EVALUATION OF TRIBOLOGICAL BEHAVIOR IN INTERNAL COMBUSTION PISTON RINGS ENGINE DURING WORK WITH ALCOHOL AND GASOLINE IN A FLEX FUEL ENGINE

Gustavo Augusto Volci, gustavo.a.volci@renault.com
Federal University of Paraná
Carlos José de Mesquita Siqueira, siqueira@ufpr.br
Federal University of Paraná

Abstract. *Tribological behavior of internal combustion piston rings engine includes complex interactions of mechanical contacts, temperatures, pressures, velocities and accelerations. This system is responsible to assure the combustion sealing with direct influence to the engines performance and oil consumption. Many solutions are applied in these days by automotive industries and many studies and developments were realized in the past for alcohol engines, but actually with the technology of flexible engines called Flex Fuel many classical gasoline engines were adapted to work with alcohol fuel and solutions to work with these two kinds of fuel were established. These Flex Fuel engines have a growing tendency in the Brazilian Market in the last years because the electronic flexibility technology to control the engines and the low price of alcohol in the market. The purpose of this paper is evaluate the wear and durability of first piston rings working with gasoline and ethanol alcohol as a fuel. This presentation will also describe the wear and friction of cast iron and steel Flex Fuel piston rings during reciprocating bench tests, vehicles durability tests and dyno tests. The results will guide the optimization of technical definitions for Flex Fuel piston rings.*

Keywords*: Tribology, piston ring, piston, wear, durability, ethanol, alcohol, engine, flex fuel.*

1. INTRODUCTION

Engine OEMs and piston ring and lubricant additive manufacturers are attempting to meet the challenges of changing consumer needs and new legislation for a cleaner environment and energy conservation. Developments in effective power train components and energy-conserving lubricants are essential in addressing these problems (Ballerini, 2006), (Yüksel and Yüksel, 2004). Better friction performance of piston rings, higher friction reduction engine oils and better fuel-efficient engines/vehicles will become increasingly important in the face of both the saving of natural resources and the reduction of friction, and improve de performance of systems.

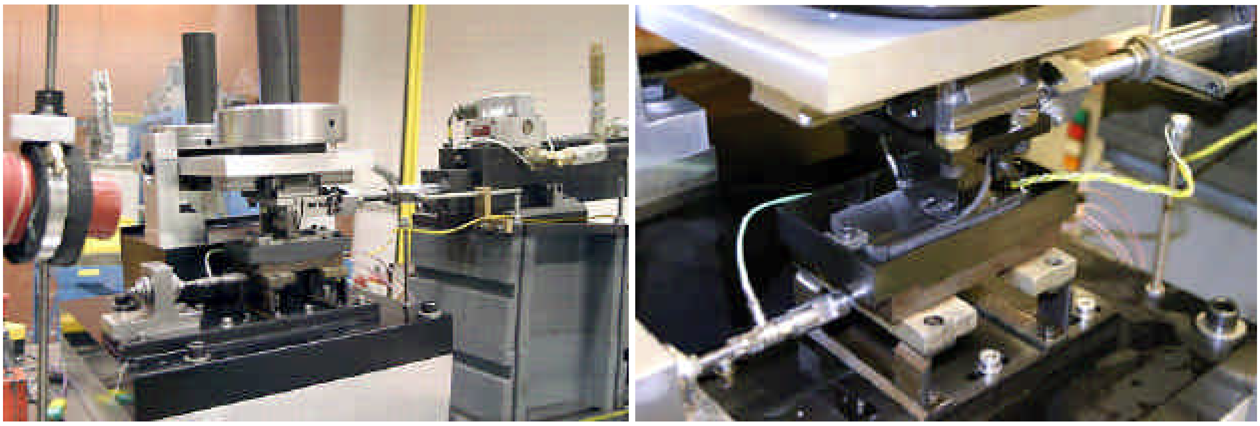
Stringent government regulations for improved fuel economy and reduced emissions are the driving force for utilizing alternative fuels, improved lubricants or coatings that are compatible with future engine materials and advanced fuel and lubricant systems.

Piston rings and cylinder bore wear with ethanol fuel E100 (a fuel with 100% of Anhydrous ethanol) has been a problem for Brazilian automakers. Some durability bench tests with E100 has shown piston rings deteriorations and scuffing, increasing oil consumption, reduction of life prevision and loss of performance. Wear occurs at the side of piston rings with risks of scuffing because de parts of piston ring coating damaged. Some changes have been shown to reduce wear and adapt surfaces with the environmental condition of work in a flex fuel engine (Andersson and Tamminen and Sandström, 2002). Cast iron piston rings with plasma molybdenum deposited and steel piston rings with nitrided layer are the most common types of piston rings used by the engine industry. Friction and wear performances of piston ring-cylinder bore system were studied in different ways of modeling and experiments (Taylor, 1993), (Truhan and Qu and Balu, 2004). The effects of engine speed, ring tension and face curvature on wear were studied under steady-state conditions (Rabinowicz, 1995), (Gahr, 1987). Surface topographical changes were analyzed, and measures of friction coefficient were done to identify the differences between piston rings during work with different oils specifications.

In the present study, the tribological characteristics of piston ring are evaluated running in ethanol piston ring configuration and gasoline piston ring configuration with different engine oils grades. In this study 2 top pistons rings specification were utilized, nitrided steel and cast iron ring. Stribeck curves for each type of ring were traced with SAE engine oil grades 15W40, 10W40 and 5W30 (Georges, 2000). Bench tests were conducted to determinate the Stribeck parameters and correlated with engine tests to evaluate the correlation between benches and real engine solicitation.

2. EXPERIMENTAL

The top rings were tested in a high frequency reciprocating friction machine. A section of piston ring is installed in a fixture holder and reciprocates against the counter cylinder liner segment, as shown in Fig. 1.

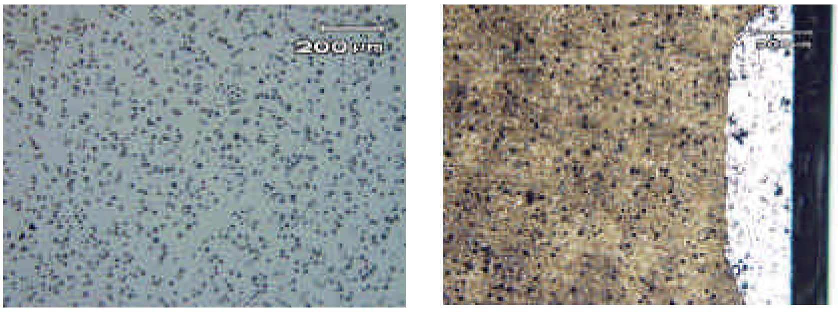


(a) (b)

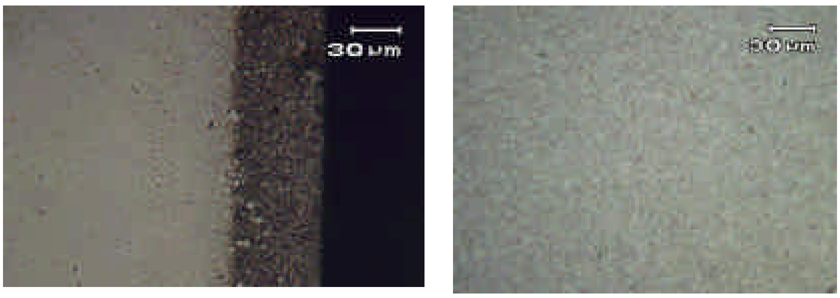
Figure 1. Picture of reciprocating friction machine (a) and piston ring assembly.

The cylinder liner segment is fixed on the machine and the ring fixed on the oscillating arm. Over the oscillating arm a normal load was applied to simulate the movement and effort between the ring and cylinder line during an engine work. A heater block under the cylinder liner segment assures the control of operating temperature, and a peristaltic pump delivers engine oil with a flow rate of 1 drop each 120 seconds. To measure the friction force, a piezoelectric is attached to the block heated

Piston rings for the tests were obtained from the supplier with a metrological control report and the cylinder liner segments directly cutting the engine block. Cylinder segments were measured and roughness controlled. The engine oils used were SAE 15W40, 10W40 and 5W30 as specified for these applications. The cylinder bore has a cast iron composition and the top piston rings tested were with nitrided in martensitic stainless steel and martensitic ductile iron as illustrated in Fig. 2.



(a)



(b)

Figure 2. Microstructure photographs on piston ring coating and structure. (a) Martensitic ductile iron and molybdenum thermal plasma coating 100 X (Without and with nital attack). (b) Nitrided layer of depth with 70 mm in martensitic stainless steel. 500 X (Vilela attack).

The nitrited stainless steel rings are normally used for alcohol and flex fuel engines in Brazilian market, while iron with molybdenum thermal plasma coating piston rings are in general applied in different types of classical gasoline engines as shown in Tab. 1.

Table 1. Materials and coatings of top piston rings in Brazilian Market.

Company	Engine Capacity (cm3)	Nº Valves	Engine fuel type	Top Ring Width (mm)	Top Piston Ring Material	Coated
FORD	1600	8V	Flex	1,2	Stainless Steel	Nitrated
FIAT	1000	8V	Flex	1,2	Stainless Steel	Nitrated
	1300	8V	Alcool	1,5	Cast Iron	Chrome
	1300	8V	Flex	1,2	Stainless Steel	Nitrated
	1400	8V	Flex	1,2	Stainless Steel	Nitrated
	1500	8V	Alcóol	1,5	Cast Iron	Chrome
	1800	8V	Flex	1,2	Stainless Steel	Nitrated
GM	1800	8V	Alcóol	1,5	Cast Iron	Chrome
	1800	8V	Flex	1,2	Stainless Steel	Nitrated
	2000	8V	Alcool	1,5	Cast Iron	Chrome
	2000	8V	Flex	1,2	Stainless Steel	Nitrated
PEUGEOT	1400	16v	Flex	1,2	Stainless Steel	Molybdenum
	1600	16v	Flex	1,2	Stainless Steel	Molybdenum
RENAULT	1000	16v	Flex	1,2	Stainless Steel	Molybdenum
	1600	16v	Flex	1,2	Stainless Steel	Nitrated
VW	1000	8V	Flex	1,2	Stainless Steel	Nitrated
	1600	8V	Alcool	1,2	Stainless Steel	Nitrated
	1600	8V	Flex	1,2	Stainless Steel	Nitrated
	1800	8V	Flex	1,2	Stainless Steel	Nitrated

The test conditions to determinate the Stribeck curves for each type of ring are listed in Tab. 2. The curvature of the ring is set to conform to or be a little smaller that of the cylinder liner segment. Each type of ring was tested twice with each oil and the average was taken for the final results.

Table 2. Experimental conditions.

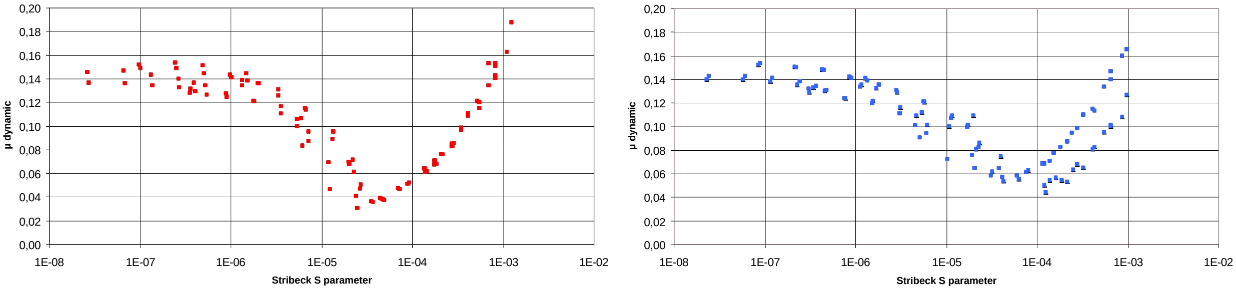
Normal load	10, 15 and 50N
Oscillating frequency	0.2, 0.5, 1, 2, 3 and 4Hz
Sliding distance	50mm
Cylinder liner segment dimensions	40mm x 88mm
Top piston ring width	1,2mm and 1,5mm
Engine oil specifications	15W40, 10W40 and 5W30
Engine oil flow rate	1 drop each 120 seconds
Temperature	90ºC, 23ºC and 7ºC

To obtain the wear comparative between each ring definition, a long test was developed during 48h with each ring, engine oil 15W40, 55N of load and 4Hz and block heated with 100ºC. After the tests, the surfaces of ring and cylinder liner segments samples were analyzed using 3D Cartography, and the wear identified for each pistons ring tested.

3. RESULTS AND DISCUSSION

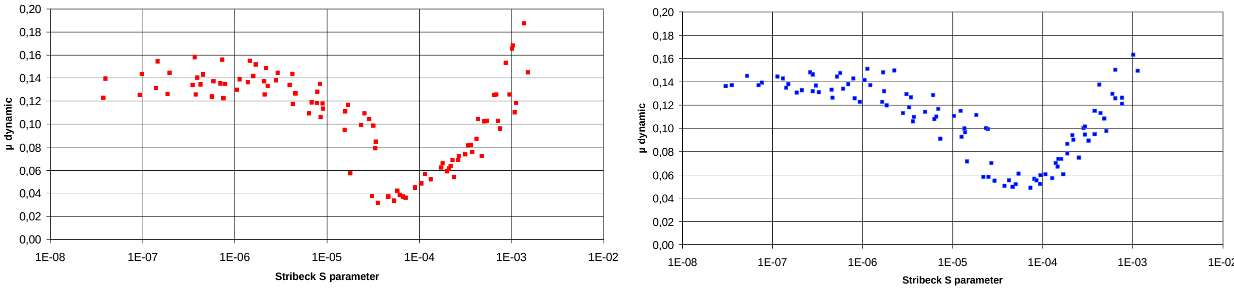
3.1. Friction caracteristics of rings

Engine components behavior influence directly the durability and operation period of vehicle parts. Friction characteristics affect the fuel economy, engine oil consumption, power loses, emissions and wear of engine components. This wear is normally related to lubricant properties of engine oils, working conditions and piston ring material and coatings. Fig. 3, 4 and 5 shows coefficient of friction measured in a high frequency reciprocating friction machine.



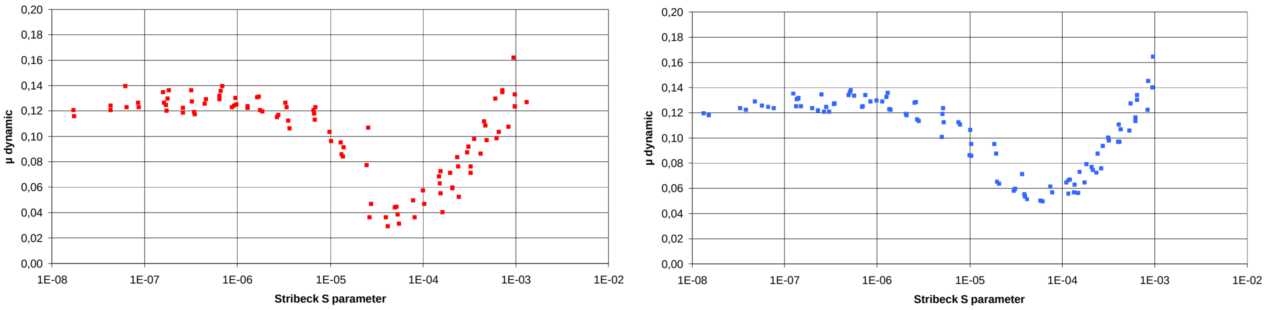
(a) (b)

Figure 3. Variation of friction coefficient and Stribeck parameter of Cast ion ring (a) and Stainless steel ring (b) against cast iron cylinder liner segment with engine oil grade 15W40.



(a) (b)

Figure 4. Variation of friction coefficient and Stribeck parameter of Cast ion ring (a) and Stainless steel ring (b) against cast iron cylinder liner segment with engine oil grade 10W40.



(a) (b)

Figure 5. Variation of friction coefficient and Stribeck parameter of Cast ion ring (a) and Stainless steel ring (b) against cast iron cylinder liner segment with engine oil grade 5W30.

The cast iron piston rings shown lowest friction coefficients in the beginning of hydrodynamic phase of Stribeck curve (S= 4.10^{-5}). The values of friction are around 0,035μ for cast iron rings and 0,060 for stainless steel. We can identify the initial of hydrodynamic phase earlier for the cast iron rings. This difference likely occurs because the interactions of tribofilm produced by the contact of cylinder liner segment and the molybdenum coating in the surface of the ring. The Fig. 6 shows a comparative between measures with 2 types of rings and 3 different engine oils.

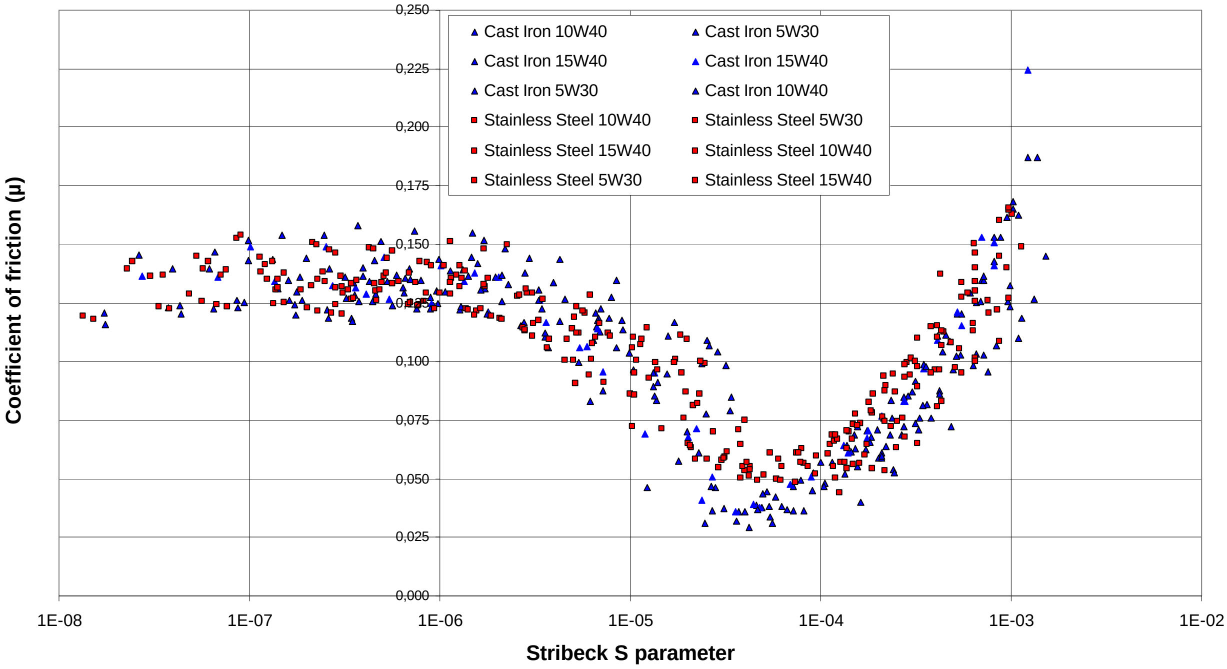


Figure 6. Stribeck values for each ring and oil tested.

The friction characteristics of both piston rings done the values of friction coefficient very similar in boundary lubrications condition (Stribeck parameter = 1. 10^{-7} to 1.10^{-6}), as showed in Fig. 7.

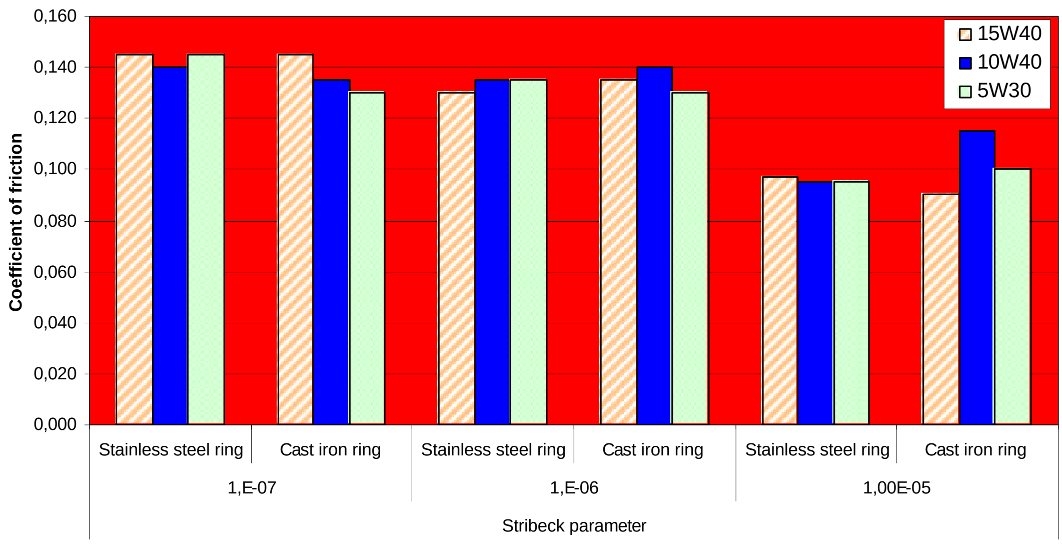


Figure 7. Average values for boundary and mixed phase of Stribeck curve.

3.2. Wear caracterisation

To determinate the wear of each ring of this study, each sample was stabilized with a normal charge of 50N, frequency 1Hz, block heated at 90ºC until the coefficient of friction stabilization. Around 4000 seconds were performed to arrive in these conditions. After the running-in phase, two rings of each material were tested with 15W40 oil during 48h or 692.000 cycles. The Fig. 8 shows the stabilization phase measured for each ring.

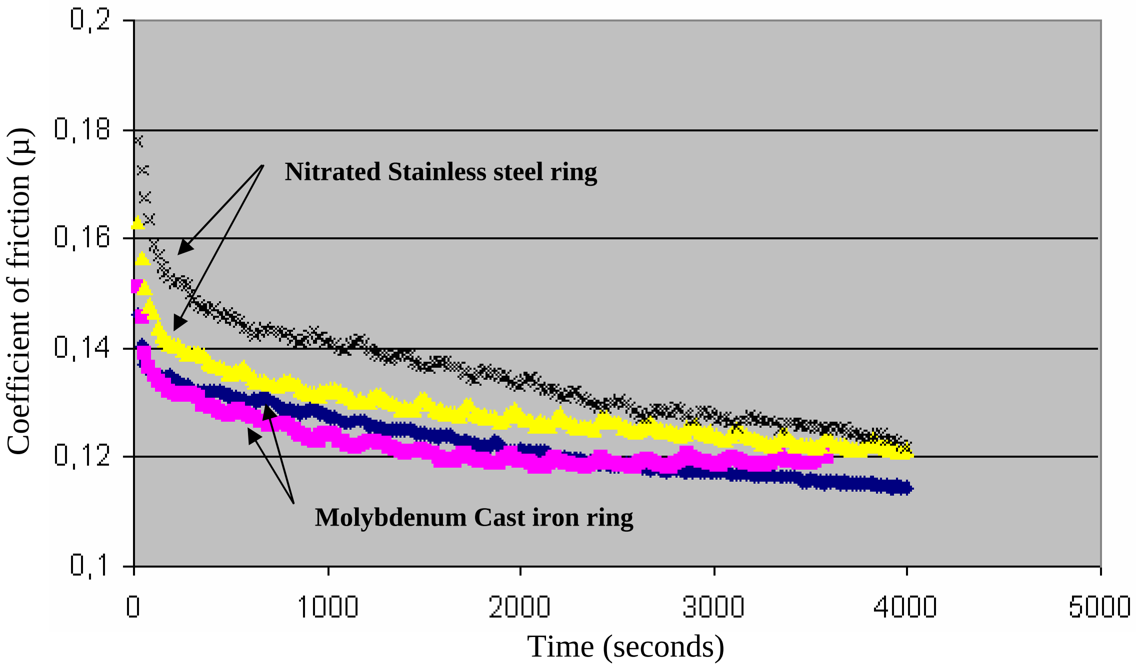


Figure 8. Stabilization of friction coefficient before long tests.

Cast iron rings with plasma molybdenum coating shows a quickly reduction of friction coefficient, this indicates that the transfer of molybdenum coating for the tribofilm happens in the beginning of the contact and the lubricant properties of molybdenum helps to avoid the wear and reduce the friction. Nitrated stainless steel rings have a slow down friction coefficient evolution, this ring has a hardness around 900-1400Hv against 28-38HRC of cast iron ring. This hardness of this ring, the nitrided layer and the inexistence of a lubricant coating indicates that the running-in process of this ring spends more time to reduce the friction condition and wear the surface.

After 48 hours of sliding condition related, the surface of rings and cylinder liner segment were inspected with 3D cartographies and the wear rates determinate. Fig. 9 shows the values of wear in cylinder liners and piston ring contact surfaces.

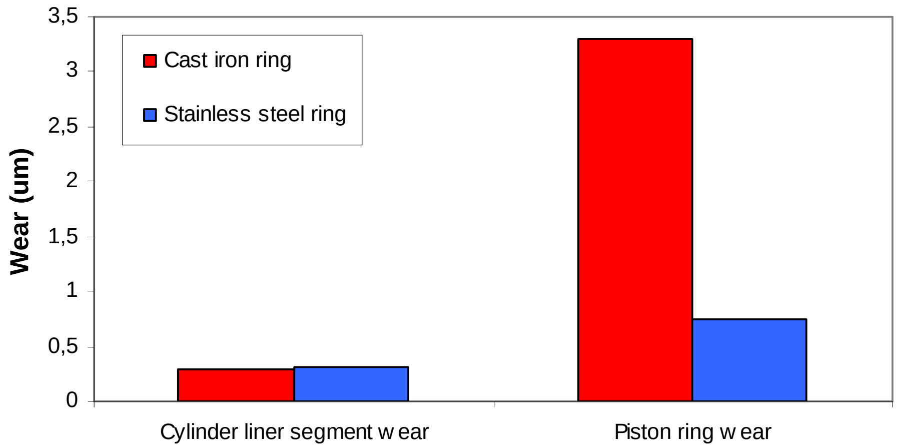
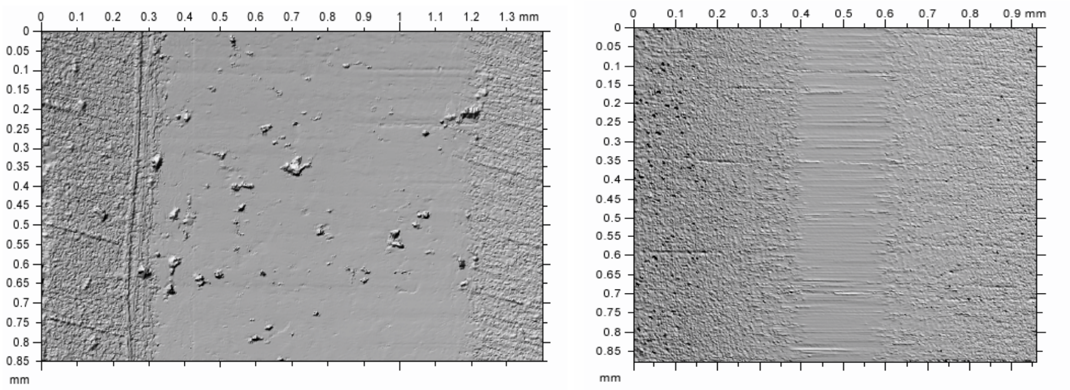


Figure 9. Wear in cylinder segment liner and piston ring surfaces after 48h of sliding conditions.

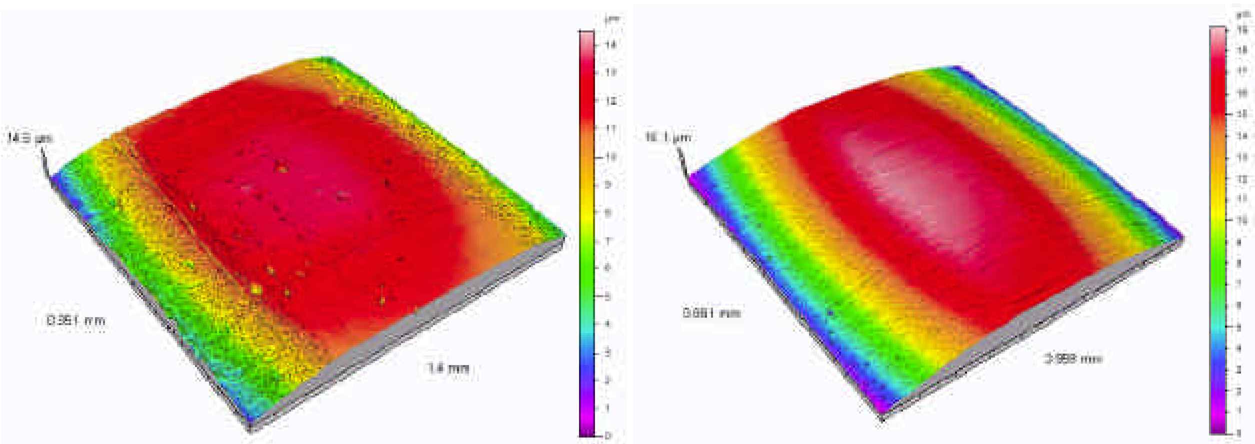
Regarding cylinder liner surface, the wears measured between two different conditions of sliding samples are very similar around 0,3µ. The wear showed in the cylinder liner surface in the 2 conditions of test was very low as verified in the samples with ocular microscope. In many parts of the sample the wear not arrived to touch the cylinder horning and the roughness of the cylinder liners has the same values.

The behavior of piston rings surfaces wear shows a great difference between cast iron and stainless steel. The wear of cast iron rings was four times superior of the wear with stainless steel rings. This verification explains why molybdenum coating helps the initial contact between the ring and the cylinder liner forming a very lubricant tribofilm, but after this initial contact the wear of molybdenum coating occurs continually during the sliding process (Yuansheng and Huadong and Nicoll and Barbezat, 1992). The contact area and the friction coefficients grow during the test. The contact between stainless steel and the cylinder liner occurs without evolution of friction coefficient and area, and finally without greats values of wear. Fig. 10 and Fig. 11 show the width of contact area and cartographies 3D of piston rings surface after the tests.



(a) (b)

Figure 10. Width of contact in cast iron piston ring (a) and stainless steel piston ring (b) after 48h of test.

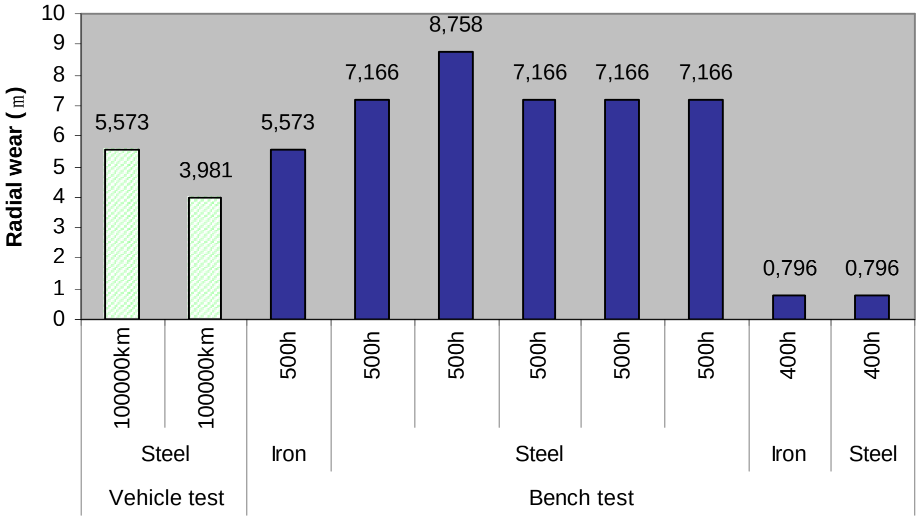


(c) (d)

Figure 11. Cartographies 3D of cast iron piston ring (c) and stainless steel piston ring (d) with the values of surface wear.

3.3. Wear of rings during vehicle and bench tests

Piston rings of engines tested with dynamometer bench facilities and vehicle tests were analyzed to determinate the rate of wear after objectives of 100.000km. All the rings were tested with 15W40 oils in a flex fuel engine running with ethanol fuel. Two piston rings after vehicles tests and 8 rings from bench tests were measured to determinate the values of wear and the difference in wear evolution in each type of test. Fig. 12 shows the values of radial wear measured in the rings tested.



Figures 12. Values of radial wear in stainless steel and cast iron rings running in vehicle and bench tests.

In general the values showed in vehicle tests are lower than the values of bench test, as expected, because the full load of bench tests (Wide Open Throttle condition) and the speed of the tests (500h between power and torque speeds, and 400h at power speed) impose more charge, temperature and finally degradation at contact surface. The vehicle test was realized with stainless steel ring because just this vehicle was available for tests in that time.

The radial wear of rings tested in bench facilities shows a very different condition between the 2 types of cycle tests realized. The 500h test between torque and power demonstrate a high level of wear if compared with the test at 400h in power conditions, this difference can be explained by the influence of torque speed when the engine is exposed to a maximum combustion pressure and for consequence maximum charge over the piston structure.

Evaluating the wear in 500h tests, the values of wear of cast iron rings were lower than steel rings, in coherence with the measures verified with Stribeck curves. This happens because in normal and constantly use the engine piston rings work in mixed and hydrodynamic lubrication phases, where the Stribeck curves traced demonstrated a better performance in friction of the cast iron rings (Tung, 2004).

In summary, the tribological characteristics of 2 types of top pistons rings normally used in Flex Fuel engines have been investigated in this paper. Different types of engine’s oil were characterized ant tested. And finally the radial wear of rings was compared during vehicle, bench and rig tests. The performance of each ring type in different oils grade has been studied and measured by the Stribeck curves. For the cast iron ring coated with molybdenum, the Stribeck curve shows lower values of friction in the mixed lubrication, while the friction coefficient at lowest values of Stribeck are very similar for both rings. At boundary lubrication condition 5W30 and 10W40 oils showed similar values of friction coefficient, but 15W40 oils demonstrated the values of friction a slightly superiors than the others. With this conclusion the cold start of engines, normally more difficult in Flex Fuel engines, has the tendency to be more rigorous with 15W40 oil and the wear in these conditions more elevated. The long tests performed with the rings demonstrated a better wear resistance of stainless steel rings during the 48h tests. In this condition of high load and frequency of sliding contact, the rates of wear of the molybdenum coating were elevated, and this wear increase the friction coefficient and the removal of tribofilm formed in the beginning of the test. Bench tests demonstrated radial wear higher than vehicle tests and rig tests (Downson and Priest and Dalmaz and Lubrecht, 2003). The better behavior of cast iron piston rings in mixed lubrication condition of sliding and the better results of lower oil grades in boundary condition demonstrate a good potential to use this combination in Flex Fuel engines.

4. ACKNOWLEDGEMENTS

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