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INCREASING ENGINE EFFICIENCY BY REDUCING ENERGY LOST BY FRICTION USING HARD CHROME PLATING

BY

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Abstract. Vehicles’ engines require low friction forces between machine elements in order to decrease fuel consumption and pollution. The solution recommended by us after many researches in specialty literature is hard chrome plating the crankshaft. In this way friction forces will be reduced significantly and implicit the energy lost. We have performed hard chrome plating on a shaft and we have analyzed it with SEM equipment. The structure of the coating resulted homogeneous and the layer compact. The sample has also been subjected to scratch test in order to determine the friction coefficient. Based on destructive test, have been determined a series of important parameters of the coating which helped us to calculate the adhesion.

Key words: coating; hard chrome plating; SEM; scratch; adhesion.

1. Introduction

Automotive industry is one of the most important domains of researches because the tendencies nowadays are reducing fuel consumption and also the pollution. As is known engines have been studied by many researches through the energy loss by friction perspective. Regarding transport vehicles, more than 30% of fuel energy is lost by friction (Holmberg, 2014), 18% from this loss being caused by engine’s machine elements friction fact that led to the

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"wasting" of more that 150000 million litres of fuel and generating more than one million of CO_2 emissions. Regarding passenger vehicles, less over 20% from fuel energy is used for movement (Holmberg, 2012).

Of course the researchers have found new technical solution of power loss by friction recovery from brake system, but the studies are in continuous improvement.

Machine elements inside the engine have been studied by the most important automobiles manufacturers (Kamil, 2013), and it was discovered that the crankshaft is subjected to a high friction between bearings and connecting rod bearings, especially when it starts and the lubrication is not performed successfully.

At start and at low speeds crankshaft has the higher friction according to studies performed in specialty literature (Rakopoulos, 2007). When the wear appears, friction loss increases fast (Zhenpeng, 2014) and the energy is wasted.

Crankshafts are subjected to torsion, bending and fatigue solicitations.

Torsion and bending are calculated by designers and the deformations are kept under control. Fatigue is a problem. It depends of material behaviour under periodical solicitations. In this sense have been developed studies (Ktari, 2011) and it was discovered that the defect appeared due to internal stresses and also due to inclusions which are the main cause of cracks appearing. After the material yields around the inclusions, the internal stresses accelerate the crack's propagation to the surface. Therefore we consider that is required a homogeneous material, without inclusions in order to increase crankshaft's fatigue resistance and implicit it's durability.

Crankshaft wear has been studied deeply and it was found that the wear diagram is elliptic (Nikolic, 2012), and we could estimate that is required a low friction coefficient.

Crankshaft is made by steel and connections rod by bronze, and the kinematic couple of friction is generating a friction coefficient around 0.6 according studies from specialty literature (Equey, 2011).

In order to increase crankshafts durability, we have made a study of their damages, which led to surface modification. We have taken into consideration that crankshafts manufacturing have a great importance in passenger safety and high requirements are imposed.

Important studies in Surface Engineering have been performed (Axinte, 2010a; Axinte, 2010b; Bistriceanu, 2010; Chicet, 2010; Barbinta, 2010) referring to plasma spraying deposition, a process used in obtaining of high properties coatings in domains of activities, where are required good mechanical, thermal, corrosion and tribological properties.

2. Experimental

The aim of this study is increasing engine's crankshaft tribological properties in order to reduce fuel consumption and pollution.

Hard chromium plating is realized by immersion the metallic material in a solution of chromic acid (CrO_3). The coating resulted is very hard and have a high resistance in aggressive corrosion environment. This type of coating are used in domains where is necessary high wear and corrosion resistance (ASM Handbook, 1994).

Studies in Surface Engineering analyzed by us led us in choosing of applying hard chromium electroplating on crankshaft. As is well known chromium has a high corrosion and thermal resistance, therefore we decided to use it in our future study.

We have chosen a shaft made by classic forged steel 42CrMo4. The steel has classic chemical composition and its hardness is 250 HB.

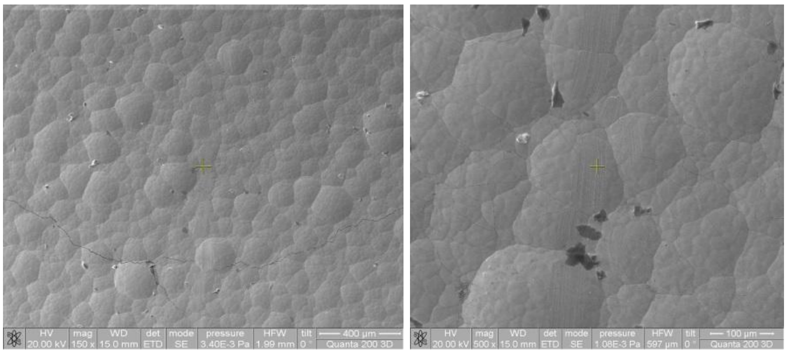
For experimental activity it has been used a shaft which has been immersed in a chromium bath and after that it has been subjected to a dehydrogenizing heat treatment.

The coating obtained has the hardness value 38 HRC.

The shaft has been cut and analyzed using scanning electronic microscopy and also a microtribometer.

2.1. Coating Nondestructive Analysis

The sample was used first for nondestructive analysis which has been performed in order to observe the microstructure and the chemical composition, using scanning electronic microscopy.



a *b*

Fig. 1 – SEM microstructures of Cr coating: *a* – 150x magnification; *b* – 500x magnification.

In Fig. 1, it could be observed the coating's microstructure which is homogeneous and compact.

As we detailed before, in operating is required a homogeneous material in order to avoid fatigue damages. Using hard chrome plating we have obtained a coating with the requested microstructure.

As is shown, in Fig. 1*a*, surface finishing is good, without porosity, defects or inclusions, being a positive and important aspect in our future tests.

In Fig. 1*b*, is shown, a detail of coating at higher magnification, where could be observed some particles with irregular geometry. From this image results that these particles are not from coating's structure.

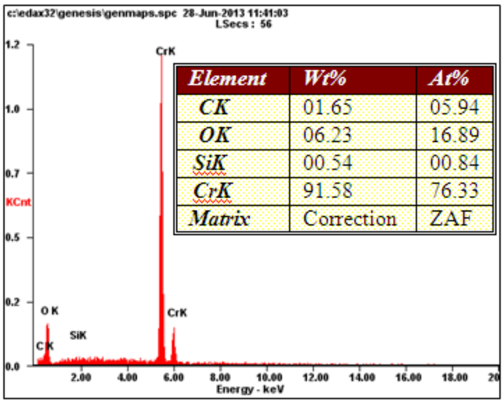


Fig. 2 – EDS analysis – Cr coating chemical elements.

In Fig. 2 is represented coating chemical analysis which displays the appearance of Si resulted from atmosphere dust. In low percentage the coating consists of oxygen and we could approximate that is chromium oxide.

From this analysis we could estimate that the coating has not been contaminated during and before deposition process, aspect which is important in our future tests.

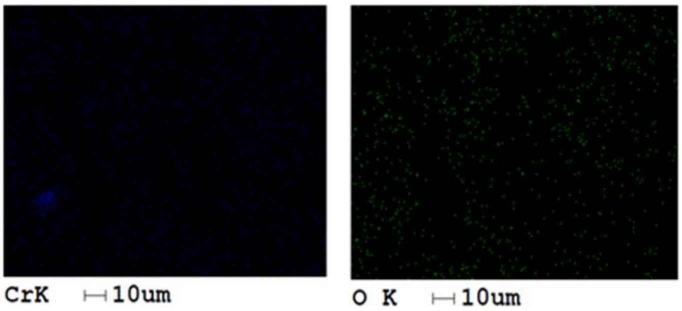


Fig. 3 – EDS analysis: *a* – Chromium mapping; *b* – Oxygen mapping.

In Fig. 3*a*, is displayed chromium distribution in coating. As is shown, there are some areas where is not very well defined. These areas are gaps where the oxygen and silicon are present. In Fig. 3*b*, is shown the oxygen presence in chromium layer gaps.

2.2. Coating Destructive Analysis

The sample has been subjected to scratch test in order to determine friction coefficient and also the adhesion of the coating to the substrate, using microtribometer with an indenter of diamond with tip angle of 120°.

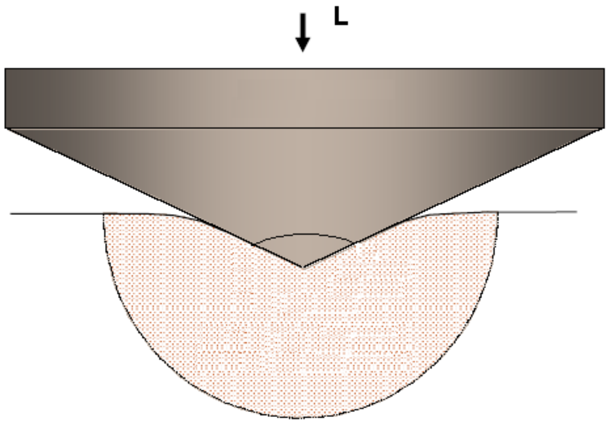


Fig. 3 – Scheme of scratch test.

Scratch test has been performed in dry contact at room temperature and humidity and in Fig. 3 is observed the testing scheme.

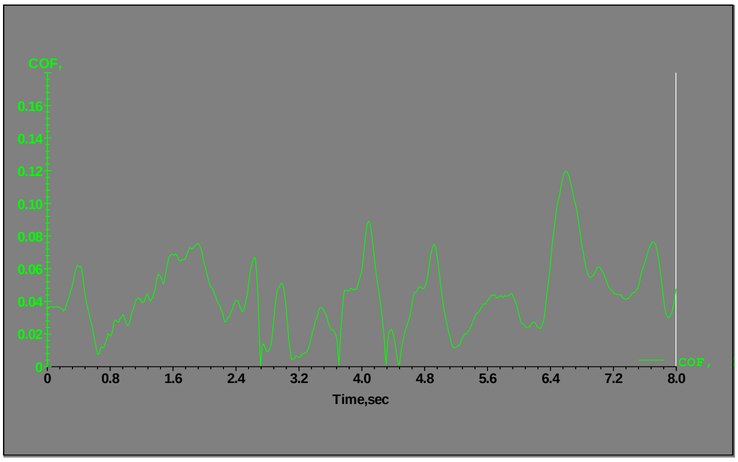


Fig. 4 – Cr coating friction coefficient.

In Fig. 4, it could be observed the evolution of friction coefficient during scratch test.

The value of friction coefficient is 0.04, but it has a variation during testing in the interval of 0.02-0.12.

It must be taken into consideration that friction coefficient has been determined in contact of diamond and chromium coating. If it has been determined between Cr and Cr the value would have been lower.

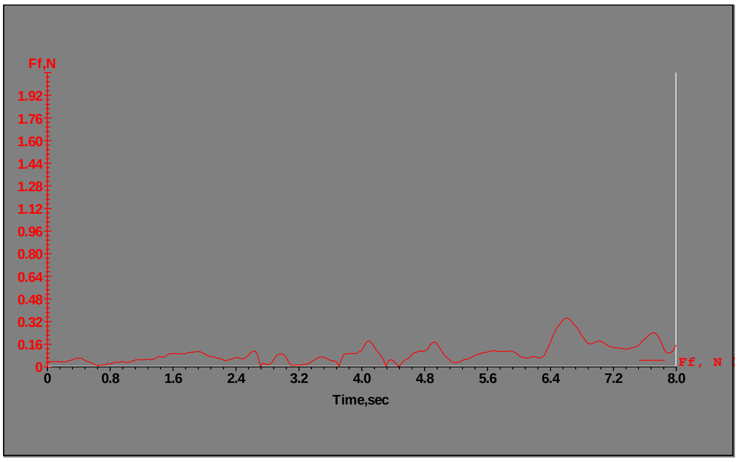


Fig. 5 – Cr coating Friction Force.

In Fig. 5 is represented friction force between the indenter and coating. As it could be observed it starts from a low value and increases when the test is finishing, due to heat transfer. The value of friction force is 0.4475 N.

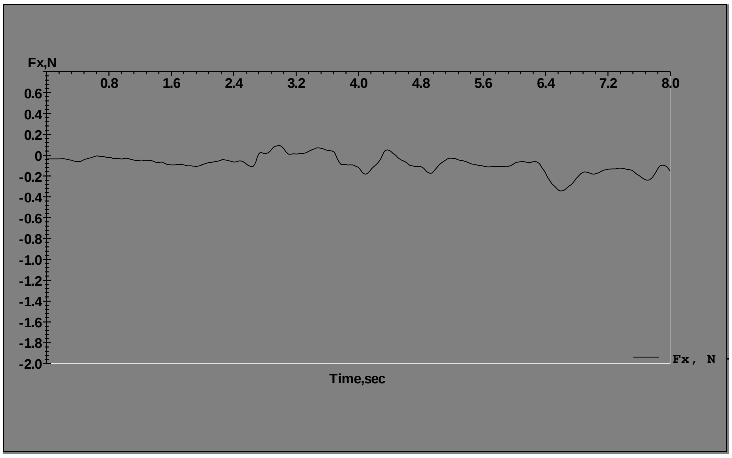


Fig. 6 – Cr coating Tangential Force.

In Fig. 6 is represented tangential force which is constant at the beginning of test and increases at the end, nominal value being 0.4191 N.

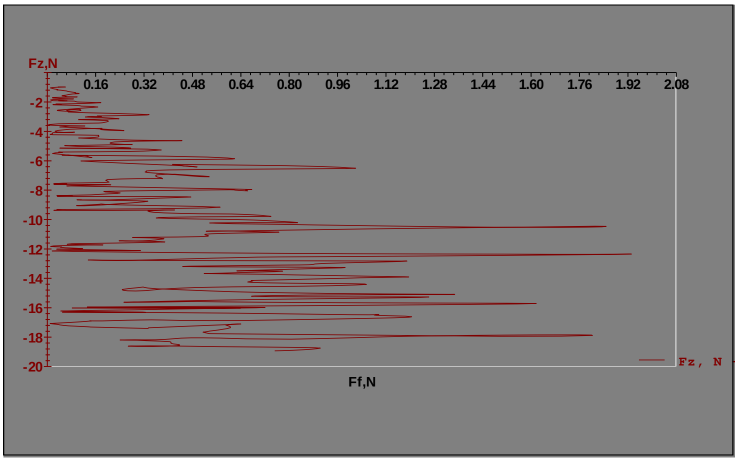


Fig. 7 – Cr coating Friction Force.

In Fig. 7 is sown normal force which generates the friction coefficient. Normal force’s value is 10 N.

After the scratch test has been performed, we have analyzed again the sample in order to observe the damage produced and to measure the scratch width.

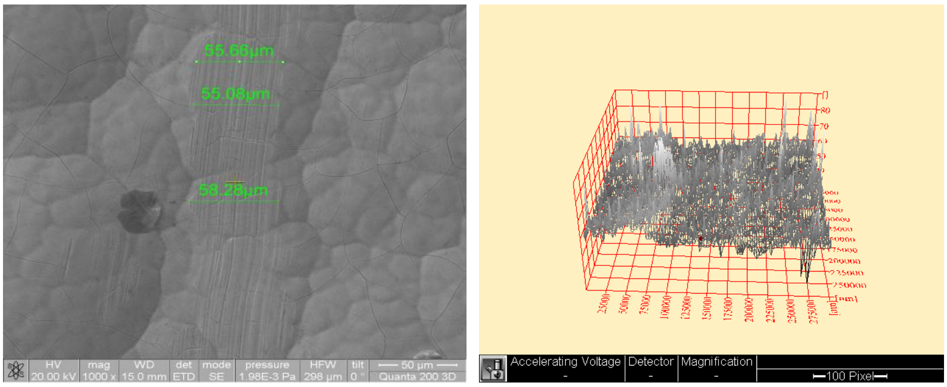


Fig. 8 – The scratch of Cr coating:
a – scratch width; *b* – scratch topography

In scratch test was used the maximum force and, as is shown in Fig. 8*a*, the scratch does not generated the coating exfoliation. The scratch width is around 56 µm. On the scratch, Cr coating has a uniform surface profile excepting the area from the end of the test, when, as Fig. 8*b* shows, the compressive stresses generated surface modification.

3. Coating Adhesion

In coating analyses one of the most important parameter is the adhesion. The coating must have strong bond stresses in order to avoid exfoliation. For adhesion calculation were used equations from Kuiry S. paper in 2012.

The known parameters resulted from scratch testing are detailed in Table 1.

Table 1

Scratch Analysis Parameters

Parameter	Value
F_x = Tangential force	|-0.4191| N
F_z = Normal force	10 N
d = Scratch width	0.056 mm
R = Tip radius	0.2 mm
H_s = Substrate hardness	850 N/mm^2
H_c = Coating hardness	1200 N/mm^2
t = Coating thickness	1 mm
ν_s = Substrate Poisson coefficient	0.3
ν_c = Coating Poisson coefficient	0.28
E_s = Substrate Young Modulus	2.1·105 N/mm^2

The known parameters of coating and substrate and of scratching test will be used in adhesion calculation.

$$F_x = \frac{d^3}{12R}H_s + \frac{\pi}{4}\tau d^2 + dtH_c \quad (1)$$

Using Formula 1 we have calculated the shear stress at the interface. The value obtained is: σ = 27282.85 N/mm^2.

$$a = \frac{d}{2} \quad (2)$$

Using Formula 2 we have calculated the contact radius between the indenter and the coating during the scratch test. The value obtained is: a = 0.028 mm.

$$a^3 = \frac{3}{4}F_z R\left(\frac{1-\nu_s^2}{E_s} + \frac{1-\nu_c^2}{E_c}\right) \quad (3)$$

Using Formula 3 we have calculated the Coating Young Modulus which is one of the representative characteristic of the coating. The value obtained is: $E_c = 0.894 \cdot 10^5$ N/mm^2.

$$\tau = \frac{\sigma_x a}{R} \tag{4}$$

Using Formula 4 we have calculated the Compressive stress which appears at the contact surface between indenter and coating. This stress is the most representative for the coating evaluation because it could generate the exfoliation of the layer. The value obtained is: $\sigma_x = 0.974\cdot10^5$ N/mm^2.

$$W = \frac{\sigma_c^2}{2E_c} \cdot t \tag{5}$$

Using Formula 5 and considering compressing stress as being critical, we have obtained the value of Work on adhesion: $W = 0.5305\cdot10^5$ J.

$$L_c = \frac{\pi d_c^2}{8}\sqrt{\frac{2E_c W}{t}} \tag{6}$$

Using Formula 6 and considering scratch width as being critical, we have calculated the value of Critical load which is the adhesion force of the coating to the substrate. The value obtained is: Lc = 119.8754 ≈ 120 N. The adhesion force resulted around 120 N which is a very good value.

4. Results and Discussions

Studies from specialty literature shown that in vehicles engines, machine elements by their movement, are generating friction. Due to their friction the engine loses 18% of fuel's energy.

Starting from the supposition, that friction must be decreased, we have used the hard chrome plating on the crankshaft.

The couple shaft connecting rod is steel-bronze. Friction coefficient between steel and bronze is around 0.6.

We have performed scratch test on chromium coating using diamond indenter. Friction coefficient resulted from our experiment is around 0.04.

In specialty literature similar scratching tests have been shown. A sample consisting of diamond like carbon coating on steel substrate has been subjected to linear scratch with similar microtribometer and it was obtained a force of adhesion of 25 N.

In our test performed in normal conditions, we have obtained better results.

Adhesion value, calculated based on experimental parameters resulted from scratching test, is 120 N.

The coating scratch profile is smooth and is not damaged by indenter.

5. Conclusions

1. On SEM analysis it was obtained coating's microstructure which is compact and homogeneous.

2. Using the same electronic microscope it was determined by EDS analysis chemical elements percentage, distribution and mapping analyses that gave us information regarding the elements location, discovering the oxygen in chromium gaps.

3. On scratch test it was determined the friction coefficient $\mu = 0.04$, and it is very clear that friction coefficient of chromium coating analyzed by us is 15 times lower than the friction coefficient of steel crankshaft.

4. After a precise calculation, adhesion force resulted 120 N, which is almost 5 times higher than in DLC's case.

This study has been performed in order to find technical solution for increasing vehicles efficiency by decreasing fuel consumption and implicit to decrease the pollution.

Based on experimental results obtained in our work we could consider that the scope of this paper has been reached.

We have obtained a homogeneous and compact coating which will resist well on fatigue.

We have obtained a coating which has a very good adhesion; therefore we could estimate a higher durability.

We have obtained a very low friction coefficient; therefore we could estimate a higher wear resistance of the crankshaft and lower friction.

More studies are required in order to determine exactly the value of energy lost by friction's decreasing, but in this moment we could approximate that using hard chrome plating power lost by friction will be reduced significantly.

In consequence will increase the vehicle efficiency, and will decrease the fuel consumption, costs and also the pollution, which is a big issue nowadays.

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CREŞTEREA EFICIENŢEI MOTORULUI PRIN REDUCEREA ENERGIEI PIERDUTE PRIN FRECARE UTILIZÂND CROMAREA DURĂ

(Rezumat)

Cercetările care au stat la baza studiului efectuat au condus la găsirea unei soluţii pentru a reduce frecarea arborelui cotit din motorul cu ardere internă. Prin procedeul de cromare dură s-a obţinut o acoperire omogenă şi compactă cu o duritate de peste 1000 MPa. Proba a fost supusă la testarea prin „zgâriere” în vederea obţinerii proprietăţilor tribologice şi de aderenţă. Coeficientul de frecare obţinut are valoarea 0.04 şi este de 15 ori mai mic decât coeficientul de frecare arbore cotit – cuzineţi. S-a efectuat ulterior calculul forţei de aderenţă a stratului la substrat, obţinându-se valoarea de 120 N care este de 5 ori mai mare decât în cazul acoperirilor cu structura în retea hexagonală. Prin prisma rezultatelor obţinute putem estima o creştere a eficienţei motoarelor.