (1999)[5]*

Studied on Scuffing and wear behavior of aluminum piston skirt coatings against aluminum cylinder bore. Various coatings, especially nickel based ceramic composite coatings, have been considered as an alternative to the use of iron plating on aluminum pistons in aluminum cylinder bore engines. Laboratory simulation tests were conducted to determine the scuffing and wear behavior of piston coatings against 390 Al engine cylinder bore. The tested piston coatings included nickel–tungsten plating, electrolysis Ni plating, Ni–P coatings with ceramic particles such as boron nitride, SiC, or Si 3 N4, as well as titanium nitride physical vapor deposition coating, diamond-like carbon coating, and hard anodizing. . The scuffing and wear resistances of these coatings were evaluated and compared with tin plating and iron plating. Wear tests were performed in lubricated sliding at 400 K, using a modified Cameron Plinth High Frequency test machine with a special fixture to hold the piston samples. Scuffing tests were conducted under the conditions in which lubricant starvation occurred. The simulation test results ranked the relative performance of the coatings against 390 Al bore, and revealed their tribological characteristics. Ni–P–BN coating, iron plating and Ni–W plating showed very good scuffing resistance when sliding against 390 Al bore samples. Ni–P–Si 3 N4 and TiN coatings had marginal scuffing resistance against 390 Al. TiN PVD coating had the most severe wear on 390 Al bore samples. Hard anodizing, Ni–P–SiC and Ni–Si 3 N4 coatings had less severe wear on 390 Al than TiN coating. With very good wear resistance themselves, Ni–W plating, electrolyses Ni plating, iron plating and Ni–P–BN coating produced the least wear on 390 Al. This work indicates that the scuffing and wear bench simulation tests can be used as a rapid, low-cost and repeatable means of screening and studying the tribological behavior of the potential material combinations of piston coatings and cylinder bores.

The simulation test results ranked the scuffing and wear resistance of the piston coatings against 390 Al bore, and helped study their tribological behavior. The coatings with very good scuffing resistance against 390 Al included Ni–P–BN coating, iron plating, Ni–W plating. The coatings with moderate scuffing resistance against 390 Al included electrolysis Ni plating, and Ni–P–SiC coat- ing. Ni–P–Si 3 N4 and TiN coatings had scuffing resistance when sliding against 390 Al. TiN PVD coating had the most severe wear on 390 Al bore samples. Hard anodizing, Ni–P–SiC and Ni–P–Si 3 N4 coatings had less severe wear on the bore samples than TiN coating. Ni–W plating, electroless Ni plating, iron plating and Ni–P–BN coating produced the least wear on the aluminum bore samples, with very good wear resistance themselves.

C. P.N. Bindumadhavan (2000)[6]

Studied on Aluminizing and subsequent nitriding of plain carbon low alloy steels for piston ring applications. Nitriding is a case hardening process that is commonly used for increasing the wear life of automotive piston rings. However, special alloy steels are required to achieve high surface hardness and nitrided case depth values required by the automotive industry. The cost of such alloy steels is one of the major components of the total cost of the nitrided piston ring. To address this issue, efforts have been directed towards development of cheaper raw materials as substitutes for nitridable steels. In this study, an attempt this been made to increase the surface hardness of two plain carbon low alloy steels by aluminizing and subsequent diffusion treatment and nitriding. It has also been found that the nitrided cased obtained 0.13 mm for steel. The diffusion of aluminum in to the alloy layer has also been discussed and the theoretical predictions were compared with actual values of Al concentration. It is proposed that aluminizing followed by diffusion treatment and nitriding of plain carbon low alloy steels could provide an alternative to the use of expensive nitridable steels for piston ring applications.

The surface hardness of the two plain carbon low alloy steels studied could be increased by nearly a factor of two when aluminized and nitrided as compared to plain nitriding.

The case depth obtained compares well with the general requirements of case depth on nitrided piston rings.

The final nitrided depth of the component can be controlled by controlling the initial aluminizing conditions, especially the Si content in the aluminizing bath.

D. Yucong Wang (2001)[7]

Studied the wear and scuffing characteristics of composite polymer and nickel/ceramic composite coated piston skirts against aluminum and cast-iron cylinder bores. The purpose of this research was to evaluate the tribological behavior and compatibility between coated piston skirts and aluminum or cast iron bore counter faces. Aluminum piston skirts with either composite polymer coatings (CPCs) or nickel/ceramic composite coatings (NCCs) were evaluated. Among the NCC coated piston skirts, Ni–P–BN showed consistent low wear on either cast iron or the aluminum bores. The tin plated piston skirt generated low wear depths on cast iron or 390 Al bore surfaces, but higher wear depths on 413 Al or 356 Al bore. All the CPCs generated much less wear on cast iron or aluminum cylinder bores compared with the Ni–P–SiC or Ni–P–Si3 N4 skirt coatings. Even the wear tests using 413 Al and 356 Al bores showed very low wear depths. Among the CPCs, two coatings with different percentages of molybdenum disulfide and graphite particles dispersed in the resin generated the lowest wear on 390 Al bore. Using a CPC over a hard-anodized surface, the bore wear depth was further reduced and became much more consistent compared with using a CPC alone. The response of the coatings to a simulation of the oil starvation associated with scuffing conditions revealed that the CPCs had intrinsic resistance to scuffing. However, the durability was not very good. The Ni–P–BN coating had intrinsic resistance to scuffing and good durability when sliding against 390 Al bore in the unlubricated conditions. The hard anodized surfaces with the CPCs showed much improved coating durability with good scuffing resistance.

Aluminum piston skirts with either various CPCs or NCCs have been evaluated against cast iron and aluminum alloy cylinder bores. The aluminum bores tested include hypereutectic Al–Si (390 Al), eutectic Al–Si (413 Al) and hypoeutectic Al–Si (356 Al). Among the NCCs, a Ni–P–BN coating generated the lowest cylinder bore wear depths no matter which aluminum or cast iron cylinder bores were used for these wear tests. The tin plated pistons generated very low wear on a cast iron bore, but higher wear on aluminum bores. All the CPCs generated much less wear on cast iron or aluminum cylinder bores compared with the Ni–P–SiC and Ni–P–Si3 skirt coatings. Even 413 Al and 356 Al bores showed much lower wears.

The response of the coatings to a simulation of the starvation associated with scuffing revealed that the composite polymer coatings had intrinsic resistance to scuffing and showed mixed results in durability. Any one of the CPCs on hard-anodized piston skirts provided both excellent scuffing and wear resistance. The Ni–P–BN coating had intrinsic resistance to scuffing and good durability when sliding against the 390 Al bore in the unlubricated condition.

E. Jeehoon Ahn (2004)[11]

Studied on the Improvement of Wear Resistance of Plasma-Sprayed Molybdenum Blend Coatings. The wear resistance of plasma sprayed molybdenum blend coatings applicable to synchronizer rings or piston rings was investigated in this study. Four spray powders, one of which was pure molybdenum and the others blended powders of bronze and aluminum-silicon alloy powders mixed with molybdenum powders, were sprayed on a low-carbon steel substrate by atmospheric plasma spraying. Micro-structural analysis of the coatings showed that the phases formed during spraying were relatively homogeneously distributed in the molybdenum matrix. The wear test results revealed that the wear rate of all the coatings increased with increasing wear load and that the blended coatings exhibited better wear resistance than the pure molybdenum coating, although the hardness was lower. In the pure molybdenum coatings, splats were readily fractured, or cracks were initiated between splats under high wear loads, thereby leading to the decrease in wear resistance.

F. M.B. Karamis (2004) [12]

Studied on An evaluation of surface properties and frictional forces generated from Al–Mo–Ni coating on piston ring. Surface properties of the Al–Mo–Ni coating plasma sprayed on the piston ring material and the frictional forces obtained by testing carried out under different loads, temperatures and frictional conditions were evaluated. The coated and uncoated samples were tested by being exposed to frictional testing under dry and lubricated conditions. Test temperatures of 25, 100, 200, and 300 C and loads of 83, 100, 200, and 300 N were applied during the tests in order to obtain the frictional response of the coating under conditions similar to real piston ring/cylinder friction conditions. Gray cast iron was used as a counterface material. All the tests were carried out with a constant sliding speed of 1 m/s. In addition, the variations of the surface roughness after testing with test temperatures and loads under dry and lubricated conditions were recorded versus sliding distance. It was determined that the surface roughness increased with increasing loads. It increased with temperature up to 200 C and then decreased at 300 C under dry test conditions. Under lubricated conditions, the roughness decreased under the loads of 100 N and then increased. The roughness decreased at 200 C but below and above this point it increased with the test temperature. Frictional forces observed under dry and lubricated test conditions increased with load at running-in period of the sliding. The steady-state period was then established with the sliding distance as a normal situation. However, the frictional forces were generally lower at a higher test temperature than those at a lower test temperature. Surprisingly, the test temperature of 200 C was a critical point for frictional forces and surface roughness. The results of study are as below.

The surface roughness of the coating increased with load in dry conditions. It also increased with test temperature up to 200 C and then decreased. On the other hand, the roughness had the lowest value at this temperature under lubricated conditions.

On the other hand, the lowest frictional forces are obtained for highest test temperature (i.e. 300 C) and relatively low loading (i.e. 83 and 100 N) under dry test conditions. But for higher loads (i.e. 200 and 300 N) the lowest frictional forces are observed at the test temperature of 200 C. This shows that 200 C is also a critical point for frictional forces generated for the lubricated conditions.

This kind of coatings provides an important benefit from the point of the view at frictional forces under lubricated frictional conditions only. Therefore, it is suggested to apply the coating on piston ring of two-stroke engines.

G. Mr. Shailesh Dhomne (2014)[16]

Experimental and computational investigations on piston coated externally scavenged S.I. Engine. Two stroke engines have drawback of more fuel consumption & more exhaust emission, as compared with four stroke engines. Percentage of CO & HC emission is more in two stroke engines. Reductions in fuel consumption can be achieved by a variety of measures, including Improved Aerodynamics, Weight Reductions and Hybrid Power Trains. Significant improvements have been made to improve efficiency of the IC Engine that powers nearly all the world's vehicles. One promising technology for improving IC Engine efficiency, as well as performance and durability, is the Thermal Barrier Coating (TBC). In this study the performance of the engine is studied before and after the application of coating on the piston crown. Required modification has been done in the engine to increase the power and decrease the emission of CO & HC thereby making the engine environment friendly.

There is percentage increase in brake specific fuel consumption, brake thermal efficiency, mass of fuel consumed for different speeds and loads as:

1) Percentage change in brake specific fuel consumption on an average between without coating & coating1 = -11.10%
2) Percentage change in brake specific fuel consumption on an average between without coating & coating2 = -25.41%
3) Percentage change in brake specific fuel consumption on an average between coating1 & coating2 = -12.91%
4) Percentage change in mass of fuel consumed on an average between without coating & coating1 = -8.42%
5) Percentage change in mass of fuel consumed on an average between without coating & coating2 = -18.93%
6) Percentage change in mass of fuel consumed on an average between coating1 & coating2 = -9.73%
7) Percentage change in brake thermal efficiency on an average between without coating & coating1 = 11.14%

8) Percentage change in brake thermal efficiency on an average between without coating & coating2 = 25.40%
9) Percentage change in brake thermal efficiency on an average between coating1 & coating2 = 12.73%.

The performance of an externally scavenged engine will be improved with Ni-Cr-Ce Thermal Barrier Coating, as compared to normal piston & Ni-Cr coating. Therefore Ni-Cr-Ce Thermal Barrier Coating is an effective method to enhance performance of two stroke SI Engine. The engine with TBC piston helps in increasing the power of the engine as stated above. This is because complete combustion of the charge in the combustion chamber which leads to minimization of emission of carbon & hydrocarbon in the exhaust gases.

H. Michael Anderson Marr(2009)[17]

Studied on An investigation of metal and ceramic thermal barrier coatings in a spark-ignition Engine. Surface temperature and heat flux measurements were made in a single cylinder SI engine piston when uncoated and with two different surface coatings: a metal TBC and YSZ. A new thermocouple was developed to accurately measure surface temperatures. The engine was operated in a standard full load mode and a knock promoting mode featuring heated intake air and advanced spark timing. Cylinder pressures were measured to quantify knock. It was found that average heat flux into the piston substrate was 33 % higher with the metal TBC and unchanged with the YSZ relative to the uncoated surface.

The metal TBC was completely intact after the piston tests, while the YSZ coating was chipped on its perimeter. The cause of the chip was not clear, though this observation supports the notion that the metal TBC is more durable than YSZ

Both TBCs were effective at reducing peak heat flux and damping temperature swings at the aluminum surface. Peak heat flux into the piston crown was reduced by 69 % with the metal TBC and by 77 % with the YSZ coating relative to the uncoated surface.

The above points indicate that TBCs may be advantageous when used in SI engines even though they do not significantly reduce overall heat transfer. Damping temperature swings and reducing peak heat flux would protect components against thermal fatigue. Coating application could be targeted to areas of the combustion chamber that are particularly susceptible to thermal fatigue. Improved knock resistance would allow engines to optimize spark timing for efficiency and use lower octane fuels or higher compression ratios. However, the test program covered a narrow range of engine operating conditions and more research is required to confirm these findings.

I. J.Rajasekaran[18](2013)

Studied Effect of thermal barrier coating for the improvement of SI Engine performance & emission characteristics. As per the second law of thermodynamics the efficiency of the engine depends upon the extraction of work against the heat supplied. Minimisation of heat rejection leads to increase the work. Heat rejection takes place through the engine piston, valves and cylinder heads to the surroundings. The aim of the study is to minimise this heat rejection to the surroundings. Heat transfer through the engine parts is minimised by applying the thermal barrier coating materials on the top surface of the engine piston, cylinder heads and valves. In this study an attempt is made to reduce the intensity of thermal and structural stresses by using a layer of the ceramic material, like Yttria stabilized zirconia (YSZ) which has low thermal conductivity, high thermal resistance, chemical inertness, high resistance to erosion, corrosion and high strength was selected as a coating material for engine component. This study presents the effect of coating on the piston and the performance of modified four stroke petrol engine and the emission characteristics of the exhaust gas.

As the zirconia is a low thermal conductivity material, it reduces the heat loss from the cylinder to the surroundings. Therefore the efficiencies are increased and the emissions are reduced because of various chemical reactions takes place inside the cylinder at high temperature. Brake thermal efficiency and mechanical efficiency of coated piston are increased by the average value of 9% and 25% respectively. 7% reduction in total fuel consumption and 6% reduction in specific fuel consumption were achieved with the coated piston. 14% of NOX emissions were reduced due to coating because of nitrogen has observed by zirconia. 23% of unburned HC emissions were reduced by using the coated piston. CO emissions are reduced by 48% because of at high temperature C easily combines with O2 and reduces CO emission.

III. CONCLUSION

From the above literature review we concluded that,

- Plasma spray method is best method for coating hard metal to increase the wear resistance of the material.
- Among the NCC coated piston skirts, Ni–P–BN showed consistent low wear on either cast iron or the aluminum bores.
- The physical vapour deposition (PVD) Cr_xN coatings reduced wear rates and the coating thickness can be lower.
- The surface hardness is increased when aluminized and nitrided as compared to plain nitriding.
- Mostly Chromium coating is use to increase the wear resistance of the piston rings.
- Brake thermal efficiency and mechanical efficiency of coated piston are increased by the average value of 9% and 25% respectively. 7% reduction in total fuel consumption and 6% reduction in specific fuel consumption were achieved with the coated piston.
- There is few works done on Life Cycle Analysis of Molybdenum coated piston ring.

IV. ACKNOWLEDGMENT

The author, Bhavik Hirapara would like to express their thanks to prof. P. D. Patel of automobile department and all the staff members of mechanical and automobile engineering department of L.D. College of engineering for motivation, valuable guidance and warm support.

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