LABORATORY WEAR ASSESSMENT OF CAMSHAFTS' CAMS

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Summary

In this work results of laboratory wear tests of specimens made of spheroidal graphite cast iron grade EN-GJS-900-2 have been presented. This cast iron is used for camshafts of FIAT cars manufacturing. The iron has been heat–treated to obtain a hardness, ranging from 37 up to 53 HRC. Dry sliding and lubricated wear tests have been carried out. Their results have been utilized to work out mathematical wear models of the investigated cast iron. These models enabled the assessment of the influence of: lubricant presence, pressure, cam and pusher hardness on the wear rate of the tested material.

Keywords: camshafts, cams, wear rate, spheroidal graphite cast iron, sliding friction.

LABORATORYJNA OCENA ZUŻYCIA KRZYWEK WAŁKÓW ROZRZĄDU

Streszczenie

W pracy przedstawiono wyniki laboratoryjnych badań zużycia próbek wykonanych z żeliwa sferoidalnego gatunku EN-GJS-900-2 stosowanego na wałki rozrządu samochodów osobowych marki FIAT. Żeliwo to poddano obróbce cieplnej w celu uzyskania twardości od 37 do 53 HRC. Badania przeprowadzono przy tarciu na sucho i w obecności oleju silnikowego. Ich wyniki wykorzystano do opracowania matematycznych modeli zużycia badanego żeliwa sferoidalnego. Modele te pozwoliły na ocenę wpływu takich czynników jak obecność środka smarnego, nacisk, twardość krzywki i popychacza na intensywność zużycia badanego materiału.

Słowa kluczowe: wałki rozrządu, krzywki, intensywność zużywania, żeliwo sferoidalne, tarcie ślizgowe.

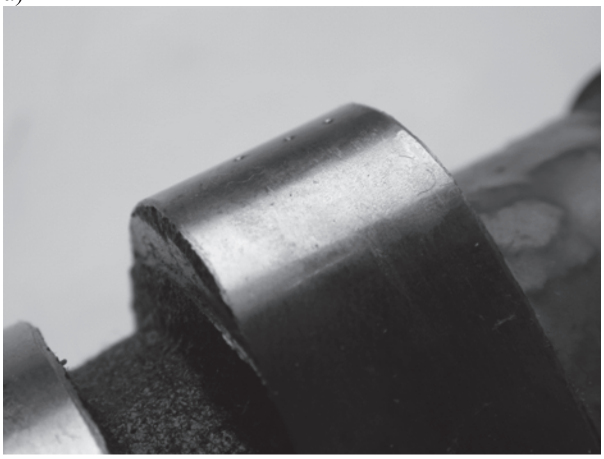
1. INTRODUCTION

The mating cam of a camshaft – pusher plays an important role in internal combustion engines, because it is responsible for controlling the movement of valves. Elements of this mating are subjected to a tribological wear, that changes their shapes. This phenomenon has an undesirable influence on an engine properties in service. Cams and pushers are made of wear resistant materials and work in lubricating friction conditions, thus their wear has usually a very low rate. So their shape remains almost unchanged during the whole service period of an engine. Fig. 1 presents an appearance of a normally worn cam, made of spheroidal graphite cast iron, and an optical micrograph of its working surface. In the latter one vertical dark and light strips, that are remains of grinding marks (made during its manufacturing), are still visible. Oblique wear grooves (Fig. 1 b) are very shallow and narrow.

Sometimes in service occur cases of severe wear of cams, that results in significantly reduced life of camshafts. An example of severely worn cam is presented in Fig. 2. Deep wear grooves, pits and plastically deformed material is present on its working surface (Fig. 2 b). Plastic deformation of cast iron matrix facilitates formation of adhesive joints, that subsequently break, causing tearing out of some portion of specimen metal and thus pits and grooves formation [1]. So the appearance of the severely worn cam surface indicates that an adhesive wear mechanism has been dominant in this case.

Severe wear of cams can be influenced by different factors. During the service of an engine they interact. From that reason it is difficult to isolate them to determine their effect on the cams' wear behaviour. Laboratory wear tests enable to control each factor, so its influence on the investigated phenomenon is easy to determine. Thus in the present work laboratory test results have been used to study wear behaviour of the cams.

a)



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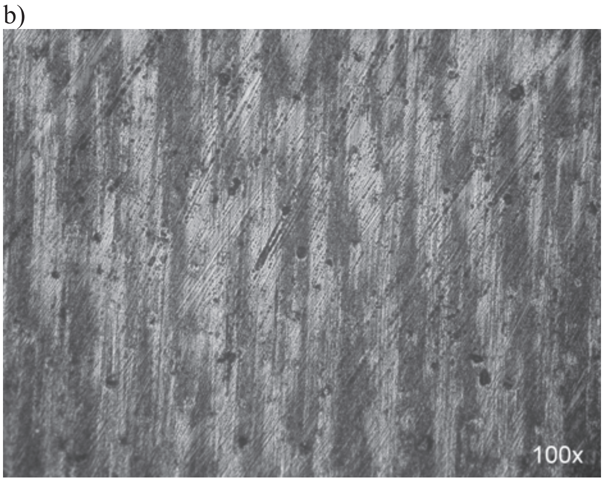
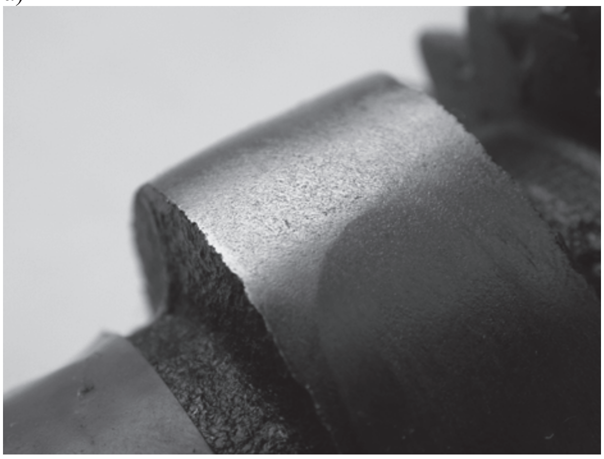


Fig. 1. The appearance (a) and the optical micrograph of working surface (b) of a normally worn cam, made of spheroidal graphite cast iron

a)



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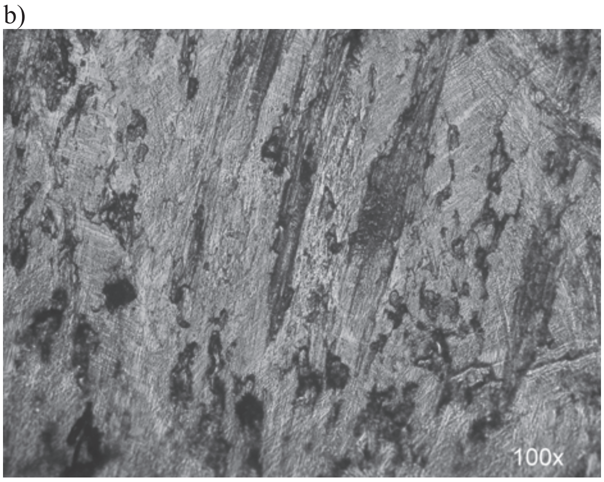


Fig. 2. The appearance (a) and the optical micrograph of working surface (b) of a severely worn cam, made of spheroidal graphite cast iron

2. WEAR TESTS

A pin-on-disc apparatus has been utilized to carry out the wear tests in the present work. Pins were machined from a spheroidal graphite cast iron grade EN-GJS-900-2 (according to the PN-EN 1563:2000 Standard), used for camshafts of FIAT cars manufacturing. To obtain a non-conformal contact, like the one of the cam and pusher, the shape of the pin tips was a half-sphere. Its radius was of 1.5 mm. Pins were water-quenched and tempered to obtain three ranges of hardness: 37 - 38 HRC, 43 - 44 HRC and 53 - 55 HRC. Discs with a diameter of 46 mm and thickness of 4 mm were made of a grey cast iron grade GJ-250, used for pushers. Tis cast iron has been hardened to a Rockwell C Harness Number of 46 – 48. The chemical compositions of the tested materials are presented in Table 1.

Test parameters are given in Table 2. Wear behaviour of pins in dry and oil lubricated friction conditions has been studied. For the latter ones the Aquila SG/CD 15W/40 engine oil have been used. In the all tests a constant load of 49.05 N and sliding speed of $1\ m \cdot s^{-1}$ have been applied. Sliding distance of a single test run ranged from 20 m for dry sliding to 1000 m for oil lubricated conditions. During each test a wear scar on the specimen surface has formed. Its area has been wear dependent. So the pin wear has been determined on the basis of wear scar diameter.

Table 1. Chemical composition of the cast irons for pins and disks

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Mg	Cu
Pin	3.38	2.65	0.50	0.02	0.01	0.05	-	-	0.025	0.11
Disc	3.35	2.40	0.78	0.10	0.04	1.05	0.42	0.46	-	0.10

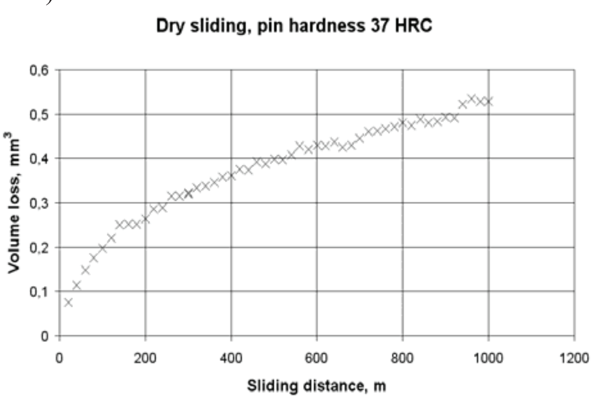
Table 2. Test parameters

Parameter	Values
Friction	dry, oil lubrica ted
Load, N	49.05
Sliding speed, m $\cdot$ s^{-1}	1
Sliding distance, m	20 – 1000
Pin hardness, HRC	37, 38, 43, 44, 53, 55
Disc hardness, HRC	46 – 48

3. TEST RESULTS

An example of test results is presented in Fig. 3. As can be seen in that figure the longer the sliding distance the greater the wear volume (volume loss) and the lower the pressure. The pressure decrease is caused by the increase of the apparent contact area, that often takes place during the sliding wear tests with a non-conformal contact [2].

a)



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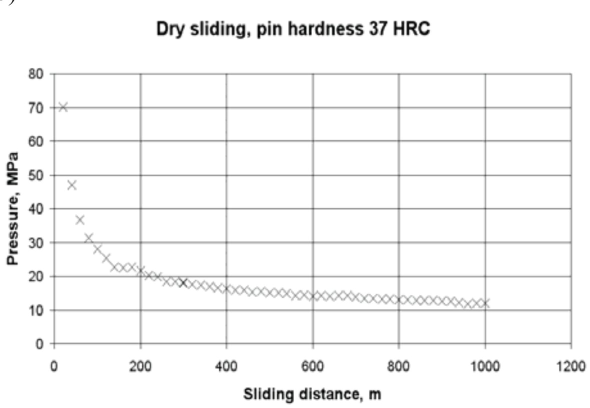

Fig. 3. Wear volume (a) and pressure (b) vs. sliding distance

4. DISCUSSION

To study the influence of the tested factors on the wear rate of the tested cast iron the dimensional analysis has been utilized [3]. With its aid the following function has been worked out:

$$\frac{Z}{l} = f\left(\frac{p}{\mathrm{H}_1}, \frac{\mathrm{H}_2}{\mathrm{H}_1}\right), \tag{1}$$

where:

Z – linear wear ($Z=V/A$), mm,
V – volume loss, mm^3,
A – apparent contact area, mm^2,
p – pressure in the pin-disc contact ($p=P/A$), MPa,
P – load, N
H_1, H_2 – hardness of pin and disc respectively, HB,
l – sliding distance, km.

A ratio Z/l is often called a linear wear rate [4]. According to Ref. [5] the following mathematical form of the function (1) has been chosen:

- for dry sliding:

$$\frac{Z}{l} = -0.020\cdot\left(\frac{p}{\mathrm{H}_1}\right) - 0.022\cdot\left(\frac{\mathrm{H}_2}{\mathrm{H}_1}\right) - 0.005\cdot\left(\frac{p}{\mathrm{H}_1}\right)^2 + 0.007\cdot\left(\frac{\mathrm{H}_2}{\mathrm{H}_1}\right)^2 - 0.003\cdot\sqrt{\frac{p}{\mathrm{H}_1}} + 0.015\cdot\sqrt{\frac{\mathrm{H}_2}{\mathrm{H}_1}} + 0.034\cdot\frac{p}{\mathrm{H}_1}\cdot\frac{\mathrm{H}_2}{\mathrm{H}_1}, \tag{2}$$

- for oil lubricated sliding:

$$\frac{Z}{l} = 0.078\cdot\left(\frac{p}{\mathrm{H}_1}\right)^2 + 0.003\cdot\left(\frac{\mathrm{H}_2}{\mathrm{H}_1}\right)^2 - 0.043\cdot\sqrt{\frac{p}{\mathrm{H}_1}} + 0.043\cdot\frac{p}{\mathrm{H}_1}\cdot\frac{\mathrm{H}_2}{\mathrm{H}_1}, \tag{3}$$

Equations (2) and (3) contain some numerical coefficients. Values of these coefficients have been determined with the aid of a regression, whose accuracy has been determined with coefficients of correlation. Their values were 0.89 and 0.96 for the equations (2) and (3) respectively. They are high enough to accept the determined dependences for the further analysis. The influence of pressure, pin and disc hardness on wear rate of the tested cast iron is presented in Figs 4 and 5.

In Figs. 4 and 5 can be seen, that the pin wear rate Z/l for oil lubricated sliding is significantly lower than the one for dry conditions. The latter one caused very intense pressure decrease in the beginning of the test. So it was unable to obtain test results for high pressures in the dry friction conditions. It is the reason that the pressure range in Fig. 4 is much wider than in Fig. 5. The pressure increase increases the wear rate, especially for low pin hardness, both in dry and lubricated conditions. High pressure facilitates plastic deformation and microcutting, thus intensifying abrasion and adhesion [6, 7]. These effects can be responsible for wear rate increase. Higher pin hardness causes greater wear resistance of the tested cast iron, visible especially in dry friction – high pressure conditions. Harder subsurface material is much more difficult to deform under high pressures and

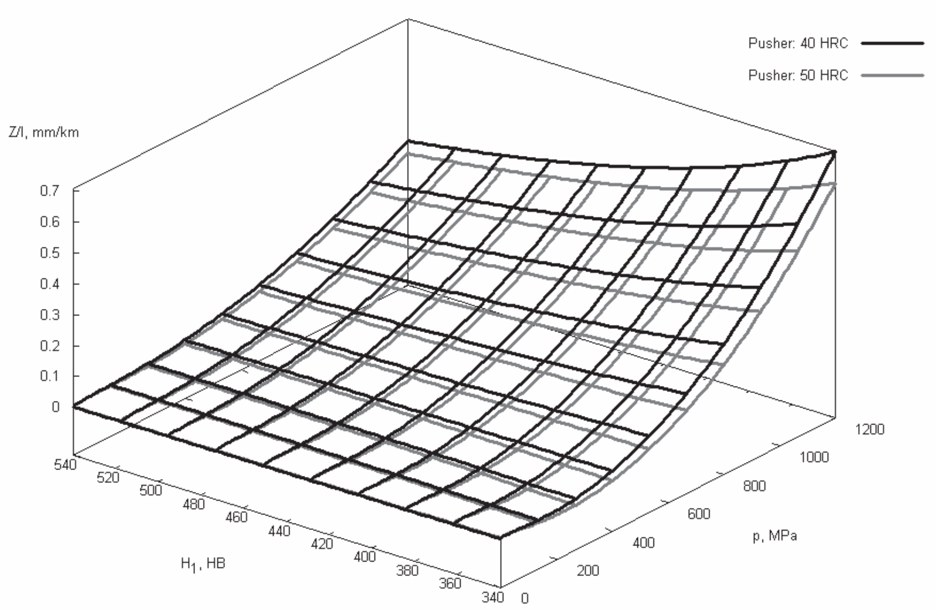

Fig. 4. The influence of pressure, pin (cam) and disc (pusher) hardness on wear rate of the tested cast iron in oil lubricated conditions

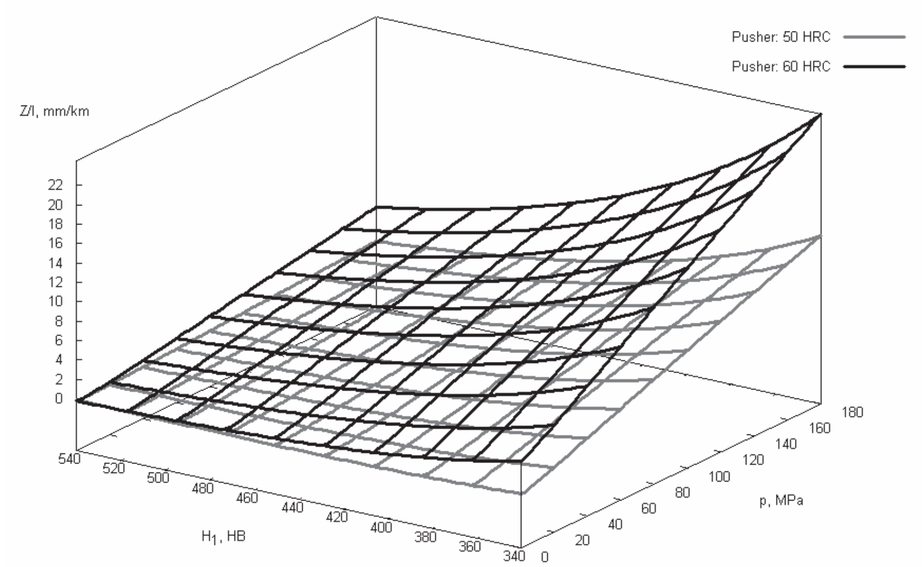

Fig. 5. The influence of pressure and pin hardness on wear rate of the tested cast iron in dry sliding conditions

can support thick films of oxides, that prevent metal – to metal contact and adhesion [6, 7], thus reducing the wear rate. Since presence of the engine oil prevents adhesive joints forming, wear rate decrease with the hardness increase in lubricated conditions (Fig. 4) is less severe than the one visible in Fig. 5.

The formulas (2) and (3) enable an assessment of the effect of the disc (pusher) hardness H_2 on the pin (cam) wear rate. As can be seen in Fig. 4 this effect in oil-lubricated conditions is negligible. It ranges within the scatter of the test results. On the other hand the hardness H_2 significantly influences the pin wear rate in dry sliding conditions. Its increase increases this rate. It can be attributed to the abrasive wear intensification, because harder asperities of disc can more easily plough and microcut pin material, especially when it exhibit low hardness.

6. CONCLUSIONS

The results of the tests and calculations carried out in the present work have drawn to the following conclusions:

- the presence of the lubricant influences the most significantly wear rate of the tested cast iron. the lubricant absence dramatically increases the wear rate. it can be explained by adhesive wear intensification.
- adhesive and abrasive wear can be intensified as pressure grows and pin (cam) hardness

drops off, especially in dry sliding conditions. So pin wear rate increases when its hardness decreases or the pressure increases. That effect is much less severe than the one of the lubricant absence (Fig. 4 and 5).

- disc (pusher) hardness significantly influences the wear rate of pins (cams) only in dry sliding conditions. its increase intensifies abrasive wear, thus increasing the wear rate.
- to understand the possible causes of severe wear of cams a further study of the effect of other factors, such as oil type, temperature and sliding speed, on the wear rate of cams is necessary. Its results can be helpful to find the best ways to prevent this wear.

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