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Bench tests results analysis of the engines modelled elements

Abstract: This paper presents an analysis of the bench tests results of an internal combustion engines modelled elements. The investigated samples was made through the technology used to manufacture the cylinder and piston rings. The original materials and coatings were retained. The aim of this research was to determine the influence of employed coatings on friction and friction pairs wear resistant in an internal combustion engines. The emphasis was given here on the variant investigation in which the counterface was made of nitrided cast iron or was not subjected to this process.

Keywords: *combustion engine, wear, surface free energy (SFE), friction*

Analiza wyników stanowiskowych badań modelowych elementów silników spalinowych

Streszczenie: W artykule przedstawiono analizę wyników stanowiskowych badań modelowych elementów silników spalinowych. Badaniom poddano próbki wykonane z użyciem technologii stosowanych do wykonywania cylindrów oraz pierścieni tłokowych. Zachowano oryginalne materiały oraz powłoki. Celem badań było określenei wpływu powłok przecizuzyciowych na tarcie i zużycie par trących stosowanych w silniakch spalinwoych. Badania przeprowadzono wariantowo z zastosowanieim przeciwpróbek żeliwnych azotowanych i nie poddanych procesowi azotowania.

Słowa kluczowe: *silnik spalinowy, zużycie, swobodna energia powierzchniowa (SFE), tarcie*

1. The Introduction

The development of new materials for friction pairs requires a series of research, ranging from numerical investigation through experiments performed on tribotester, as well as qualitative and quantitative research on the real object [3, 4]. So given a complete research program provides an authoritative response of a technical object. At each stage of the research it is necessary to implement the repetition of tests to enable statistical analysis of the results. This paper presents the second stage of the research of developed friction pair sealing the piston ring - cylinder dedicated for the internal combustion engine. This stage constitutes the model tests on a tribotester..

2. The selection of the Tribotester and execution of test items

Taking into account a large number of possible solutions, significant importance constitutes selection of the appropriate tribotester. Considering presented in the papers [9, 10] descriptions of test equipment, it appears that the most suitable tribotester for testing the rings - cylinder friction pair is a roll – block type. A suitable device is the tribotester designed and manufactured at the Institute of Sustainable Technologies in Radom, denoted with T05 symbol. This type of tribotester is preferred for the coating of low friction, including titanium nitride coating. The T05 tribotester scheme is depicted in Figure 1..

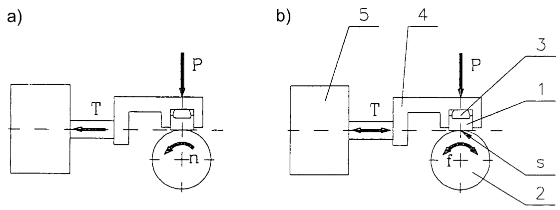
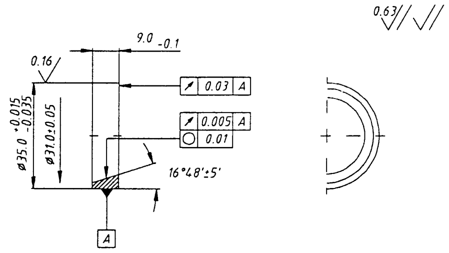


Fig.1. Scheme of tester T05 [2]. a) uniform rotational speed, b) oscillating motion:
1 – specimen (block), 2 – counterface (roll), 3 – semicircular insert, 4 – specimen grip,
5 – strain gauge of friction forces

The T05 device contains following elements: rotating counterface resembling a roll and fixed specimen, in the form of a block [2]. Figure 2 shows the ring-shaped counterface, whereas the specimen for simulating the spread contact is shown in Figure 3. The specimen has a concave surface, which being adjacent to the roller contacts the counterface on the area of 100 mm2. A counterface was made of cast iron EN-GJL-200 (see Fig. 2). There were 20 counterfaces prepared for the tests, 10 of which were subjected to the vacuum nitriding process [8]. The specimens were made of the grey cast iron marked according to EN 1560 as EN-GJL-350 (Fig. 3). The working surfaces of the specimens was coated with titanium nitride coating, using, as described in [14] arc - vacuum technology of plasma enhanced (PAPVD) gas stage vapour plat-



ing.

Fig.2. The shape and dimensions of the counterface (roll) [2]

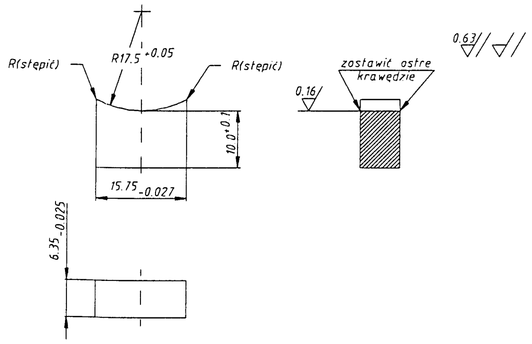


Fig.3. The shape and dimensions of specimen (block) with concave friction face [2]

3. Research on tribotester

3.1. The choice of the load and the determination of the scope of research

Essential factor when conducting the experiment on tribotester is the load on the tested friction pairs, including unit pressure and the linear velocity. Therefore, during the first comparison test, the schedule of farther investigation has been established by considering the appropriate values of the linear velocity and pressure (see Table 1). The study assumed a linear velocity equal to 1.25 m/s and a pressure equal to 5 MPa. Such a large values of pressure and low speed causes extreme hardship of friction pairs, similar to those prevailing in the area of the first piston ring TDC at the beginning of the expansion stroke in an internal combustion engine [5, 6]. This choice led to the phenomenon of mixed friction, which is evident from the values of the coefficient of friction that considerably exceeds a value close to 0.01, which is considered as a typical fluid friction.

The scope of study included the measurement of friction force and the mass temperature of the specimen, which were archived as time characteristics and values of wear, basic description of which constitutes the contents of this paper. Equal values of cycles, with constant linear velocity, under constant load emerged in a lubricant were established here. The tests were conducted on 19 friction pairs. This enabled necessary repetitions required for selection of the friction matchings (see Table 1).

1. The specimen coated with TiN cooperating with the counterface made of cast iron, lubricated with mineral oil 15W40 SPORTI elf (five combinations Nos. 3, 5, 6, 8, 10);
2. The specimen coated with TiN cooperating with the counterface made of nitrided cast iron, lubricated with mineral oil 15W40 SPORTI elf (four combinations Nos. 2, 4, 7, 9);
3. The specimen coated with TiN cooperating with the counterface made of cast iron, lubricated with synthetic oil elf SYNTHESE 5W50 (five combinations Nos. 3, 5, 6, 8, 10);
4. The specimen coated with TiN cooperating with the counterface made of nitrided cast iron, lubricated with synthetic oil elf SYNTHESE 5W50 (five combinations Nos. 11,14, 16, 19);

Table 1. Programme of research on the tribotester T-05

No of . Sp.	Counterface	Load MPa	Velocity m/s	Kind of oil
1	Cast iron	5	1,25	Mineral
2	Nitrided cast iron	5	1,25	Mineral
3	Cast iron	5	1,25	Mineral
4	Nitrided cast iron	5	1,25	Mineral
5	Cast iron	5	1,25	Mineral
6	Cast iron	5	1,25	Mineral
7	Nitrided cast iron	5	1,25	Mineral
8	Cast iron	5	1,25	Mineral
9	Nitrided cast iron	5	1,25	Mineral
10	Cast iron	5	1,25	Synthetic
11	Nitrided cast iron	5	1,25	Synthetic
12	Cast iron	5	1,25	Synthetic
13	Cast iron	5	1,25	Synthetic
14	Nitrided cast iron	5	1,25	Synthetic
15	Cast iron	5	1,25	Synthetic
16	Nitrided cast iron	5	1,25	Synthetic
17	Nitrided cast iron	5	1,25	Synthetic
18	Cast iron	5	1,25	Synthetic
19	Nitrided cast iron	5	1,25	Synthetic

Length of friction in one test run was set at 1350 m. Total friction distance was set at 10 runs of the tester working for specimen lubricated with the mineral oil and 20 runs lubricated with synthetic oil. Extension of the friction distance, in case of the synthetic oil, was dictated by intends to use the oil as a target one in cooperation with the friction pair. The total wear of the friction pair with respect to the friction distance was determined here. During the tests the temperature of the specimen was measured. Linear wear measurement using a dial gauge graduated to We = 0.002 mm was employed. After cooling of the friction pair each run was ended with the wear measurement, which was the sum of the consumption of specimen and counterface wear. The experiment was conducted according to the static, determined, complete schedule.

3.2. Elaboration of the tests results

Linear wear

Wear measurements was performed after each run of tested friction pair (specimen- counterface), by reading the value of total wear of each of those elements. This was due to the necessity of non-invasive measurement, i.e. without disassembling the test station. Otherwise, interference resulting from repeated disassembly and installation of the test station would result in multiplication of the random errors that would have affected the final results. In consequence, the only possible measurement was to measure the total value of wear of the specimen and the counterface after each test run. Measurements were carried out after the friction pair was cooled to the ambient temperature. The total values of the specimen and counterface linear wear are depicted in figures: 4, 5,

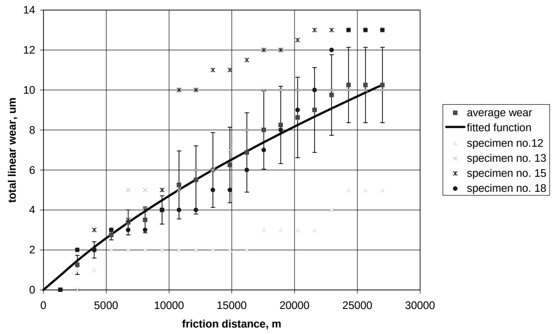


Fig.4. Total linear wear of: TiN coated specimen, cast iron counterface and bearing joint as function of friction distance and synthetic oil as lubricant.

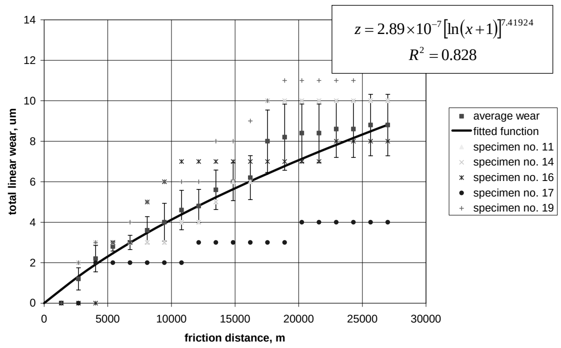


Fig.5.Total linear wear of: TiN coated specimen, nitrided cast iron counterface and bearing joint as function of friction distance and synthetic oil as lubricant.

The values of the total linear wear of the friction pair combined of specimen coated with titanium nitride and cast iron counterface, lubricated with mineral oil (16 μm) are less than in the case of nitrided cast iron counterface (20 μm). whereas the values of the total linear wear of the friction pair combined of specimen of titanium nitride coating and cast iron counterface lubricated with synthetic oils (5 μm) tends to be insignificantly lower than in the case when the nitrided cast iron counterface was employed (5 μm).

It is worth noting that more than a threefold increase in the total wear occurred compering the titanium nitride specimen coating and counterface of cast iron in the presents of the mineral oil (16 μm), with the corresponding friction pair set lubricated with the synthetic oil (5,0 μm) similar situation arose in the case when nitrated cast iron counterface was employed to the friction pair. Here, the value of total wear in the presence of mineral oil equal to 20 μm is more than four times greater than the total wear of this friction pair in the presence of synthetic oil (5 μm).

After a 27000 m run the values of the linear wear of the friction pair with employed cast iron counterface (10,7 μm) are also lower than in the case of nitrided cast iron counterface (9 μm).

The wear of the friction pair with cast iron counterface was characterized by static kinetics of the process, i.e. similar values of the wear occurring during a particular test run. Whereas, the kinetic of friction pair with nitrided cast iron counterface exhibits a clear decreasing tendency. Furthermore the maximum values of the wear tends to occur after the second run. This indicates that the friction pair are wearing-in. Previously conducted organoleptic tests confirmed the possibility of intensive wear during the initial period due to the fact that the vacuum nitriding process [8] causes the increase of surface roughness, which must be compensated in the initial period of cooperation.

The temperature of the specimen

During the test, the temperature of the specimen was measured during the overall test cycle. For this reason the average temperatures of particular runs for each friction pairs were calculated. Wherein the temperature of the friction pair after completed run are used in the calculations. . Obtained values are shown in Table 2

Table 2. An average temperature of the specimen of individual specimen

No.	Counterface	Kind of oil	The average value of the specimen temperature, ° C	The standard deviation
1	Cast iron	Mineral	37,2	1,61
2	Nitrided cast iron	Mineral	29,2	0,29
3	Cast iron	Mineral	41,3	8,14
4	Nitrided cast iron	Mineral	32,7	1,53
5	Cast iron	Mineral	65,0	1,00
6	Cast iron	Mineral	54,0	17,35
7	Nitrided cast iron	Mineral	39,7	13,32
8	Cast iron	Mineral	36,7	3,06
9	Nitrided cast iron	Mineral	51,7	15,63
10	Cast iron	Synthetic	46,0	14,42
11	Nitrided cast iron	Synthetic	53,0	29,46
12	Cast iron	Synthetic	46,7	12,90
13	Cast iron	Synthetic	78,0	38,59
14	Nitrided cast iron	Synthetic	32,7	11,37
15	Cast iron	Synthetic	92,3	2,08
16	Nitrided cast iron	Synthetic	42,0	4,36
17	Nitrided cast iron	Synthetic	67,3	17,16
18	Cast iron	Synthetic	74,3	28,94
19	Nitrided cast iron	Synthetic	32,3	10,79

Based on the results showed in Table 2 it was found that the average temperature of the specimen coated with TiN cooperating with cast iron counterface, in the presence of mineral oil (Sample No. 1, 3, 5, 6, 8, 10) is equal to 46.8 ° C, in the presence of oil synthetic (samples No. 12, 13, 15, 18) the temperature of the specimen had a value of 67.5 °. The temperature of the specimen coated with TiN cooperating with nitrided cast iron counterface in the presence of mineral oil (sample No. 2, 4, 7, 9) was equal to 38.3 ° C, in the presence of synthetic oil (sample No. 11, 14, 16, 17, 19) the temperature of the specimen was equal to 45.5 °. The measured temperature of the specimens confirm the higher value of the tangential forces arising from the TiN coated samples of cast iron counterface compared to the one cooperating with nitrided counterface. The Differences in average temperatures were equal to 18.2% of mineral oil and synthetic oil 32.6%.

4. Discussion of the results

The conducted comparative studies allowed to determine the coefficient of friction of the investigated friction pairs, lubricated with mineral and synthetic oil as well as the wear values and the specimen temperatures (see table 3)

Table. 3. Friction force, coefficient of friction, and wear values for the investigated material arrangements along the friction path equal 13,500 m (in brackets – the values of the friction path equal 27,000 m)

Kind of arrangement	Mean value of friction force N	Mean value of the coefficient of friction	Mean value of the wear μm	Mean value of temperature of specimen °C
Specimen with TiN Counterface: cast iron Mineral oil elf sporti 15W40	20,9	0,042	16	46,8
Specimen with TiN Counterface: nitrided cast iron Mineral oil elf sporti 15W40	8,9	0,018	20	38,3
Specimen with TiN Counterface: of the cast iron Synthetic oil elf synthese 5W50	35,0 (28,1)	0,067 (0,044)	5 (11)	67,5 (54,5)
Specimen with TiN Counterface: nitrided cast iron Synthetic oil elf synthese 5W50	15,3 (8,0)	0,031 (0,015)	5(9)	45,5 (40,5)

Basing on the conducted examination of the specimen and the counterface it can be concluded that virtually entire total wear falls on a counterface. Otherwise, one would expect complete removal of the TiN due to its thickness of about 3 μm. This is confirmed by the sample images of the first friction pair (Fig. 6) as well as the second friction pair (Fig. 7). The TiN coating wear identified on the basis of the inspection carried out after the tests was negligibly small (immeasurable), even when the friction distance reached 27000 meters.

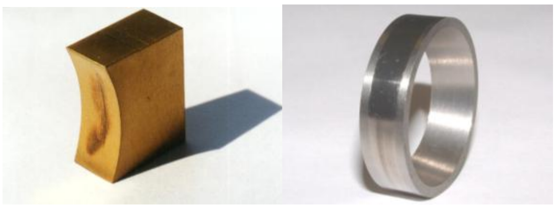


Fig.6. Photograph of TiN-coated specimen and cast iron counterface after examination (friction path equal to 13 500 m)

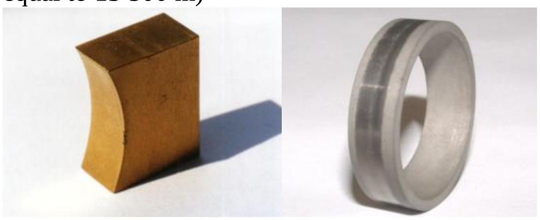


Fig.7. Photograph of TiN-coated the specimen and nitrided cast iron counterface after examination (friction path equal to 27000 m)

The total relative wear of the friction node with nitrided counterface cooperating with the specimen coated with TiN, lubricated with mineral oil appeared to be greater for 18% compering with the cast iron counterface cooperating with specimen coated with TiN in the presence of this same lubricant. However, in the presence of a synthetic oil the wear was lower by about 9%. It should be noted, however, that with such a small linear wear in order of several μm, a significant impact on measurement uncertainty has a progressive wear and position of the bearing tester.

Moreover, basing on the conducted experiment, it was found that more than twofold vale of the total wear occurs in the case of the friction pair combined of titanium nitride specimen and cast iron counterface, lubricated with mineral oil (16 μm; table 3) compering with the corresponding friction pair lubricated with synthetic oil (5 μm; table 3). In the case of friction pair equipped with the nitrided cast iron counterface, lubricated with mineral oil, the value of the wear (20,0 μm; table 3) was over two times greater than in the case when the synthetic oil was used to lubricate this same friction pair (5 μm; table 3).

Despite the higher values of the calculated friction coefficient for both material matching in the presence of synthetic oil in comparison to mineral oil, a significantly smaller value of the total wear was noticed when operating in the presence of synthetic oil.

5. Summary

The development of a well-bonded surface lubricating is conditioned by a number of factors. Starting from the surface microstructure through the properties of the lubricant and many other. Generally, stability of the lubricating layer is the greater, the greater is its binding to the substrate [12, 13]. the stability is understood here, as the time that it may endure certain damaging effects. This layer has a fundamental importance, from the point of view of co-operation with the surface of another element, when the local oil film break due to load increase when it comes to contact surface asperities. In other words, the better it is connected with the surface, the lower the generated friction coefficient.

The reasons for smaller values of wear are believed to be caused by largely reduced intensity of adhesive wearing during the mixed friction, as a consequence of the micro contacts of rough surfaces [3]. This attribute demonstrates coatings with low value of the componential sum of the dispersion and the polar surface free energy, including used during the experiment titanium nitride coatings. During cooperation with the counterface with high value of componential sum of the dispersion and the polar, surface of which is well bonded with the lubricant layer, the conditions allowing to reach low values of tangential forces as well as low values of the wear, even when the system is subjected to large loads.

Another factor contributing to the prevention of the adhesive wear, in this case, is employment of the synthetic oil as a lubricant. Synthetic oil properties [1, 11], especially its ability to form an oil film from the moment of start, combined with the properties of the specimens surface, i.e. low intensity and adhesive wear and counterface properties, and good maintenance of lubricating layer allowed to achieve low wear values.

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Nomenclature/*Skróty i oznaczenia*

SFE Surface Free Energy/*swobodna energia powierzchniowa*

TDC Top Dead Center/ *ZZ zwrot zewnętrzny*

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