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Selected Tribological Properties of A390.0 Alloy

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Abstract

Emergence of new designs for internal combustion engines resulted in a necessity to search for new materials which will rise to excessive technological requirements under operating conditions of modern internal combustion engines of up to 150 kW. Focusing only on material properties, theoretically existing alloys should meet presents requirements. More importantly, existing materials are well fitted to the entire crank-piston system. Thus, there is a need for a more thorough examination of these materials. The paper presents studies on determination of coefficient of friction μ and wear for the A390.0 alloy modified with AlTi5B master alloy combined with EN GJL-350 cast iron. The characteristics of a T-11 tribological tester (pin on disc) used for the tests, as well as the methodology of the tribological tests, were described. Also, the analysis of the surface distribution of elements for the pin and the disc was presented. The studies were realized in order to find whether the analyzed alloy meets the excessive requirements for the materials intended for pistons of modern internal combustion engines. The results show that the A390.0 alloy can only be applied to a load of 1.4 MPa. Above this value was observed destructive wear, which results in the inability to use it in modern internal combustion engines.

Keywords: Tribology, Coefficient of friction, A390.0 alloy

1. Introduction

Constructional changes in modern internal combustion engines pertain to, among others, raising operational parameters and performance. It is achieved by increasing the high-speed operation, increasing the mean effective pressure in the pistons, optimization of the combustion processes, application of supercharging. Moreover, currently, all these measures are connected with downsizing [1, 2]. It consists in a reduction of the engine displacement while maintaining or even increasing the engine's operational parameters, *i.e.* its torque and power, decreasing simultaneously its fuel consumption and emissions of toxic components of the exhaust gas. It may be achieved, among others, by a reduction of the number of cylinders (most often from 4 to 3) and a reduction of dimensions of the combustion chamber. In this connection, engines with engine displacement of 1.6-2.0 l are being replaced with turbocharger-assisted engines having engine displacement of 1.0-1.4 l [3, 4]. Additionally, to improve the operational parameters of the engine, the direct injection technology is used. However, all these measures result in an increase of heat and mechanical loads of the engine components, mainly the pistons. Particularly dangerous consequences of those of the increase of the range of variable loads, causing significant tribological and fatigue loads of materials of these pistons. It leads to a situation where the manufacturers of pistons consider all structural and operational factors more rigorously, which translates into a careful selection of materials and development of precise manufacturing technologies [5]. One should remember that selection of the materials for pistons of internal combustion engines constitutes a compromise between the structural requirements, technical properties of the individual materials, and technological possibilities for the manufacturing while maintaining a proper economical level [6-9]. In contemporary engines, pistons made of AlSi casting alloys are used most frequently. In the case of heavy-duty engines, circum- and hypereutectic silumins found the largest use. It is dictated by a favorable relationship between the strength and technological properties, resulting from an optimum microstructure of silumins. Apart from many advantages, silumins have also an important flaw – namely the propensity to form a coarse-grained structure, which affects the mechanical properties of the casts adversely. Modification processes are used to improve this structure [10-14]. In the case of hypereutectic silumins, main modifiers include phosphorus-based compounds, e.g. CuP10 or master alloys with titanium and boron, added separately or jointly [15].

The goal of the paper is to determine the suitability of the A390.0 material for pistons of a heavy-load engine, by investigating the tribological wear and the coefficient of friction. In order to achieve the assumed goal, the scope of works includes, among others:

- assumptions of tribological studies' methodology using a T-11 tester,
- determination of wear and friction coefficient for dry friction conditions in the piston-cylinder barrel connection.

2. Material and methodology

An A390.0 alloy (from A3XX.X series) was chosen for the tests, intended for gravity sand casting and gravity casting in permanent molds.

The selected silumin was smelted from EN AM-AlSi20 (acc. to PN-EN 575), pure aluminum (acc. to PN-EN 576), and AlCu30 and AlMg10 master alloys (acc. to PN-EN 575). The alloy was melted in a VSG 02/631 Balzers induction vacuum furnace in a SiC crucible with a capacity of 800 cm^3. After a required time, the alloy was subjected to a modification with the AlTi5B master alloy at approx. 840°C, in such an amount that the titanium content was approx. 170 ppm. After a defined time, the alloy was refined using Rafglin-3 preparation in an amount of 0.2% by wt. The microstructure of the A390.0 silumin was showed in Fig. 1. Metalographic examinations were performed on the basis of Buehler's expert system recommendations on the Delta Abrasimet Cutter.

The T-11 tribological tester of the pin on disc type was designed for determination of tribological properties of materials used for friction nodes of machines. The courses of the quantities being measured are displayed on a display monitor in real time, and they may be stored after the tests. The drive motor of the device is stopped automatically when the time defined by the user has elapsed or after it reached the defined number of revolutions. Also, the software enables to print a report showing plots of changes in the individual quantities *vs.* time [16].

The tests were carried out in a pin on disc system, according to the ASTM G 99 standard. It means that the coefficient of friction may be determined after grinding in, *i.e.* when the whole pin surface exhibits traces of wear. Otherwise, the test should be repeated. In the case of the studies carried out, the pin was made of the A390.0 alloy, and the disc was made of the EN GJL-350 cast iron (Fig. 2). The tests were carried out for technically dry friction, at a temperature of 150ºC, a rate of v = 1.0 m/s, and under a variable load of 1.2-1.6 MPa. The path of friction amounted to 1500 m. The parameters were selected so as to correspond to the conditions in a spark-ignition internal combustion engine up to 150 kW, with a turbocompressor installed and a direct fuel injection. Because of the high load, the whole surface of the pin exhibited traces of wear in all cases. In total, 12 tests were carried out. The mass decrement measurement of the mating pin and disc elements was performed using a Radwag AS 220/C/2 balance with a precision of 0.1 mg. The observations of the surface after friction were carried out using an Olympus SZX9/8X stereoscopic microscope and a Hitachi S-3400N scanning electron microscope equipped with a detector of secondary electrons. The chemical composition analysis and the analysis of the surface distribution of elements were carried out by energy dispersive X-ray microanalysis (EDS) using a Thermo Noran detector (System Six).

An exemplary microstructure of the A390.0 silumin after modification with the AlTi5B1 master alloy is shown in Fig. 1, while Figures 2 and 3 present the pins, the disc and the T-11 tribological tester used in the studies.

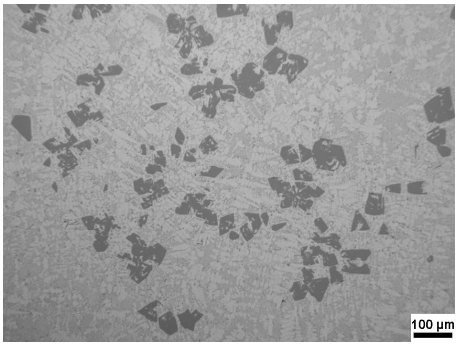

Fig. 1. Microstructure of the A390.0 silumin modified with AlTi5B1

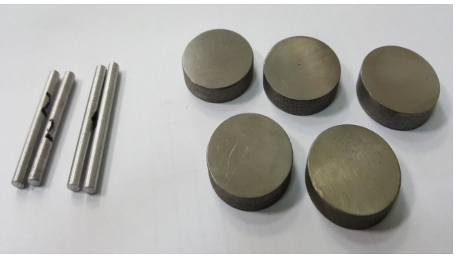

Fig. 2. View of the pins Ø4 mm (material – A390.0) and the disc Ø25 mm (material – EN GJL-350) used for the tests

3. Results and their analysis

Chemical composition of the A390.0 alloy is shown in Table 1. The mechanical properties (in accordance with the PN-EN ISO 6892-1:2011 and PN-EN ISO 6892-2:2011) of the tested material were as follows: at temperature 20ºC tensile strength R_m

= 210 MPa, the yield strength $R_{0,2}$ = 161 MPa and relative elongation A_5 = 2,9%; at temperature 250ºC tensile strength R_m = 158 MPa, the yield strength $R_{0,2}$ = 95 MPa and relative elongation A_5 = 3,7%. The hardness of the test material was 133 HBS. The presented values of mechanical properties are average results for 20 measurements. These parameters theoretical are in line with the expectations of the manufacturers of internal combustion engine pistons up to 150 kW.

The obtained results for the coefficient of friction for the studies A390.0/EN GJL-350 connection at a temperature of 150°C are gathered in Table 2, while the wear of the materials is shown in Fig. 3. The surface of the A390.0 alloy after friction is illustrated in Fig. 4, and the analysis of the surface distribution of elements is shown in Fig. 5.

Table 1.
Chemical composition of the A390.0 alloy

Si	Cu	Mg	Ni	Mn	Fe	Cr	Al
16.84	4.48	0.89	0.02	0.03	0.49	0.02	rest

Table 2.
Test results for the connection A390.0 alloy/EN GJL-350 cast iron at 150°C

Tested alloy A390.0	v, m/s	P MPa	μ	σ_μ
Sample #1	1.0	1.2	0.33	0.006
Sample #2	1.0	1.4	0.34	0.005
Sample #3	1.0	1.6	0.37	0.003

where:
μ – friction coefficient
σ_μ – coefficient of friction's standard deviation

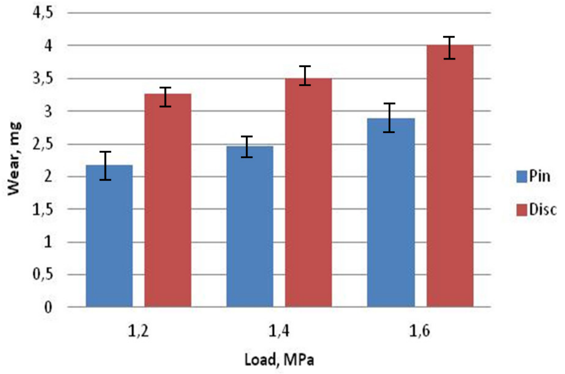

Fig. 3. The scale of material wear in the A390.0 silumin/EN GJL-350 cast iron connection

It may be observed in the presented Fig. 5 that an increase in the load lead to formation of larger extracts in the pin surface (A390.0), which is evident particularly in Fig. 5c. Simultaneously, the analysis of the surface distribution of elements shows iron (Fe) elements present on the pin, visible as white traces. The studies indicated that the higher the load is, the larger the „transfer" of disc parts onto the pin surface.

The highest coefficient of friction μ = 0.37 was obtained for the highest load of 1.6 MPa, while the lowest coefficient of friction was obtained for the lowest load of 1.2 MPa and amounted to μ = 0.33, which was consistent with the expectations. However, one should note the fact that for the highest load, the standard deviation was only 0.003, while for the lowest load, it was twice as high.

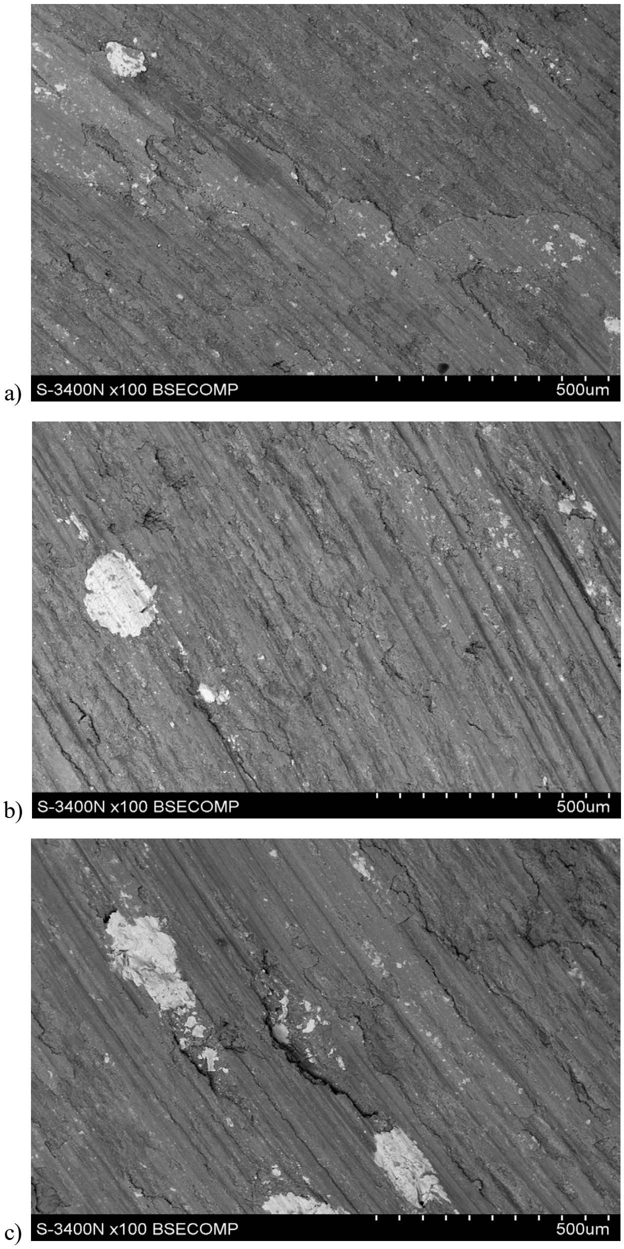

Fig. 4. Surface of the pin made of the A390.0 alloy after friction under the following loads: a) 1.0 MPa, b) 1.2 MPa, c) 1.4 MPa

The wear value for the load of 1.2 MPa was 2.1 mg for the pin (A390.0) and 3.4 mg for the disc (EN GJL-350). In the case of the load of 1.4 MPa, the wear amounted to 2.48 mg for the disc and 3.5 mg for the pin. For the highest load of 1.6 MPa, the wear amounted to 2.9 mg for the pin and 4.0 mg for the disc.

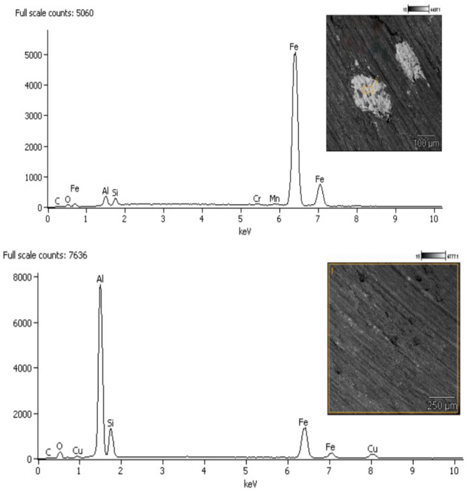

Fig. 5. Analysis of the surface distribution of elements after the tribological test for the pin (A390.0): a) point, b) surfacial

4. Summary

Application of air supercharging (turbocompressor), particularly in case of spark-ignition engines, and installation of direct injection systems changed the characteristics of loads occurring during operation of a car-engine piston to such extent that it became necessary to test the known materials under new operating conditions. Focusing only on material properties, theoretically existing alloys should meet presents requirements. More importantly, existing materials are well fitted to the entire crank-piston system. Thus, there is a need for a more thorough examination of these materials.

Based on the tests carried out, it may be ascertained that the A390.0 material modified with the AlTi5B1 master alloy does not meet the requirements of operating conditions of modern internal combustion engines without additional modifications. Values of the coefficient of friction for all tested loads were on the level above 0.33, and the wear of the pin made of the A390.0 alloy amounted to 2.1 mg even for the lowest load. The studies were carried out specifically at an elevated temperature (150ºC) so as to reproduce the conditions of the actual engine operation most accurately. In the case of the tested material, there are no literature results for such heavy loads, because it was not necessary before [7]. Comparing the obtained results with modern materials for eg. composite materials, the results obtained for coefficient of friction are higher by about 20% [7, 17]. The investigations indicate a necessity to search new material solutions and prove that yet used materials has ceased to meet the design requirements for new engine technologies.

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