A Comparative study on the effect of oil Pocket Distribution on Coefficient of Friction at the Liner-Ring interface with Coated Piston Rings

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ABSTRACT

It has become necessary to optimize cylinder liner and piston ring surface finish design in order to achieve lesser friction, greater durability and decreased oil consumption in internal combustion engines. The frictional losses taking place at the engine liner-piston ring interface affects the efficiency of the engine.The effectiveness of the lubrication affects the coefficient of friction and the resulting wear between sliding surfaces. Retention of lubricant during sliding of surfaces is one of the major problems encountered in liner ring interface. One of the methods to achieve good lubrication is by making oil pockets on the surface of the sliding components. This study focuses on the influence of oil pocket distribution on the effectiveness of lubrication in the liner ring interface. Oil pockets were made on two sets of ring samples with two different coatings. To analyze the wear behavior, reciprocating wear tests were performed on liner-ring samples at different experimental conditions. Three basic parameters such as load, temperature and frequency were varied for the analysis. It was observed that the coefficient of friction as well as wear was found to be comparatively low in the case coated ring with dimples.

KEY WORDS: Cylinder Liner, Piston ring, Dimples, Lubrication, Base Oil.

1. INTRODUCTION

Friction losses in an internal combustion engine play a very important role in determining the fuel economy and performance of the vehicle. Approximately 20–30% of the friction losses in an engine are due to the piston/cylinder system, of which a large part is attributed to the piston ring. Proper lubrication and surface texture are most important factors in reducing friction in the liner ring interface.

Surface texturing is one of the methods of enhancing tribological properties. One of the most effective texturing methods to reduce friction in mechanical components is the laser surface texturing (LST). It has been found out that the friction between rings and cylinder liner can be reduced and thus fuel efficiency can be improved with laser surface textured piston rings with a surface micro- structure in the form of spherical micro-dimple (Etsion, 2009). Studies have also been carried out on the effect of oil pockets size and distribution on wear in lubricated sliding (Waldemar Koszela, 2007). As per the results of the work, optimum ratios of micro-dimple depth over diameter were calculated, which shows a friction reduction of almost 30% compared with an un-textured ring.

Laser texturing is the most popular technique in forming micro sized oil pockets. The oil pockets helps to reduce friction in the following ways: by providing the required lift as a micro-hydrodynamic bearing, and by acting as a reservoir of lubricant. These pockets also serve as a micro-trap for wear debris in sliding. Laser surface texturing also resulted in minimizing the surface ability to seizure. The dimples of spherical shape were formed on the coated ring surface. The three dimensions that characterize the surface texturing are diameter, depth and area density. For assemblies operated in lubricated sliding conditions, dimple depth over dimple diameter ratio range of 0.01–0.3 and area density to 30% exists. The presence of dimples with an area density of 10% improved seizure resistance of sliding pair. Textured surfaces can provide traps for wear debris in dry contacts subjected to fretting. Another advantage of the existence of micro sized oil pockets is that they improve the fretting wear resistance and increase in the fretting fatigue life.

Oil pocket depth to diameter ratio was in the range 0.03 and 0.11. Specimen surface had dimples with depths ranging from 45 to 115 µm. Oil pocket depths are comparatively large because, oil pockets should exist on the surfaces during the entire test duration.

2. MATERIALS

The cylinder liner segments used for the experiment were cut into 9 equal parts from 115mm diameter of cast iron cylinder sleeve with each part of 41.1×30×4.4 mm. Similarly the piston ring segments were cut into 9 equal parts from a 115mm diameter ring with each sample of 40 degrees profile angle. Two sets of coated rings were used for the experiment. The first set was copper coated ring segments while the second was phosphate coated ring segments. Both the sleeve and ring were cut by wire cut process. The surface of the sleeve segments was as honed with 120° honing angle and cleaned with acetone. The lubricant employed was base oil. Base oil was used because it contains no additives thus ensuring accurate wear data at the end of the experiment. The test was conducted on a reciprocating wear testing machine for duration of four hours.

Experimental Equipment and Specimen Preparation: All the experiments were conducted according to the standards of ASTM G181-11. Proper care and necessary precautions were taken during the experiment.

Description of the Equipment: High frequency reciprocating wear testing machine was used to conduct wear tests on cylinder sleeve. The machine is equipped with data acquisition and control systems. The test apparatus consists of an upper specimen reciprocating over the lower specimen with a constant stroke length. The drive consists of a motor of power 1 kW which drives a cam for executing the reciprocating motion. The frequency of reciprocation can be varied between 10Hz and 15Hz. The average sliding speed for each stroke, s, in meters per second, is calculated as follows:

$$s = 2\,f\,L$$

In the above equation ‘f’ is the frequency of reciprocation in cycle per second and ‘L’ is the stroke length in meters. The machine is provided with facility for setting the load, temperature, frequency and duration of the test. An LVRT (Linearly variable resistance transducer) is used for wear depth measurement. Friction force will be maximum at the reversal points. The contact is in the boundary lubrication regime at these reversal points. The stroke length is limited to 15 mm in the present test and these reversal points are well simulated as in the case of an engine.

Ring Specimen: The ring specimen is prepared by wire cut from a production piston ring of 115 mm diameter. Each ring specimen is cut at 40 degrees central angle. The ring is coated cast iron production piece. The rings were copper and phosphate coated. These rings are one of the mostly used rings in commercial vehicles. Proper care was taken in order to clamp the ring in its specific holder in order to avoid loosening during sliding.

Cylinder Bore Specimen: The specimen of cylinder bore is of cut section of production finished 115 mm diameter cylinder bore. The cylinder bore specimen is a cut section. Proper holders are provided in order to mount the bore specimen in a lubricant container.

Figure.1. Reciprocating wear test rig

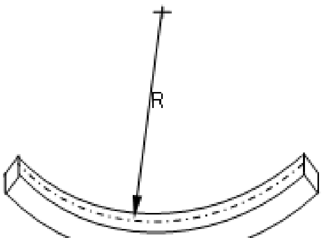

Figure.2. Schematic figure of the Ring specimen

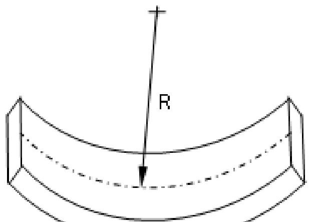

Figure.3. Schematic figure of the Liner specimen

Specimen Fixing: The ring specimen was fixed in a specimen holder which is screwed on to the reciprocating arm provided in the setup. The bottom specimen was fixed in the specimen holder which is placed in the container. The container can be filled with the lubricant. Proper alignment and centering between sliding surfaces is a critical factor for ensuring repeatable friction test results. Alignment affects the distribution of normal forces on the contact surface as well as the lubrication regimes that change as the ring specimen moves back and forth.

Lubricant: The lubricant used to analyze the wear behavior of the bore and ring specimens was base oil (SAE 30) with viscosity index of 97 and with flash point of 252°C.

Procedure: There are several parameters that can affect the wear but among them load, temperature and frequency are the three main parameters which are considered for the wear test.

The gray cast iron liner was made to slide against two commercially available sets of coated rings with oil pockets. One set of rings were copper coated and the other phosphate coated. The process parameters and their working ranges are given in Table.1.

Table.1. Parameters of the experiment

Parameter	Range
Stroke	15 mm
Frequency	10-15 Hz
Loads	10 - 200N
Temperature	Room - 200^0C

Initial mass of the specimens were measured using an electronic weighing machine. Ring and liner specimens were mounted in respective holders and verified for proper alignment. Load, temperature of lubricant and speed were adjusted according to the experimental design. The actual tests of 9 runs were conducted for 4 hours with base oil as lubricant. The lubricant bath is filled to cover the contact surface with at least 2mm of the selected lubricant.

After completing the test, the specimens were allowed to cool with the load removed. Specimens were removed, cleaned thoroughly in acetone and were dried. Final mass of the specimen was measured and the wear volume of the specimen was calculated by mass loss method. The coefficient of friction and wear volume were the responses whose behavior is mainly dependent on operating parameters.

3. RESULTS AND DISCUSSION

In the first phase of the experiment, copper coated ring segments with oil pockets were tested and the results obtained were further compared with the results obtained by testing copper coated rings without oil pockets. The comparison of results is shown in table.2 and 3.

Table.2. Mass loss observed in liner samples at three loads when tested with copper coated rings (with and without oil pockets)

Load (N)	Temperature (^{0}C)	Frequency (Hz)	Mass loss without oil pockets (gm)	Mass loss with oil pockets (gm)	Mass loss percentage (%)
100	100	10	0.0007	0.0005	28.57
150	100	10	0.0012	0.0008	33.33
200	100	10	0.0016	0.0009	37.50

Table.3. Mass loss observed in copper coated rings at three loads and the percentage decrease in mass loss

Load (N)	Temperature (^{0}C)	Frequency (Hz)	Mass loss without oil pockets (gm)	Mass loss with oil pockets (gm)	Mass loss percentage (%)
100	100	10	0.0005	0.0003	40.00
150	100	10	0.0006	0.0004	33.33
200	100	10	0.0008	0.0006	25.00

The wear observed in both liner and ring samples by calculating the mass loss kept increasing as the load increased. The copper coated rings with oil pockets on the ring surface showed less mass loss compared to the copper rings without oil pockets. The decrease in mass loss in the liner was observed to be around 28-38 %. The copper coated ring sample with oil pockets showed a decrease of about 25 -40% in the mass loss.

In the second phase of the experiment, phosphate coated ring samples with oil pockets were tested and the results that were obtained were compared with the results obtained by testing phosphate coated rings without oil pockets. The comparison of results is shown in table.4 and 5. Just as observed in copper coated rings, the phosphate coated rings with oil pockets on the ring surface showed less mass loss compared to the copper rings without oil pockets thus showing the effectiveness of the oil pockets in decreasing the wear in both the sets of coated rings. The decrease in mass loss in the liner was observed to be around 46 -55%. The copper coated ring sample with oil pockets showed a decrease of about 25-38% in the mass loss. The comparatively high percent of decrease in mass loss observed in liner and coated ring samples may be due to transfer of materials that takes place when bodies slide at very high speeds and temperature. The coefficient of friction data obtained after conducting wear test on both the sets of copper and phosphate coated rings with oil pockets were compared.

Table.4. Mass loss observed in liner samples at three loads when tested with phosphate coated rings (with and without oil Pockets) and the percentage decrease in mass loss

Load (N)	Temperature (^{0}C)	Frequency (Hz)	Mass loss without oil pockets (gm)	Mass loss with oil pockets (gm)	Mass loss percentage (%)
100	100	10	0.0009	0.0004	55.55
150	100	10	0.0011	0.0005	54.54
200	100	10	0.0013	0.0007	46.15

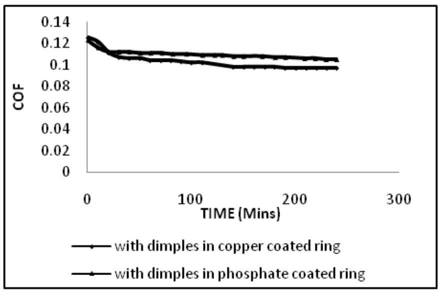

Figure.4. Comparison of the COF with respect to time in copper ring samples and phosphate ring samples with oil pockets at 100N load

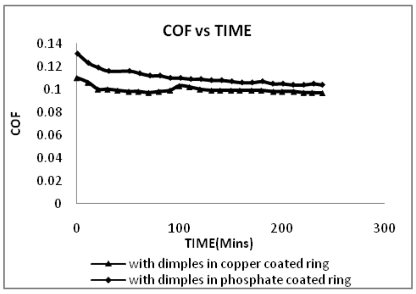

Figure.5. Comparison of the COF with respect to time in copper ring samples and phosphate ring samples with oil pockets at 150N load

Table.5. Mass loss observed in copper coated rings at three test loads and the percentage decrease in mass loss

Load (N)	Temperature (^{0}C)	Frequency (Hz)	Mass loss without oil pockets (gm)	Mass loss with oil pockets (gm)	Mass loss percentage (%)
100	100	10	0.0004	0.0003	25.00
150	100	10	0.0006	0.0004	33.33
200	100	10	0.0008	0.0005	37.50

It was observed that at the beginning of the test the coefficient of friction values were high (at around 0.120) but towards the end of the test the coefficient of friction values decreased considerably in case of both the coated sets of ring samples (about 0.90). Figures.4, 5 and 6 show the variation of coefficient of friction with respect to time at three test loads. When the test condition approaches the boundary regime, the samples showed the boundary friction coefficient of about 0.11 to 0.090.This also proves the effectiveness of the oil pockets in reducing the friction in the liner ring interface.

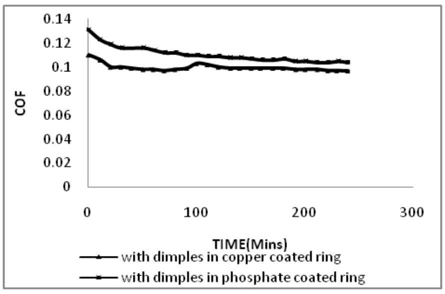

Figure.6. Comparison of the COF with respect to time in copper ring samples and phosphate ring samples with oil pockets at 200N load

4. CONCLUSION

After the completion of wear tests on both the sets of coated ring samples, the effectiveness of the oil pockets were analysed by comparing the results obtained after the wear tests on copper coated rings with oil pockets and phosphate coated rings with oil pockets. Surface texturing of the ring surface by laser sintering technique resulted in significant improvement in wear resistance in comparison to a system with untextured samples. The following conclusions were made.

- Both copper coated and phosphate coated rings with oil pockets showed considerably less mass loss in liner samples compared to coated rings without oil pockets. The percentage decrease was observed to be around 28-55%.
- The copper coated and phosphate coated rings with oil pockets also showed considerably less mass loss in ring samples with oil pockets compared to coated rings without oil pockets. The percentage decrease was observed to be around 25-40%.
- The decrease in mass loss signifies that making oil pockets on the ring samples is an effective method of reducing the wear in the liner ring interface.
- The oil pockets area ratio should not be very large, because it could cause increase of unitary pressures and then increase of wear intensity. The smallest wear was obtained for the largest dimple depth.
- The coefficient of friction observed at the end of wear tests conducted on both the sets of coated piston rings implies that when the test condition approaches the boundary regime, most of the samples showed the usual boundary friction coefficient of about 0.11 to 0.090.
- Making dimples on the ring surface in the manufacturing stage itself can enhance the precision and hence the effectiveness of lubrication.

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