Materials Science Forum Vols. 727-728 (2012) pp 1931-1937
Online available since 2012/Aug/24 at www.scientific.net

doi:10.4028/www.scientific.net/MSF.727-728.1931

Laser Modified Thin Layers in Piston Rings

F. de Oliveira[1]; W. de Rossi[2]; J. L. Rossi[2]

[1] MAHLE Metal Leve, Jundiaí, SP, Brazil
[2] Instituto de Pesquisas Energéticas e Nucleares, IPEN - CNEN/SP
Av. Professor Lineu Prestes, 2242 - Cidade Universitária - 05508-900 - São Paulo, SP, Brazil
felipe.deoliveira@br.mahle.com

Keywords: piston ring; laser hardening, microstructure, ovality.

Abstract: The new engine developments are providing engine mechanical and thermal loads increase on the components. Besides the unfavorable wear conditions, the components should provide similar or improved performance compared with current baselines. For piston rings, the performance is given by the ring capacity of sealing and scrapping. These performances can be measured in an engine using the results of lube oil consumption and blow-by. The main intention of this work is to provide support for new piston rings developments by laser hardening parameters optimization, reducing the wear degradation. Hence, the aim of this work was to evaluate the influence of laser hardening on contact surface from the second ring and verify the microstructure modification and ring's shape distortion due to heat input. The results indicate that the laser parameters can be tailored in order to achieve adequate macrostructures and micro constituents distribution. The ring ovality was inside to acceptable levels.

Introduction

The demands on piston rings applied in diesel engines are increased as the engines are developed. This means that new manufacturing and surface treatments methods must be used to improve the performance of the piston rings. The main advantage of laser surface treatment is that the energy from the laser beam can be concentrated at the surfaces that need to be improved [1]. Stricter emission regulations on heavy-duty diesel (HDD) engines have brought more demanding conditions to the engine piston ring pack. The current heavy-duty diesel scenario already demands, in several markets, for more resistant components due to the more severe engine operation conditions. This reflects on rings meaning higher temperature, higher combustion pressure and more abrasive and oxidant environments, added to longer interval for lube oil change. These trends are connected to the emissions regulations. Fig. 1 summarizes the present and future limits for emissions of particulate material and nitrous oxide (NOx) that those engines shall comply with [2].

In order to provide products for any engine condition, we can offer a second groove ring solution that meet increased wear resistance with environmental responsibility: using laser to improve wear and low friction [3]. Low fuel consumption is a target for all engine developers. This demand is aligned with many others: high power output, improved mechanical efficiency, low emissions etc. These demands are linked to economic, politic and environmental aspects and they all come to a key-demand: low friction components [4]. Global environmental concerns are driving internal combustion engine designs to higher efficiency. New legislations are setting up milestones to reach emission goals and limit NOx and particulate material emission levels to achieve more environmentally friendly engines. Latest developments are heavily focused on the reduction of pollutant emissions through the improvement of the combustion efficiency or the introduction of after treatment systems. Following all these trends, this paper presents the pre-development of an advanced piston ring surface modified by laser process.

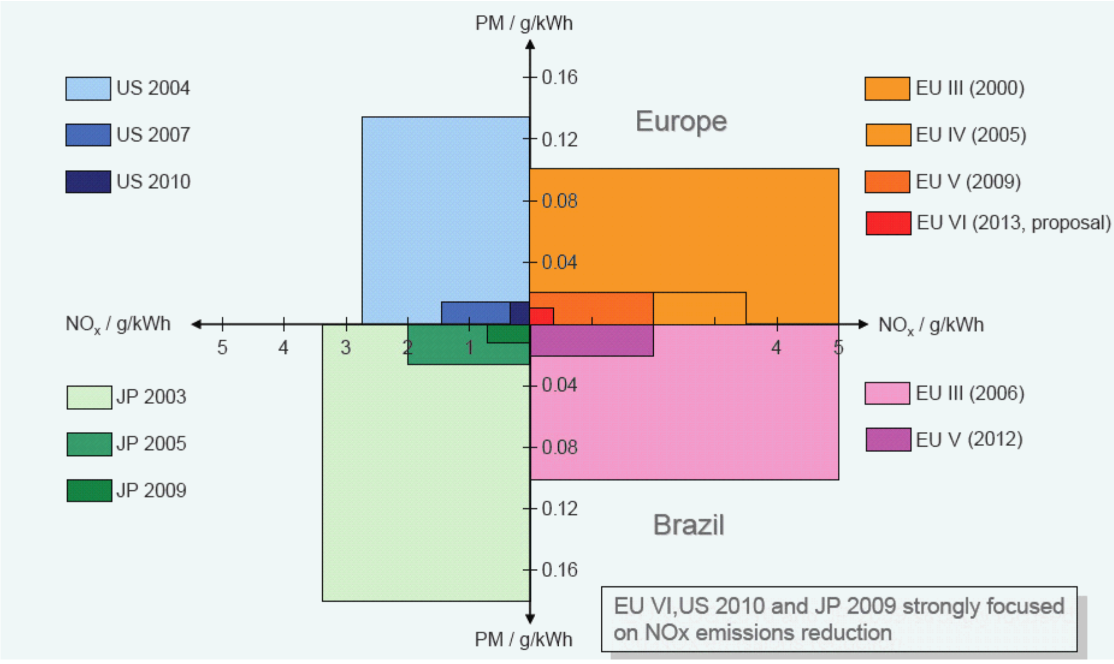


Fig. 1. Emission legislation map for HDD engines [2].

Experimental

Due to the complexity of laser treatment, it was carry out tests in prototypes where were changes variables as velocity of focal point of laser beam (V = mm/s), energy of laser pulse, temporary width of the pulse (Tp = ms) and repetition rate (F = Hz) in order of to know the best parameters to be applied in the final samples. The preliminary tests were worked on the lateral face of the piston rings, once the initial proposal was to evaluate the interaction of the laser beam with the material. Latter, these parameters were changed to accomplish the hardening of the periphery of the rings as well called as the running face. Another aspect taken into account was the behavior of heating occurred on samples. The difference of temperature interfered on hardened region due to the surface time exposure and the heat transmission. This fact generated a small adaptation in the parameters in order to adequate the hardness on the peripheral surface of the rings. All Vickers hardness measurements were done with load of 50 g. The rings were made of gray cast iron which predominant graphite phase was type D and E according to ASTM A247-67. The chemical composition of the gray cast iron (% mass) is: C 3.22; Si 3.26; Mo 0.97; Cu 0.88; Mn 0.62; Cr 0.44; P 0.19; V 0.12; S 0.043; Nb 0.12; Ni 0.67.

Results

It was registered the behavior of eleven sets of laser parameters, in order to verify the variables of hardened coating thickness and visual aspect as well. Fig. 02 shows laser traces obtained after exposure of the lateral surface of the ring. It is observed that sample #3 the laser trace was misplaced and in some samples the laser trace is not visible. It was carried out a metallographic characterization of cross sections of these rings are showed in Fig. 03. This figure shows a typical martensitic structure with visible heat-affected zone (HAZ) caused by the laser irradiation under different parameter condition.

Based on these results it was possible to observe a selection of the best conditions for irradiation parameters. In this case, it was chosen samples #9 and #11. The Tab.1 shows the set of parameters used to control the laser for samples #9 and #11. Figs. 03 and 04 show the enlarged microstructure for samples #9 and #11.

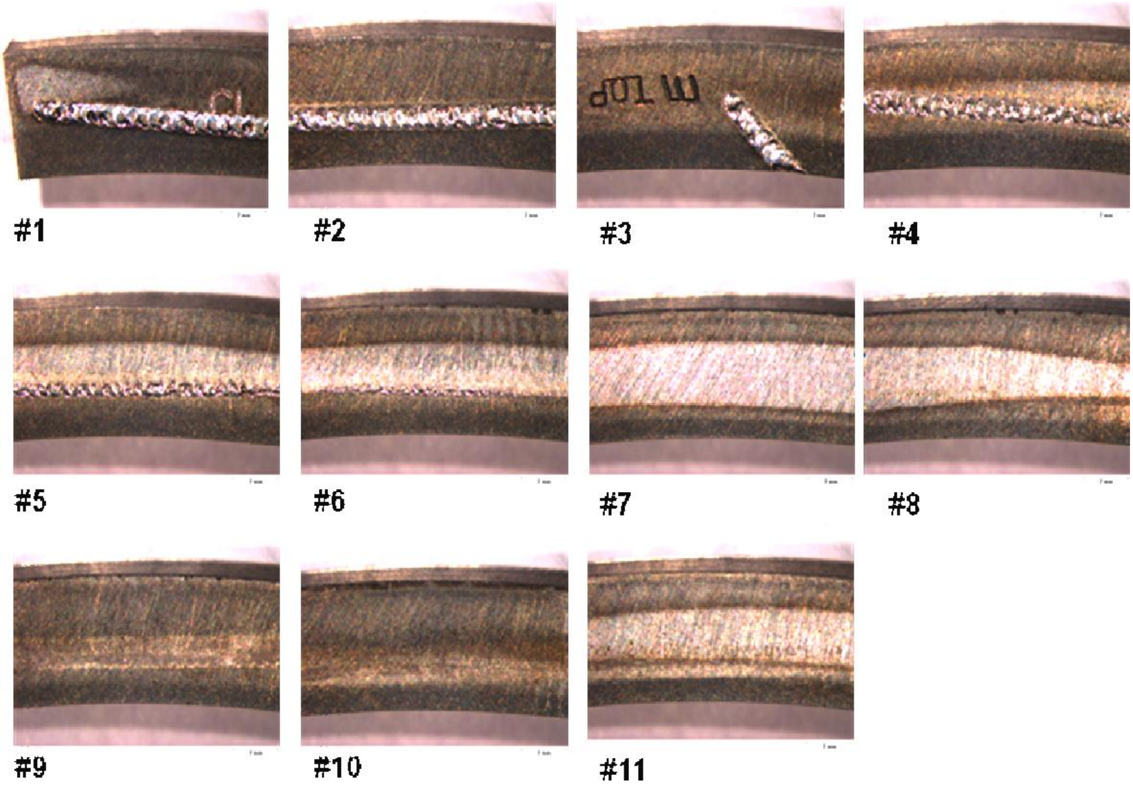


Fig. 2. View of lateral surface of the piston rings under influence of different laser irradiation parameters.

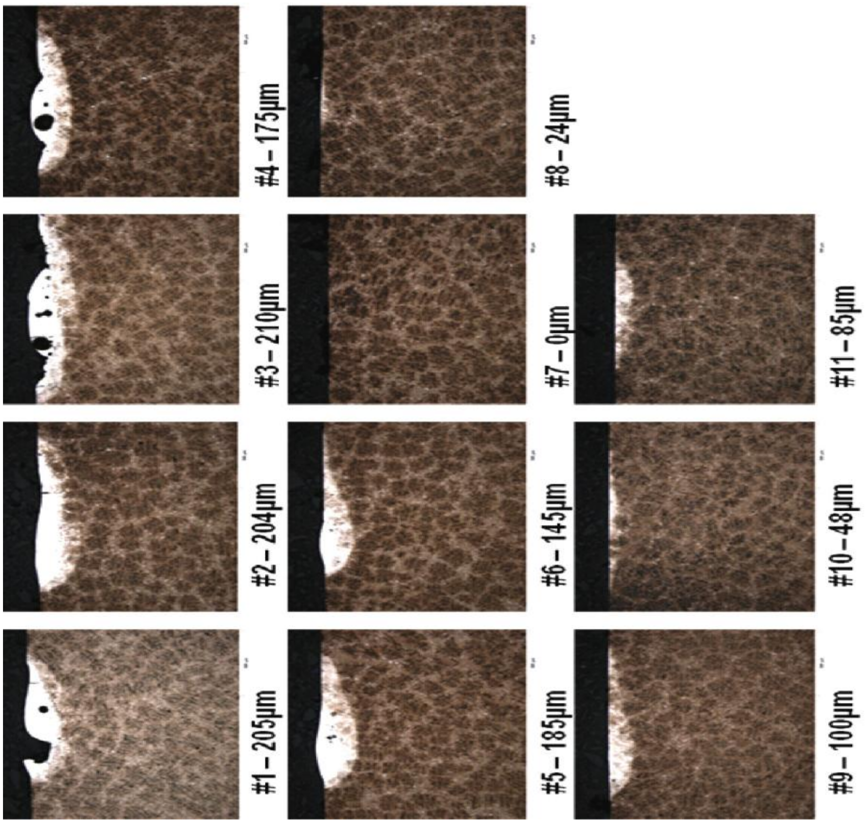


Fig. 3. Microstructure showing the section views of the piston rings under influence of different irradiation parameters. The white contrast phase is the laser-modified layer. Nital 3% etch.

Table 1. Laser parameters used in the hardening of rings lateral side, samples #9 and #11.

V = 270 m/s - Trace length = 15 mm	
Protection of argon = 15 L/min - Focal length = 100 mm	
Sample #9	Sample #11
Tp = 12 ms	Tp = 10 ms
F = 9 Hz	F = 9 Hz
Es = 5.0 J	Es = 5.0 J
Z = - 8	Z = - 9

Where: V = Velocity of laser focal point; Tp = pulse temporary width; F = repetition rate; Es = energy of laser beam; Z = position of a focal point in relation to the irradiation surface.

The Fig. 4 shows the heat-affected zone thickness caused by laser irradiation for samples #9 and #11, measuring 100 µm and 85 µm, respectively. The head-affected-zone had a Vickers hardness level higher than the ring nucleus average, as showed in Table 2. The hardening input data were done along the ring surface, where laser marks could be seen. All measurements were done with 50 g of load. Table 2 shows results from samples #9 and #11. Based on Table 2, a hardness curve was plotted see Fig. 05. The maximum superficial hardness located in the heat-affected zone by laser irradiation presented a hardness value 70 % higher than the ring nucleus region.

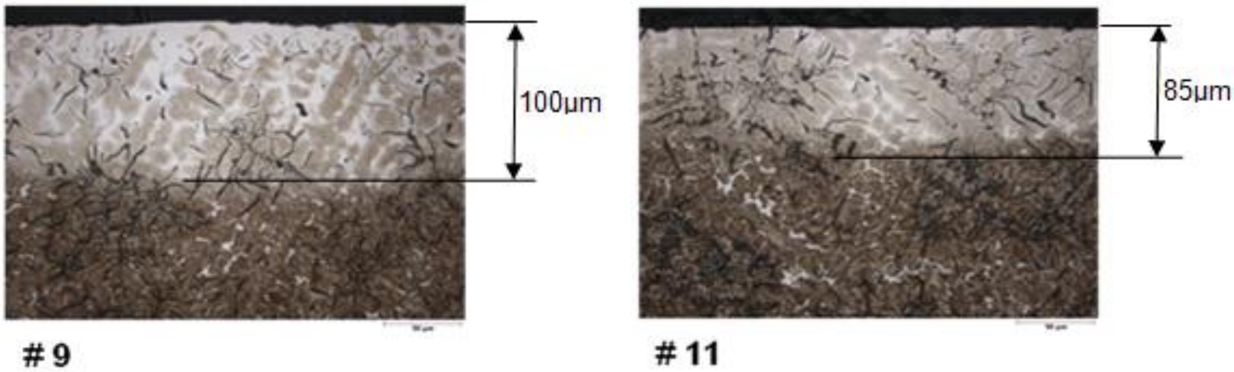


Fig. 4. Optical micrograph showing detail of samples #9 and #11 of ring section under influence of chosen irradiation parameter as showed in Table 1. Nital 3% etch.

Table 2. Vickers $HV_{0.05}$ hardness taken values from different depths for samples #9 and #11.

no.	10 µm	20 µm	30 µm	40 µm	50 µm	60 µm	70 µm	80 µm	90 µm	100 µm
#9	575±3	655±3	726±4	644±3	759±4	766±4	613±3	457±4	466±4	453±4
#11	566±5	603±6	623±3	644±3	660±3	644±3	532±4	516±4	532±4	509±4

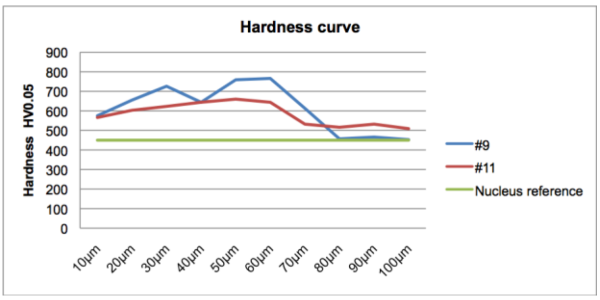


Fig. 5. Case depth average values hardness considering samples #9 and #11, under influence of different irradiation parameters.

For the preparation of the final samples, where the laser irradiation occurred on the peripheral surface, it was used the parameters shown in Table 3. In this condition the whole lateral surface of the piston ring was covered with the laser irradiation.

Table 3. Laser parameters used in the hardening of rings peripheral face.

V = 270 m/s	TP = 10 ms
Trace length = 15 mm	F = 9 Hz
Protection of argon = 15 L/min	Es = 5.0 J
Focal length = 100 mm	Z = -12

It was verified the thickness of thermally affected layer by the laser and the results of hardness range as well for the lateral of the ring. Vickers hardness measurements on the peripheral surface and depths were used to characterize the case depth hardness. The maximum superficial hardness located in the heat-affected-zone by laser irradiation (blue line) in Fig. 6 presented a hardness value 70% higher than nucleus region (red line). The blue line indicates a depth of hardening treatment up to 60 μm.

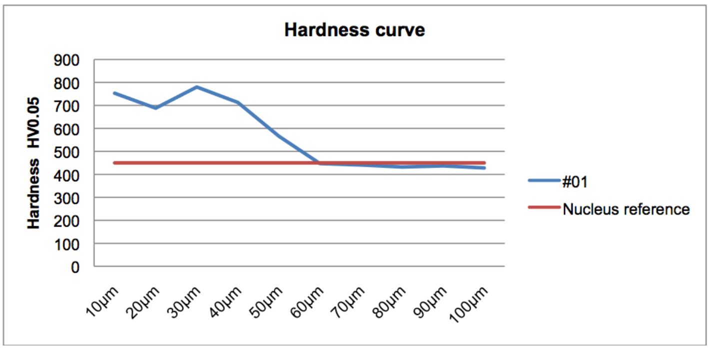


Fig. 6. Case depth average Vickers hardness values, under influence of laser irradiation process, measured for the peripheral surface of the ring.

For the laser effect characterization it is not only necessary to measure the heat affected zone a and hardness depth profiles but as well as to measure any distortion of the ring that may have been caused by the laser irradiation. The piston ring when it is out of the cylinder does not have a constant radius. Its shape is such that when inside the cylinder it produces a pressure uniformly distributed over the cylinder wall, assuming a circular shape. These types of ovalization are called positive and negative and may be considered as good requirements for the distribution of pressures [5]. The rings distortion before and after laser treatment was carried out by measuring the ring characteristics in terms of maximum outside diameter and minimum outside diameter. It was also measured the free spread, closed gap and ovality parameters. This data is shown in Figs. 7 and 8 for 5 different ring samples under the same laser irradiation parameter as showed in Table 3.

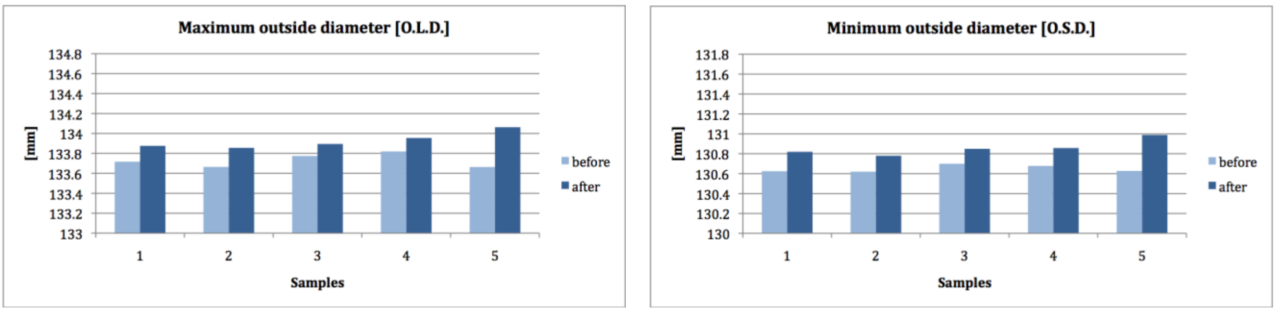


Fig. 7. Differences of maximum and minimum outside diameter before and after laser process for five different ring samples.

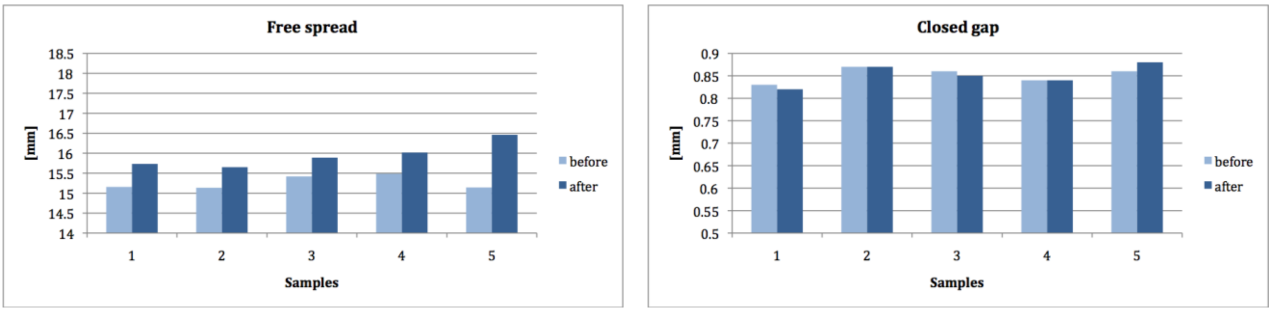
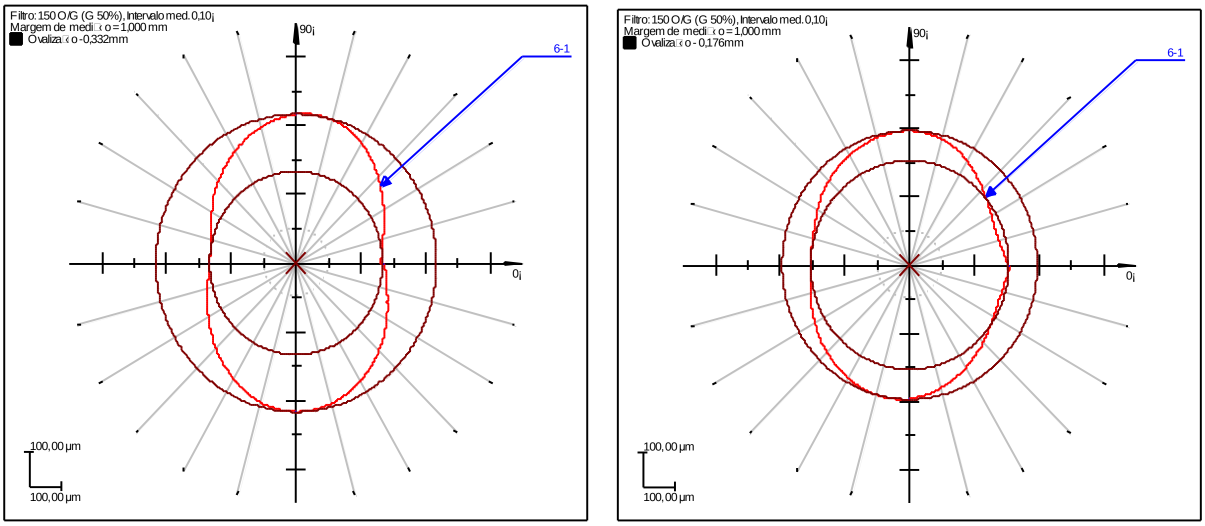


Fig. 8. Differences of free spread and closed gap parameters before and after laser process for 5 different ring samples.

The ovality of the rings was also measured and the values are shown in Fig. 9 before and after laser treatment, respectively. For the studied piston rings the results of minimum and maximum outside diameter, the free spread it demonstrated that after the laser treatment was an increase of measures extent. Regarding the closed gap it can be said that the laser treatment is irrelevant for this type of measurement. To this base material was observed graphics. The results for ovality showed that the ovality post laser treatment led to a more cylindrical profile in terms of absolute values, but with a tendency to form peaks at the tips.



(a) (b)

Fig. 9. a) Ovality graph for the ring before laser processing. b) Ovality graph of the ring after laser processing.

Conclusion

As it was presented in this work the innovative process in laser modified thin layers in piston rings. Based on results, it was possible to verify the efficiency of the achievements. Regarding visual aspects, the piston rings showed a regular contact pattern along the peripheral surface after laser hardening. In addition, it was observed some small marks originating from laser process. The hardening results showed that the piston rings had similar level of hardness (800 HV) when compared with the current piston rings with hard chromium coating usually offered for Diesel engines application. The dimensional analysis showed that the samples presented an expected shape after laser hardening and the ovality were inside to acceptable levels.

References

[1] Wiklund, G.; Kaplan, A., Laser cladding of cast iron using a 12 kW CO_2-laser combined with induction heating. 10th NOLAMP Conference: the 10th Nordic Laser Materials Processing Conference, 17-19 August 2005, Luleå Sweden. p. 217-224.

[2] Merrion, D. F., Heavy duty diesel emission regulations – past, present, and future, SAE 2003-01-0040, 2003.

[3] Basshuysen, R. and Schaefer, F., *Internal Combustion Engine Handbook*, SAE International, 2004.

[4] Richardson, D. E. *Review of Power Cylinder Friction for Diesel Engines*, ASME - Transactions, vol.122, October, 2000.

[5] Federal-Mogul, *GOETZE® Piston Ring Handbook*, Burscheid, Germany, April 2003. Accessed 10 Nov. 2011. Available < http://www.federalmogul.com/korihandbook/en/index.htm>.

Advanced Powder Technology VIII
10.4028/www.scientific.net/MSF.727-728

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