University of Banja Luka
Faculty of Mechanical Engineering

DEMI 2015
12. International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology

COATED AL PISTON AS TECHNOLOGICAL SOLUTION TO LOWERING OF FRICTION LOSSES INSIDE IC ENGINE

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Summary: *Engine technologies whose application can reduce the impact of friction and wear are surface coatings and the lubricants low-viscosity or with appropriate additives. As a contribution, we applied the eco-tribological knowledge during construction of IC engines and their spare parts. The result of the researches was patented prototype of the aluminium piston coated or modified with tribo-material in area of skirt. Modification of the piston was realized by inserting two removable pads (plates) of graphite. Another option is the piston with tribological pads of brass into which are inserted tribo inserts of graphite in the form of a sphere (nodules). The main task of the tribo-pads is to decrease friction between piston and cylinder, especially at engine-starting regime. This is confirmed during researches whose the results are presented inside of manuscript.*
Key words: *IC Engine, AL Piston, Coating, Friction.*

1. INTRODUCTION

The global climate change is due to the excessive use of fossil fuels such as coal, petroleum products, and natural gas in electric power generation, transportation, buildings, and manufacturing. Major sources of greenhouse gas emissions are industrial sector and transportation. Each kilowatt-hour of electricity produced by a fossil-fuelled power plant produces 0.6 to 1.0 kg carbon dioxide (CO_2). Each litre of gasoline burned by a vehicle produces about 2.5 kg of CO_2. This and other emissions can be reduced significantly by buying an energy-efficient car that burns less fuel over the same distance. Saving fuel also saves money and the environment.

The EU has set out an ambitious strategy to reduce CO_2 emissions from road vehicles. According to European Commission Directive 93/116/EC, total CO_2 output in Europe must aim to reach an average of 130 $g \cdot km^{-1}$ for all new passenger cars by 2015 and 95 $g \cdot km^{-1}$ by 2020 [1].

An impression of the range of measures and technologies, which are available for handling future requirements is presented on the Fig.1 [1,2].

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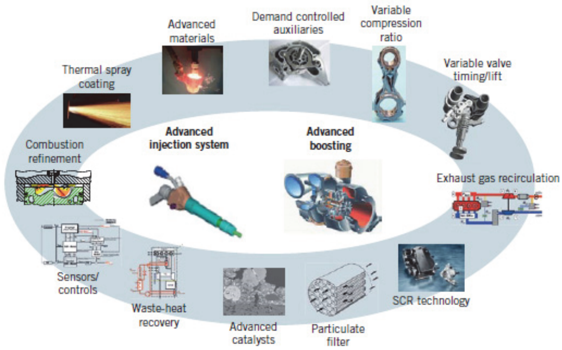
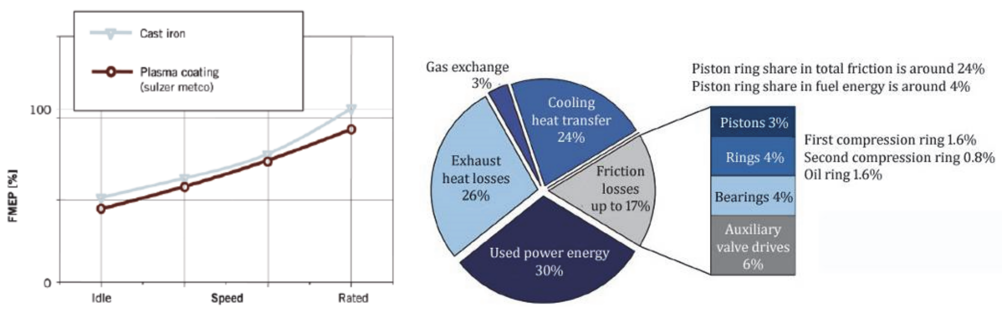


Fig. 1 *Available heavy-duty technologies for the reduction of emissions*

The reduction of mechanical losses caused due to the friction force is another important approach for decreasing fuel consumption. A reduction of the number of cylinders would offer a significant potential for decreasing the engine friction (commercial vehicles). In passenger cars, downsizing is financially only attractive, if the number of cylinders is reduced as well. The methods for application of thermal spray coatings to the cylinder running surface [2], which are meanwhile available for series application, offer potential for reducing the friction, Fig. 2 (a). This technology originating from passenger car engines has already also been used for commercial vehicles. Generally, coatings are needed to improve wear resistance and friction reduction at higher loading densities, higher temperatures and with lower viscosity oils.



(a) *(b)*

Fig. 2 *(a) Potential of cylinder liner coating for friction reduction*
(b) Energy distribution diagram showing friction losses in gasoline engines with the proportionate share of the piston and piston rings

A great number of friction power tests in motored operation show that the mechanical losses of the piston group contribute to a significant proportion of the total friction power of an engine. Parts of piston group, cylinder and crankshaft are in the focus of all research. For example, by optimizing the material of piston rings largely we can reduce friction losses. The reason for this is the high share of piston rings (24%) in the overall mechanical losses, due to friction forces in the engine. Thus, for example, in case of the gasoline engine of the total energy that is obtained by fuel combustion, only 30%

is used at the flywheel, while the rest goes to the losses, Fig. 2 (b). Of these losses, 17% goes on the friction losses. Losses of friction are distributed in the following percentages: 3% pistons, 4% piston rings as well as bearings and 6% on the auxiliary the drive system of valve [3].

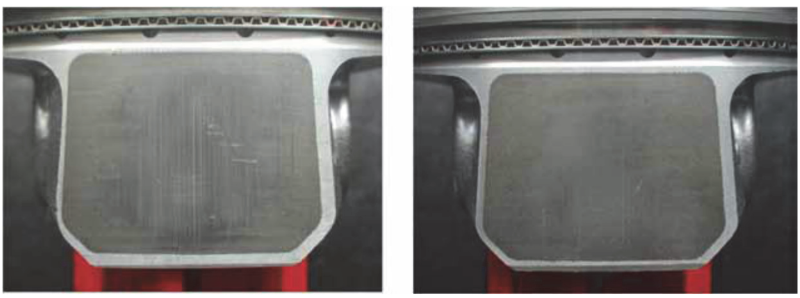
In accordance with previously set goals, we have realized the research in the field of optimal design of reciprocating engines and compressors. Consequently, we investigated new option for increasing strength and tribo-logical characteristics of the tribo-system piston-cylinder liner.

Firs result of researches is patented prototype of aluminium piston whose skirt is modified with inserts based on the tribo-materials.

2. CONCEPTIONS OF PISTONS WITH MODIFIED SKIRT

In combustion engine systems, the piston moves up and down within the cylinder liner with high speed and pressure to convert chemical into mechanical energy. During the reciprocation of the pistons, the piston skirt acts as a guide to ensure that the piston moves up and down in the cylinder in an orderly fashion. This component plays an important role in minimizing the friction and wear generated between the piston skirt and cylinder liner in an internal combustion (IC) engine.

At the same time, the engine oil basically provides the lubrication for the pistons. However, under particular conditions such as cold start or high pressure, the direct contacts between the piston skirt and cylinder liner occur due to a lack of engine oil. This results in tribological problems such as an increase of friction and wear. Friction between uncoated metal surfaces causes greater energy loss wear and the overall temperature increase. To prevent intense friction and wear between metal surfaces, on the piston skirt usually is applied the coating which includes one or more solid lubricants, Fig. 3 [4]. Usually, almost all car manufacturers use graphite and Molybdenum disulphide (MoS_2) as a solid lubricant of low friction polymer coating materials for piston skirts.



(a) *(b)*

Fig. 3 *(a) In testing at full load after 50 cold-start cycles, greater wear is seen with a piston skirt coated with a conventional coating*
(b) The new piston skirt coating (EcoTough®) displays much lower wear

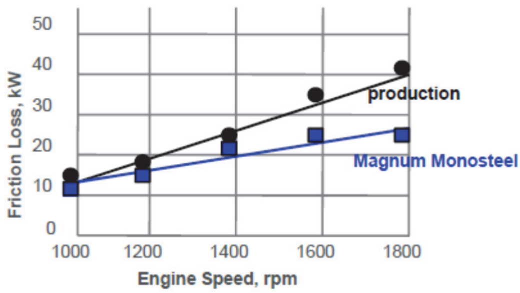
For 95% of the piston skirt coatings, graphite has been found to be a suitable coating, Fig. 3 (a). An iron coating is used in the case of aluminium engine blocks that are primarily required for high-performance automobiles.

According to previous set goals, there is the need to develop an improved piston skirt coating in order to improve the efficiency of the internal combustion engine.

As example, Federal-Mogul has developed a new piston skirt coating that provides superior friction reduction and wear resistance compared to existing technology. The coating has been commercialized and is known as EcoTough®, Fig. 3 (b). Graphite, molybdenum disulphide and carbon fibres are blended and forms new coating material. The graphite and molybdenum disulphide provide friction reduction, at same time; the carbon fibre contributes to increasing the wear resistance of the coating. A fourth key component in the coating is the resin, which enables the coating to be more durable. The piston skirt coating demonstrated 1% to 3% lower friction losses at engine speeds ranging from 1,000-5,000 rpm [4].

Second example is Federal-Mogul Magnum Monosteel® piston, Fig. 4 (a) with reduced mass by up to seven percent [5]. Key design features that reduce friction for improved fuel economy and lower emissions include:

- Double-band piston skirt design, a first for modern diesel pistons.
- Dual friction-welded construction, enabling large cooling galleries for high temperature resistance and strength.
- Friction reduction of 17%, compared to conventional steel piston designs, Fig. 4 (b).
- One percent (1%) fuel economy achieved through reduced reciprocating mass (up to 7%) and up to 40% reduction in skirt area.

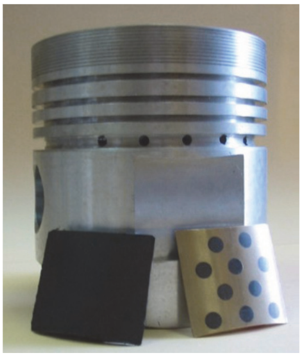


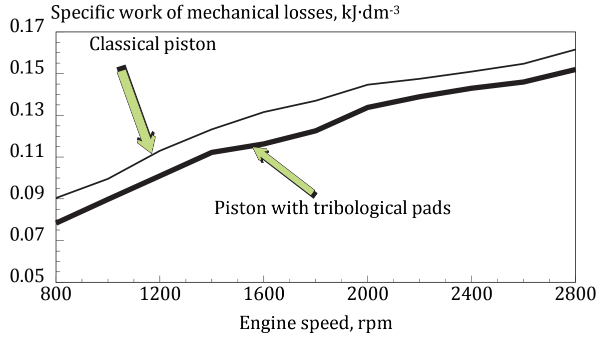
(a) *(b)*

Fig. 4 *(a) Magnum Monosteel® piston skirt design*
(b) 15L Diesel, Willans Line test results

3. NEW CONCEPT OF TRIBO MECHANICAL SYSTEM PYSTON SKIRT CYLINDER LINER AND EXPERIMENTAL RESULTS

Starting from the fact that each the optimization in terms of tribology has a theoretical basis, *i.e.* to ensure conditions when the boundary lubrication continuing to be hydrodynamic, we designed modified aluminium piston with tribo-material, Fig. 5 (a). Modification of the piston was realized by inserting two removable tribological pads of graphite. Another option is the piston with tribological pads of brass into which are inserted tribo inserts of graphite in the form of a sphere (nodules). Tribological pads are mounted opposite each other on part of piston skirts. The proposed solution is applicable inside of other reciprocating machines, too. [6].





(a) (b)

Fig. 5 *(a) Photography of patented aluminium piston with tribological pads of graphite and brass into which are inserted tribo inserts of graphite (b) Specific work of mechanical losses vs. engine motoring speed*

The task of tribological pads which are integrated into the new solution of piston design is to contribute to the reduction of losses due to friction within the tribo-mechanical system piston skirt and cylinder liner, especially during of the cold start of the machine.

Applying of invention of the piston with tribological pads, resolved is the problem of wear through replacement of easily removable pads. From the aspect of vehicle exploitation, maintenance of the piston in the future will be related to the replacement of easily removable piston rings and pads during service. In these conditions, the piston is viewed as a carrier of easily interchangeable parts.

The first experiments were carried out on the experimental IC engine (Type: 3LD450, Maker: DMB Lombardini, four-stroke, single-cylinder, and air cooled). Basic characteristics of the engine and equipment have been published in the paper, of the authors prof. R. Pešić with assistants [6].

Measurement was performed in laboratory conditions, on the IC engine without burning, with electric motor drive, by applying method of disassembling/ eliminating of its parts. First, is dismounted the cylinder head in order to determine the forces of resistance in the cylinder, and then piston rings respectively, and at the end the piston and piston rod. Any time during the change, were performed the measurement of torque so that difference presents share of dismounted part in the total losses.

Fig. 5 (b) shows the comparison of values relating to the specific effective work of mechanical losses experimental IC engine during working with conventional piston made of cast iron, as well as with aluminium piston with tribological pads. With the increase of normal forces (from compression) and the number of rpm, specific work of mechanical losses gets lower than 5%, in comparison with classical piston made from aluminium and cylinder made of cast iron.

By analysing the results it can be confirmed the aim with regard to the application of piston with tribo-logical pads, *i.e.* it is confirmed the reduction of friction within tribo-mechanical systems piston-cylinder liner.

CONCLUSIONS

The EU has set out an ambitious strategy to reduce CO_2 emissions from road vehicles. According to European Commission Directive 93/116/EC, total CO_2 output in Europe must aim to reach an average of 130 $g \cdot km^{-1}$ for all new passenger cars by 2015 and 95 $g \cdot km^{-1}$ by 2020.

Exhaust emissions can be reduced significantly by buying an energy-efficient vehicle that burns less fuel over the same distance. Saving fuel also saves money and the environment.

The reduction of mechanical losses caused due to the friction force is important approach for decreasing fuel consumption that has a direct impact on reducing CO_2 emissions.

The major part of mechanical losses takes place at piston assembly, first of all at piston rings. Improvements in design of piston and its skirt (e.g. implanting the tribo-pads and tribo-inserts), application of new coatings and layers on piston rings and cylinder liners (again, implanting the tribo-pads and tribo-inserts), directly leads to decrease in fuel consumption.

By analysing the results it is confirmed the aim with regard to the application of piston with tribo-logical pads, *i.e.* it is confirmed the reduction of friction within tribo-mechanical systems piston-cylinder liner.

ACKNOWLEDGEMENT

The paper is a result of the research within the project TR 35041 financed by the Ministry of Science and Techno-logical Development of the Republic of Serbia.

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CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

621.3(082)(0.034.2)
621(082)(0.034.2)
004(082)(0.034.2)

INTERNATIONAL conference on accomplishments in Electrical and Mechanical Engineering and Information Technology (12 ; Banja Luka) (2015)

Proceedings [Elektronski izvor] = Zbornik radova / 12th International conference on accomplishments in Electrical and Mechanical Engineering and Information Technology, Banja Luka, May 2015 ; [editor in chef Vid Jovišević]. - Banja Luka : University of Banja Luka, Faculty of Mechanical Engineering =Univerzitet u Banjoj Luci, Mašinski fakultet, 2015 (Laktaši : Grafomark). - 1 elektronski optički disk (CD-ROM) : tekst, slika ; 12 cm

CD ROM čitač. - Nasl. sa nasl. ekrana. - Bibliografija uz svaki rad.

ISBN 978-99938-39-53-8

COBISS.RS-ID 5049624

12TH INTERNATIONAL CONFERENCE ON ACCOMPLISHMENTS IN ELECTRICAL AND MECHANICAL ENGINEERING AND INFORMATION TECHNOLOGY

Supported by:
MINISTRY OF SCIENCE AND TECHNOLOGY OF THE REPUBLIC OF SRPSKA

Organizer and publisher:
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UNIVERSITY OF BANJA LUKA

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FACULTY OF ELECTRICAL ENGINEERING
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