ASPECTS OF THE APPLICATIONS OF COMPOSITE MATERIALS IN COMBUSTION ENGINES

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Abstract

The paper presents the results of investigations concerning the possibilities of application of composite materials in the construction of internal combustion engines. The total mass of the engine can be reduced by allying composite materials, which have a much higher strength than hitherto applied conventional materials. Less thermal expansion allows reducing assembly clearance between the piston and cylinder. The surface topography after the process of machining of composite materials contains hollows, which act as trays for lubricant, wear products and pollution particulates. Therefore, it is possible to reduce friction, fuel consumption, level of exhaust emission and improve the durability of engine. During the investigations, the engine piston made of aluminium matrix composite has been tested. The tests were related to the influence of surface topography of the piston skirt containing Al_2O_3 particles on the adsorption of lubricating oil, which facilitates lubrication in small displacement test engine. Aluminium matrix composite materials have some disadvantages, too. The most important are higher finishing costs and higher wear of the other sliding element. To reduce the finishing costs of making the suitable surface, special methods for example water jet cutting, have been worked out. To reduce the wear of the other sliding element, reinforcing spherical particles without sharp edges should be applied. Covering the tribological partner-sliding surface with a composite surface layer (e.g. $Cr+Al_2O_3$) can result in a relevant reduction of its wear.

Keywords: *combustion engines, composite materials, wear*

1. Introduction

Obtaining the required level of durability is possible by using engine components made of materials with significantly increase resistance to mechanical and thermal load.

Composite materials elaborated in the second half of the 20th century have been widely applied in all kinds of vehicles. It was possible because of certain selected properties of composite materials such as:

- higher tensile strength than the matrix (about 30% for cast and wrought aluminum alloys),
- higher fatigue strength than the matrix material (20% by 15%Al_2O_3),
- lower thermal expansion coefficient of composite than the matrix which allows to reduce
- maintenance clearance between piston and cylinder liner,
- possibilities of using solid lubricant in machine parts by applying porous composite materials,
- particular topography of the composite surface after finishing of the machining process
- improves oil absorption (about 25% in a drop test) compared to the surface of matrix material,
- which improves lubrication and reduces wear intensity,
- wear resistance which is several times higher than that of a matrix.

Using composite layers makes it possible to create new lubrication conditions on surfaces of different materials.

The influence of pistons, which have been made of composite materials based on aluminum alloys upon the operating of the engine, has been presented in this paper. The results of initial tests which were carried out in the laboratories of The Vehicle Operating and Durability at the Department of Transport of the Silesian University of Technology in Katowice, show that the fuel consumption of a test engine with a composite piston is lower and its durability is higher than that of the engine with piston made of silumin.

2. Physical properties of composite materials

Tensile and fatigue strength of composite materials used for the production of vehicle components are 10 to 30% higher than that of the matrix materials. There is a possibility to reduce the weight of particular elements like pistons, connecting rods, which reduces engine vibrations or brake disc and brake drum, which in turn improves vehicle dynamics. Reduction of mass and dimensions of the engine and greater service life are possible using thin-walled sleeve in the classic engine block cast in silumin. Thermal properties of composites are also better than the properties of the matrix material. Thermal expansion decreases with the increased content of reinforcing particles, e.g., $\alpha=22\cdot10^{-6}K^{-1}$ for the alloy AC-47000 and $\alpha=16\cdot10^{-6}K^{-1}$ for alloy AC-47000 + 20%SIC and thermal conductivity increases $\lambda=96{,}2$ W/(m·K^{-1}) for AC-47000, $\lambda=144$ W/(m·K^{-1}) for AC-47000 + 20% SiC. This makes it possible to reduce the assembly clearances which is associated with the reduction of exhaust gas scavenging and fuel consumption at cold start.

Tab. 1. Strength properties of chosen composite versus their matrix [1]

Property / Material	Tensile strength, Rm, MPa	Young modulus E, GPa	Fatigue strength MPa
AW6061-T6	310.3	68.9	110
AW-6061+22%Al_2O_{3P}-T6	372.4	97.24	115
AC-47000-T6	252	78	90
AC-47000+20%SiC_P-T6	359	98.6	150

3. Tribological properties of composite materials

Good tribological properties of composite materials used in combustion engine components are connected with high hardness and wear resistance of ceramic reinforcing particles and the topography of the surface of composite after the finishing treatment. As a result of the great difference in the hardness of the matrix material (80-100 MPa for AC-47000) and particles (200 MPa for Al_2O_3 and 230-290 MPa for SiC), cutting tool removes a bit more of matrix material than the particles. The surface layer of the composite consists of two planes. One is located below the surface of the composite and the tops of particles of reinforcing phase form the other. The distance between these planes depends on the material of the reinforcing phase. It is bigger for the alumina particles and smaller is for glassy carbon. The spaces between the particles jutted out of the surface of a matrix from 0.4 μm up to 2 μm form trays for lubricant, wear products and pollutants. The surface roughness profile of the composite containing alumina particles (RP) and lubricant trays (OD) has been shown in Fig. 1. The distances between the particles are irregular, but with the applicable share of the reinforcing phase (10-15% fibre and 20% particles) is sufficient to ensure large real contact surface, which in turn decreases surface pressure. Tribological model composite piston skirt – surface of cast iron cylinder has been shown in Fig. 1. The small-enclosed spaces are formed between the points of contact of the piston skirt with the surface of a cylinder. Small amount of oil in these spaces is sufficient to improve the lubrication conditions. Dimension values, which are used in model, are characteristic for reinforcing phase of composites currently used in the manufacturing of machine parts.

Droplet test has been elaborated and performed in order to check the adhesion of oil to the silumin and composite piston skirt. Shape changes of oil drop flowing on the piston skirt were observed. The results of test have been shown in Fig. 2. A drop of oil flows more slowly on the surface of the composite piston skirt.

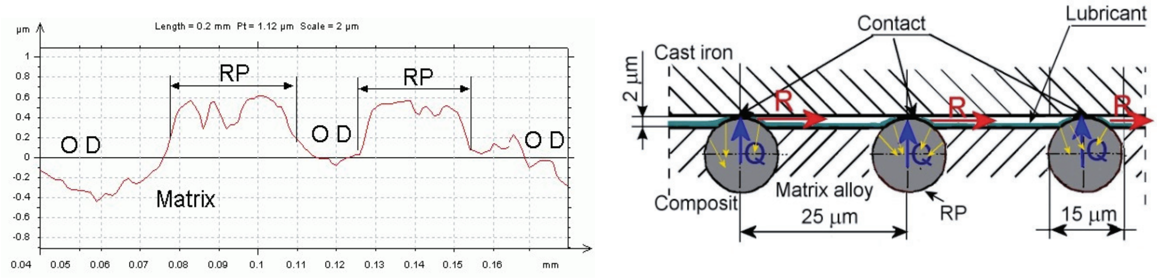

Fig. 1. 2D-roughness profile of composite piston skirt (a) and model of composite piston/cast iron cylinder liner contact: OD- oil depot, RP – reinforcing particle, R- friction force, Q – heat generated by friction

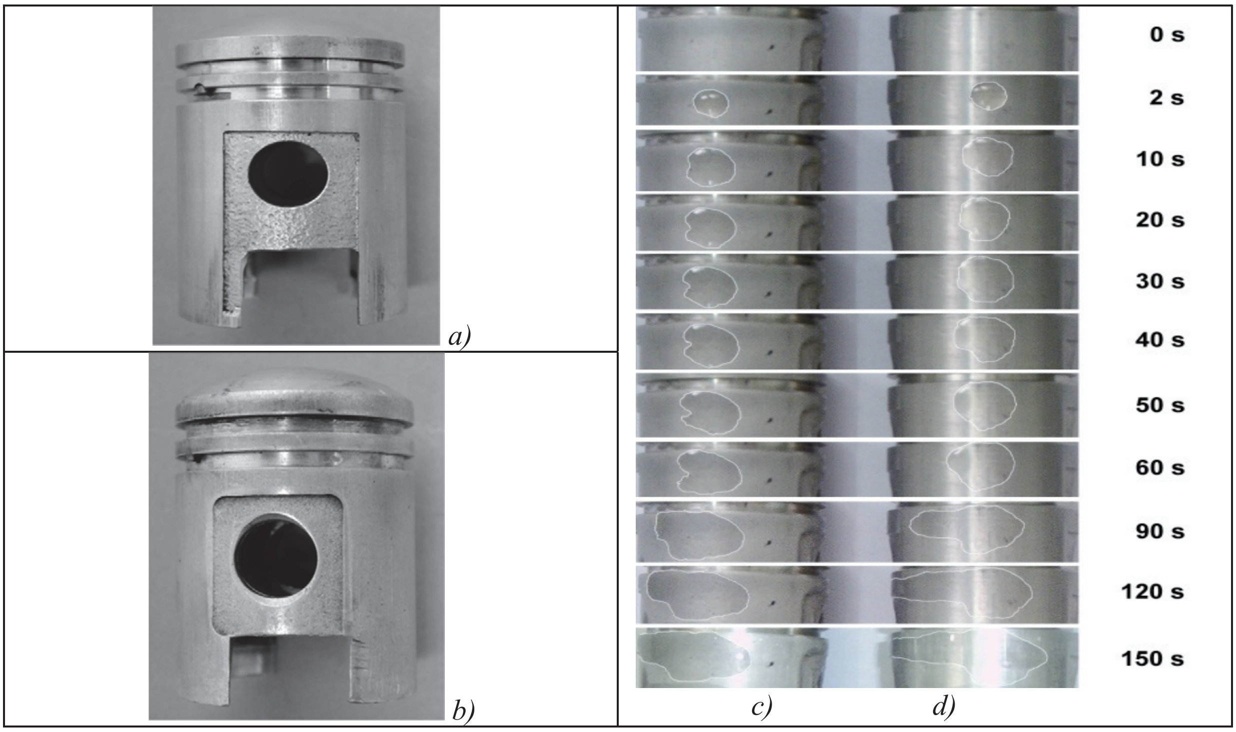

Fig. 2. Silumin (a) and composite (b) piston and drop-test results on composite (c) and silumin (d) piston skirt

Tribological properties of selected composites in conjunction with cast iron have been examined on the test stand simulating the cold start of the engine. Oil viscosity is too high to provide effective lubrication spray during the cold start of the engine. This increases the wear of friction surfaces. The test surfaces were lubricated with oil mist (Lotos Semisynthetic oil) every 30 minutes, about 0.2 mg per square centimetre. The relative speed of samples corresponded to the speed of the piston ring movement on the surface of the cylinder near the dead centre (2.5 m/s). The pressure of 3 MPa corresponded to the pressure of the first piston ring on the cylinder surface. Values of coefficient of friction and weight loss of the piston ring made of cast iron GLJ-300 have been shown on Fig. 3.

Wear of piston ring made of cast iron GLJ-300 in contact with the surface of cylinder made of silumin (AC-47000) is more intensive than during the contact with the cylinder made of composite containing Al_2O_3 fibres or glassy carbon. Wear of the surface of cylinder made of composite is about eight times smaller than the silumin. The value of coefficient of friction in conditions with limited lubrication during cold start of an engine ($\mu = 0.03$ after about 40 hours of grinding-in) lowers the friction loses. Another advantage of the composite containing glassy carbon is the ability to protect surfaces of cylinder or piston skirt from a seizure as a result of temporary lack of oil lubrication.

Separate issue is the possibility of the use of composites containing catalytic material affecting the decrease of harmful compounds in exhaust gases. The possibility of catalytic activity, among others, facilitates the presence of the glassy carbon particles [3].

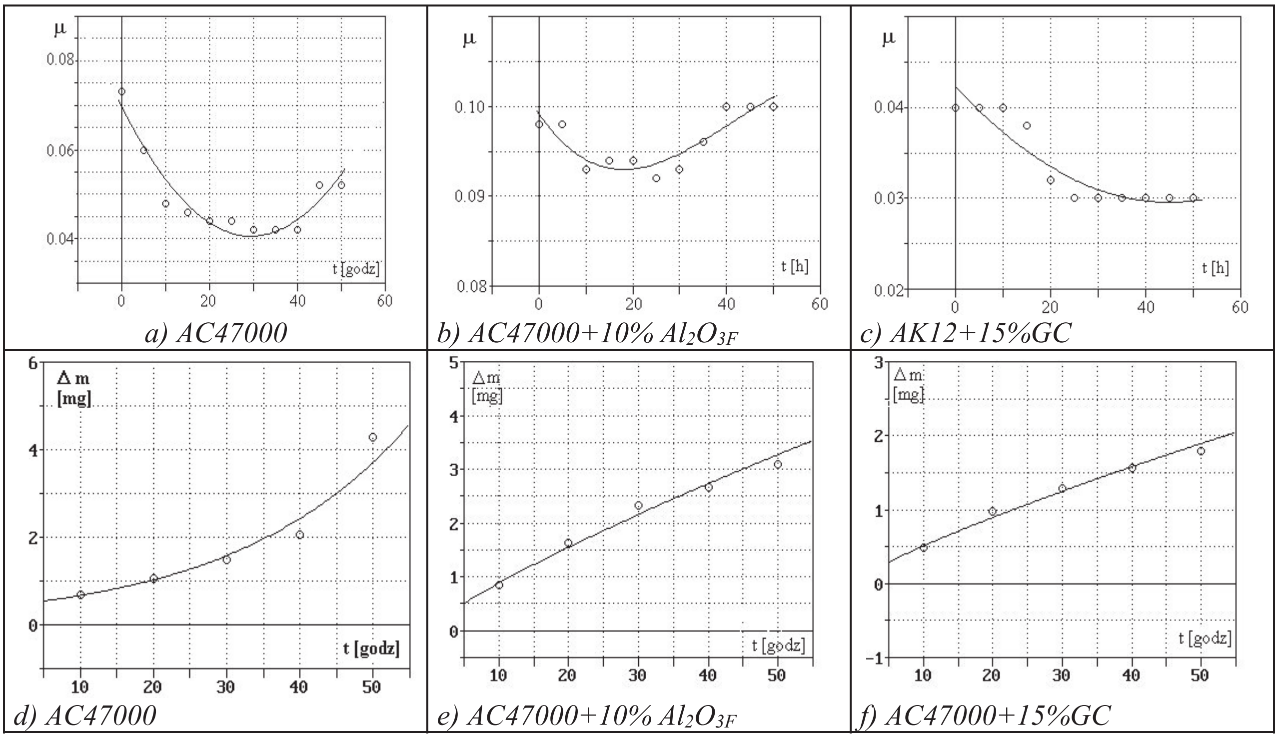

Fig. 3. Wear rates of piston ring (a, b, c) and friction coefficient (d, e, f) in GJL-350-piston ring/composite cylinder liner contact [2]

4. Tests of engine with composite pistons

Preliminary tests were carried out for two-stroke engine with a displacement 50 ccm. Removable cast iron cylinder composite piston and silumin piston were used in the test engine. Fifty hours grinding-in tests and fuel consumption test were carried out for original silumin piston and piston made of composite. The wear of piston rings, piston skirt and cylinder surface were controlled during the grinding-in test. Clearance between the piston and cylinder for composite piston increased much less than in the test with original silumin piston. Tests showed significantly less wear of the piston skirt with an increased wear of the cylinder surface.

To reduce wear of the cylinder surface being in the contact with the composite piston, a new composite material has been developed. Hybrid composites contain ceramic and glassy carbon particles. This type of material has already been used in piston for compressors [4]. Research tests of a piston made of new materials are currently under way. Preliminary tests confirm the possibilities of reducing fuel consumption.

5. Conclusion

The use of composite materials containing reinforced ceramic phase for the manufacturing of engine components has both some advantages and disadvantages. These are the advantages: possibilities of reducing assembly clearances, which results in lower fuel consumption and less harmful exhaust gases emission, reduction of friction and wear of a particular part of cylinder-piston system, which results in the improvement of engine durability.

More intensive wear of cast iron cylinder liner, which works with a composite piston, is the main disadvantage. When there is lack of oil within a short period of time, glassy carbon acts as a lubricant and protects the engine from seizure. Catalyst materials used as particles in composites can also be applied which might have impact on the reduction of harmful components in exhaust gases and the improvement of engine efficiency.

References

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