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TRIBOLOGICAL REINFORCEMENTS FOR CYLINDER LINER OF ALUMINUM - EXAMPLE COMPRESSORS FOR BRAKE SYSTEMS OF TRUCKS AND BUSES

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Abstract: *Aluminum gained in importance as a material for lightweight design of reciprocating engines and compressors. The application of aluminum alloys contributes to lower fuel consumption and exhaust emissions. The benefit of using aluminum is evident due to the reduced weight of the parts, but in parallel there is a problem due to the lower strength of this metal. Surface texturing and oils of low viscosity are used successfully to improve the tribological characteristics of sliding parts. For research purposes, the inner surface of cylinder which was produced of aluminum was reinforced by integrating tribological inserts. Their task is to reduce friction and wear between the piston and cylinder and to increase strength of the cylinder liner. Tribological optimization was made on the basis of the measurement results of the coefficient of friction. It is confirmed that the tribological properties of the cylinder with the tribological reinforcements are more optimal, compared to the case of aluminum construction (coating or honing of the cylinder liner). For this purpose is currently being brought into operation the test bench in the Laboratory for Engines as well as Tribology of the Faculty of Engineering University of Kragujevac.*

Keywords: *brake systems, tribology, cylinder liner, aluminum, optimization.*

1. INTRODUCTION

Heavy-duty vehicles (HDVs), trucks and buses are responsible for about a quarter of carbon dioxide (CO_2) emissions from road transport in the EU and for some 6% of total EU emissions. Transport is the only major sector in the EU where greenhouse gas emissions are still rising. The European Commission has therefore set out a strategy to curb (CO_2) emissions from these (HDVs) over the coming years. Emissions from transport could be reduced to more than 60% below 1990 levels by 2050 [1].

In city buses and trucks a lot of fuel energy is engaging for power of auxiliary units. Specifically, the fuel energy is engaged for drive of periphery units on engine, as example, for the air compressor, the alternator, the steering pump, the oil pump, the coolant pump, the fuel high pressure pump and the fuel delivery pump, as well as for air conditioning (A/C) compressor. The share of auxiliaries on the total power consumption is especially high for city buses due to (A/C) system and additional consumers of electricity and pressurized air, Figure 1 [1,2]. As a result, an increasing losses resulting in increase of fuel consumption, that is directly proportional to emission of (CO_2).

Reasons for this are the higher air demand of the wheel brakes, fewer headwinds for the engine cooling or more steering in curves i.e. the main influence factors on fuel consumption are the engine off heat or the wheel brakes air demand.

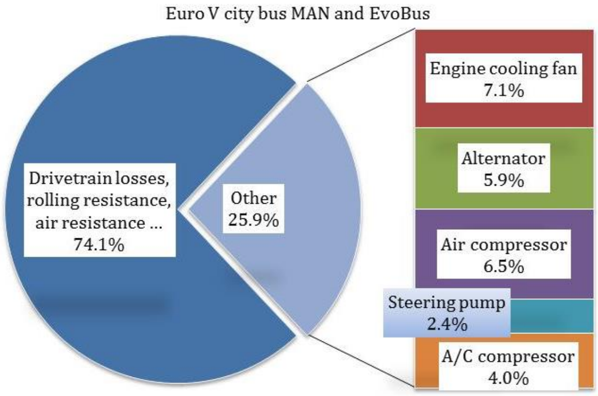


Figure 1. Percentage of driving resistances and auxiliary power demand on the fuel consumption of the city bus

Generally, city buses (classes with gross vehicle weight GVWR 18 t and length 12 m) are associated with 4.4% of total (CO_2) emissions [1]. City buses are frequently purchased by public institutions and thus they are in the public eye, yet may be the focus of cost-cutting measures [2-5].

Vehicles equipped with a conventional combustion engine can be still further improved by minimizing the internal friction of the mechanical parts in order to reduce (CO_2) emissions [6].

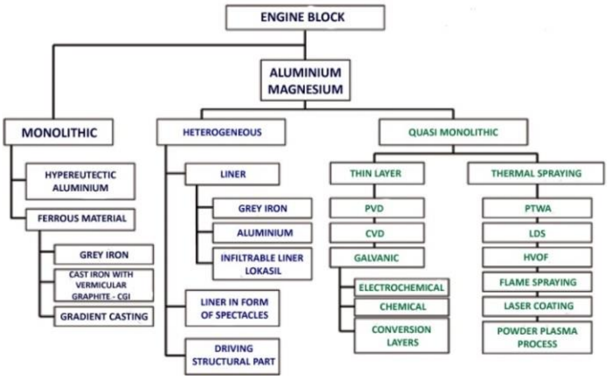
Potential actions to reduce friction in vehicles include the use of advanced coatings and surface texturing technology on engine and transmission components, new low-viscosity and low-shear lubricants and additives, and tire designs that reduce rolling friction [7-10].

In accordance with the above mentioned facts, we have realized the research in the field of optimal design of reciprocating aluminum engines and compressors. Consequently, we investigated new option for increasing strength and tribological characteristics of the tribo-system piston-cylinder liner [9-15].

The result of researches is patented prototype of aluminum piston and cylinder whose contact surfaces are coated or modified with reinforcements based on the tribo-materials [9].

2. PRODUCTION METHODS FOR ENGINE BLOCK AND CYLINDER SURFACES

If one compares the diverse options for realizing the engine block, Figure 2, and compares them with a view of today's requirements, on arrives at the conclusion that the profile is best met by an aluminum engine block [16]. The casting processes have become so advanced that the dynamic strengths demanded can be achieved by reducing casting faults, improving the microstructure and by targeted application of heat treatment.



(PVD and CVD-physical and chemical vapor deposition; PTWA-plasma transferred wire arc; LDS-twin wire arc; HVOF-high velocity oxygen fuel)
Figure 2. Production method for engine block and cylinder surfaces

As the mechanical efficiency of the combustion engine i.e. reciprocating machines is strongly influenced by the tribological situation between piston, piston ring and cylinder surface, the properties of the cylinder surface become particular significant. Specifically, because the tribological properties of pure aluminum are poor compare with grey cast iron. Currently, one of solutions to resolve these problems is the use of cast iron liners. But, this is not the best solutions because of needed specific wall thickness, increasing dimensions and weight.

Another option is to provide protection of aluminum alloy, and chemical and thermal spray coatings are most predominant surface treatments. Today, any makers utilize thermal spraying to manufacture fully sprayed cylinder consisting of (Fe-Al) composite [10,11,13].

Looking from the second side, liquid-type lubricants have effectively served in reducing the friction and wear of various mechanical devices. However, in compressor components, the liquid-type lubricants have negative effects on their thermodynamic efficiencies, and also the state of lubrication in these components is usually not known and is considered to be in the boundary and mixed lubrication regimes. Recently, research interest and efforts are on oil-less compressor conditions to eliminate the adverse effects of liquid-type lubricants and to further improve the performance of compressors. Consequently, it becomes necessary to develop advanced coating materials that exhibit lower friction and higher wear resistant under compressor specific conditions [17].

2.1 New concept of aluminum cylinder with tribological reinforcements

Generally, according to real machining conditions, the full contact between piston rings and cylinder is not possible. This fact leads us to the idea that by casting tribological inserts in the cylinder, we can determine in forward, contact area between piston rings and cylinder liner.

With the aim to achieving strength as well as tribological characteristics similarly as in case of the application grey cast iron, we patented the cylinder of composite material for reciprocating air compressor with the reinforcements consisting of tribological materials, Figure 3 [9].

The internal surface of the aluminum cylinder as base material-matrix, (alloy EN AlSi10Mg), was modified by putting tribological inserts of cast iron that are arranged in the form of continuous pads, the plates or like discrete tribological plugs in the form of spheres (nodule), or particles spherical shape, as reinforcements, Figure 3 [9].

By transferring the contact between the piston rings and cylinder made of aluminum on the tribological inserts, we reduce the wear. This technology extends the service life of cylinder and piston rings.


Source: S. Milojević

Figure 3. Photography of patented aluminum cylinder with tribological reinforcements

This optimization can lead to reduce machine weight as well as reduced friction and wear. A reduction of friction between piston rings and the cylinder running surface is particularly effective, because the majority of frictional losses in the reciprocating machines are generated inside of this tribological system [14].

3. EXPERIMENTAL RESEARCHES

Wear is progressive loss of material caused by friction resistance between contact surfaces. The present work wants to investigate and evaluate the effect of tribological plugs as reinforcements on tribological behavior of patented aluminum cylinder.

Tribological tests were carried out on CSM nanotribometer with ball-on-plate contact pair for different normal loads, sliding speeds and distances without lubrications. Generally, tribological tests are based on variation of three different normal loads (0.3, 0.6 and 0.9) *N* and three different speeds (3, 9 and 15) $mm \cdot s^{-1}$. Duration of each test was 500 cycles (distance of 1 *m*), whereat one cycle is represented by full amplitude sliding distance (half amplitude is 0.5 *mm*).

The friction coefficient was automatically recorded during the testing, by using data acquisition software. Simultaneously, the friction coefficient curve was recorded and plotted during experiments.

4. RESULTS OF TRIBOLOGICAL TESTS AND DISCUSSION

4.1 Optical microscopy analysis

Experiments were carried out with the base material for cylinders (aluminum alloy) and with the material for reinforcements made of cast iron. Figure 4 presents optical microscopy of base aluminum alloy surface, where grey phases, which are noted on the surface presents eutectic silicon.

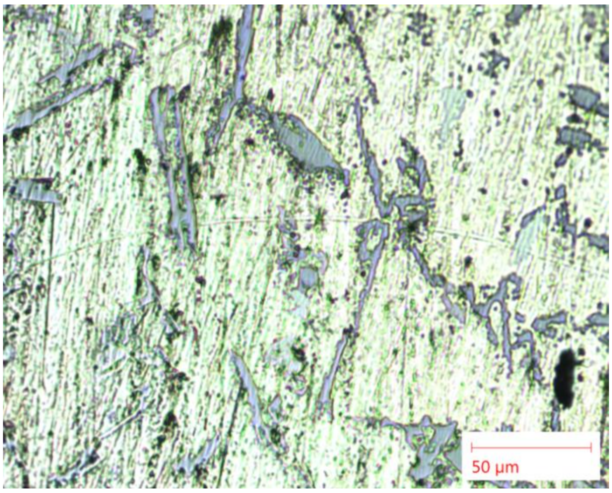


Figure 4. Optical microscopy of base aluminum alloy

Figure 5 presents surface of cast iron nodular discrete pads (reinforcements). Deeper analysis of the presented surface revealed that black lines across the surface are not micro cracks but graphite inclusions in the cast iron.

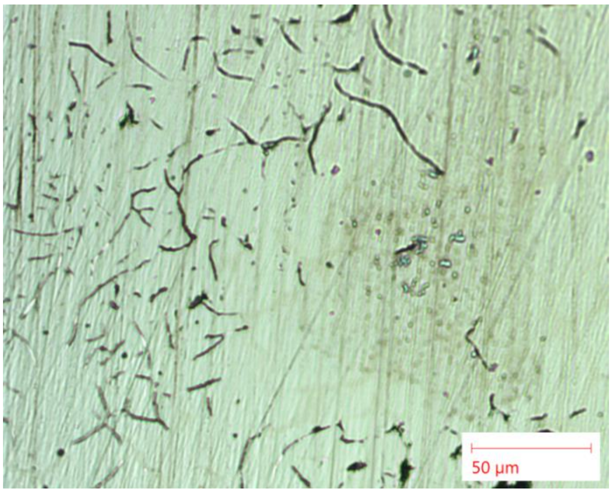


Figure 5. Optical microscopy of cast iron discrete nodular inserts

4.2 Coefficient of friction and penetration depth

Diagrams of friction coefficient (COF) and penetration depth during reciprocating sliding are shown in (Figure 6) for base material (aluminum) and in (Figure 7) for tribological inserts of cast iron.

Figure 6. Coefficient of friction and penetration depth for base material $(F_N = 0.3\ N;\ V = 15\ mm \cdot s^{-1})$

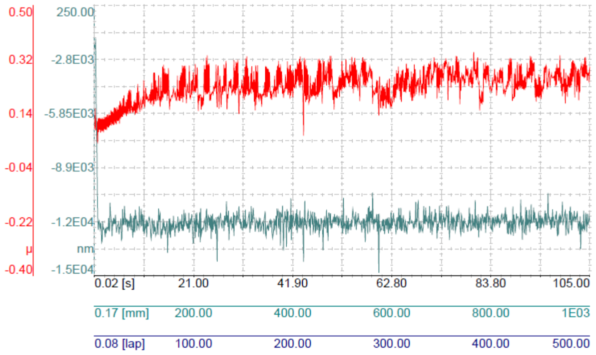
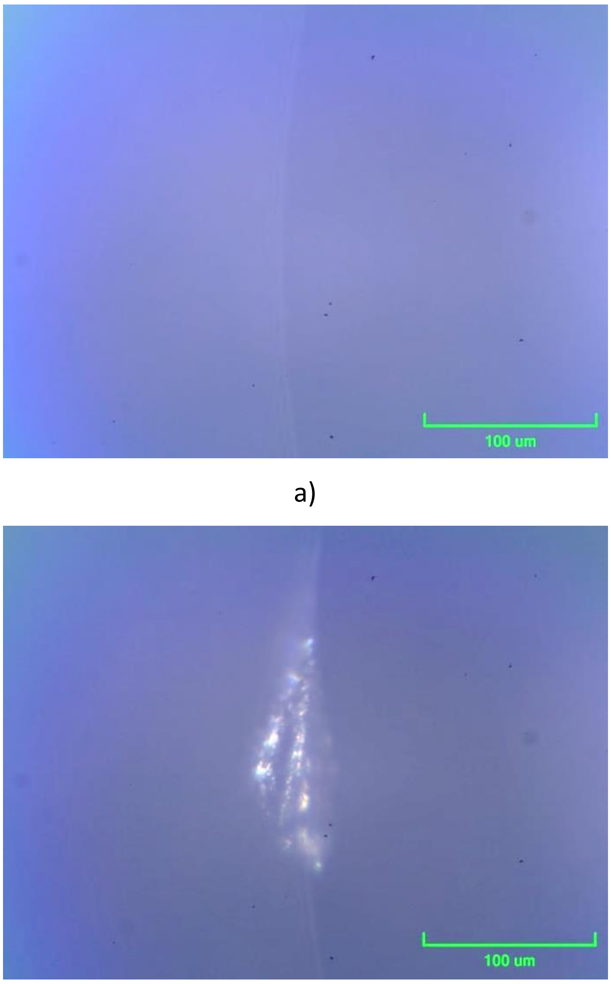


Figure 7. Coefficient of friction and penetration depth for tribological inserts (nodular discrete pads) under $(F_N = 0.3\ N;\ V = 15\ mm \cdot s^{-1})$

The values of the friction coefficient for tribological inserts were ranging from (0.041 up to 0.344), and these maximal values are lower to the results of base material (0.016 up to 0.662). This decrease was specifically lower for higher values of sliding speed and higher regimes of load. A steady-state value for the friction coefficient was reached shortly after the beginning of the test. Penetration depth of tribologically optimized material has relatively stable and constant values compared to base material.

On the Figure 6 it is noticeable that coefficient of friction sharply rises after a certain period of sliding as result of material transfer on counter body steel ball. After the material was transferred on the steel ball contact between transferred aluminum and aluminum as a base material was achieved. The latter results at that moment penetration depth also register a change in comparison to the previous period of contact. A cyclic change of penetration depth indicates that transfer of material on the counter body is cyclic process that means transferred material accumulates on counter body surface and after certain period fall off and became wear debris. In addition to this conclusion Figure 8 presents the profile of the steel ball before and after sliding test. Figure 8.b clearly indicates accumulated transferred material on the counter body surface.



a)

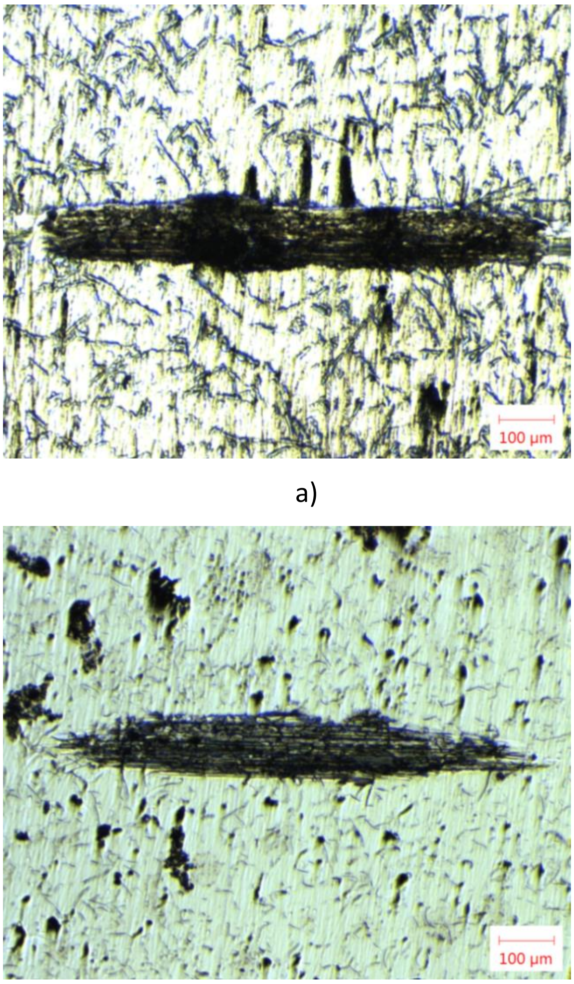
b)

Figure 8. Optical microscopy of the counter body steel ball profile a) before and b) after sliding test

(COF) and penetration depth obtained for cast iron discrete nodular insert are presented on Figure 7. In the case of cast iron there is no drastic change in (COF) and penetration depth in steady state regime.

4.3 Wear analysis

Optical microscopy was also used to examine obtained wear tracks. Figure 9.a and 9.b present wear tracks obtained under the same sliding conditions, but on two different materials. Comparing obtained wear tracks it is noticeable that wear of aluminum is higher than cast iron sample due to transfer material and increase of coefficient of friction which occurs for aluminum. Based on that it is fully justified the presence of cast iron discrete nodular inserts in aluminum that is widely used for engine cylinders.



a)

b)

Figure 9. Wear tracks of a) aluminum and b) cast iron under ($F_N = 0.3\ N;\ V = 15\ mm \cdot s^{-1}$).

Deep grooves in wear track of both tested material indicates that abrasive wear is the most dominant wear mechanism.

5. CONCLUSIONS

In trucks and city buses a lot of fuel energy is engaging for power of auxiliary units of engine, as it is air compressor inside braking system, reciprocating compressor for air conditioning system, pump of the steering system, alternator etc.

Aluminum continues to gain in importance as a material for lightweight machine design. One of the applications is replacing of material for engine blocks, which has been traditionally produced of gray cast iron. Application of aluminum contributes also to reducing fuel consumption that has a direct impact on reducing exhaust emissions.

Coatings of the tribo-materials on contact surfaces between the parts of system in sliding contact contribute to reducing friction while increasing resistance to abrasion.

Inside the paper are presented the realized researches in the field of optimal and tribological design of reciprocating aluminum compressors.

Presented results of the researches, obtained during tests of materials from which consisting cylinder, shows that by transferring the contact between the piston rings and cylinder made of aluminum on the reinforcements, it is possible to reduce the friction and wear. This technology extends the service life of cylinder and piston rings.

Penetration depth of tested material which is used for reinforcements has relatively stable and constant values compared to the base material, named as the matrix.

Comparing obtained wear tracks it is noticeable that wear of aluminum is higher than cast iron sample due to transfer material and increase of coefficient of friction which occurs for aluminum.

The values of the friction coefficient for reinforcements were ranging from (0.041 up to 0.344), and these maximal values are lower to the results of base material-matrix (0.016 up to 0.662).

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