ENHANCING THE WEAR RESISTANCE OF CAM SURFACES BY A 40CR130 COATING DEPOSITED IN ELECTRIC ARC

Băsescu Gică Narcis[1], Crîșmaru Ionuț Vasile[1], Imbrea Marius[1], Bărbînţă Andreea Carmen[1], Iacob Strugaru Sorin Claudiu[1] and Munteanu Corneliu[1]

[1] *"Gheorghe Asachi" Technical University of Iasi, Faculty of Mechanical Engineering, 61-63 Prof. dr. doc. D. Mangeron Blvd, 700050, Iasi, Romania, basescunarcis@yahoo.com*

Abstract: *This paper presents the contact fatigue wear behavior of a 40Cr130 metallic coating obtained by electric arc deposition. The coating was deposited on an 18MnCr11 steel alloy. Wear is one of the major failure causes for many component parts from an internal combustion engine. The cams of a camshaft are subjected to wear due to the sliding of contact surfaces in an EHD lubrication regime. The samples were tested on the AMSLER installation for a period of 30 hours to fatigue wear in mixed and limit lubrication conditions. To highlight the results obtained after the test electron microscopy was used. For this purpose the QUANTA 200 3D DUAL BEAM microscope installation was used.*

Keywords: *40Cr130, SEM, AMSLER*

1. Introduction

In first half of the 20th century studies were made regarding the contact between two cylinders working in dry lubrication regime. Grubin and Vinogradova (1949) were the first to consider the simultaneous hydrodynamic and elastic deformation effects of the two metallic cylinders placed in a theoretic linear contact configuration. They also were the first to calculate the thickness of the fluid film in EHD regime.

The first measurements of the film thickness were made by Crook (1958) and Cameron (1960). Dowson and Higginson also did a series of experiments and theoretical studies regarding the elastohydrodynamic lubrication. Other researchers (Johnson, Berthe, Winer, Bair, Hamrock at.al.) analyzed factors (thermal effects, rheology, microroughness, and so on) which influence the EHD lubrication.

The camshaft used in internal combustion engine has the purpose to control the working fluid distribution system in the engine.[1] The accuracy with which the cams impose the law of motion to the cam follower is very important for this reason the influence of wear on contact surfaces is crucial.[2]

The deposition of the 40Cr130 metallic coating had the purpose to enhance the performance of the cam mechanism to abrasive, adhesive and fatigue wear. The reason for choosing this steel alloy was due to its high toughness and very good mechanical properties.[3] For the cam/cam follower mechanism the elastohydrodynamic lubrication regime is piezoviscous and with elastic bodies.[4] This fact leads to local rises of lubricant viscosity, due to the increase of pressure, very high pressures and elastic and plastic deformations. [5]

The electric arc deposition method, unlike other methods (D-gun, plasma spraying, flame spraying, laser surfaces alloying), induce low structural changes in the base material due to the lower temperature regime involved in the deposition process.[6] The layer adherence of the electric arc obtained coating is better than others obtained by another method in similar conditions.[7]

2. Experimental procedure

In this paper is presented a means to enhance the friction wear resistance by thermal deposition of a 40Cr130 coating with the Smart Arc 350 installation by Sulzer Metco. The coating was deposited on the rolling side of an 18MnCr11 disc sample. The coating has to withstand the abrasion, adhesion and fatigue wear caused by intense friction. In table 1 are presented the deposition parameters used for the Smart Arc 350 installation to achieve the desired coating.

Table 1: Technical parameters

Smart Arc 350	40Cr130
U	28V
I	252A
Air pressure	60PSI

To highlight the results electron microscopy was used. This was achieved with the QUANTA 200 3D DUAL BEAM electron microscope. The working chamber of the microscope is presented in Fig. 1. After each testing cycle, the samples were removed and cleaned with a special solution in an ultrasonic bath.

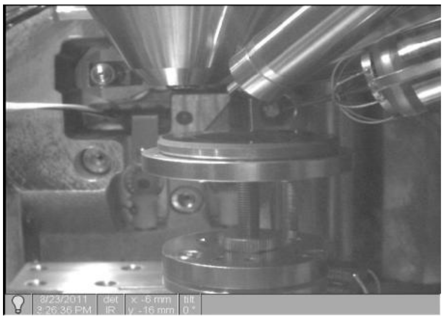


Figure 1: *The clamping of the sample in the working chamber of the microscope.*

For the contact fatigue test the samples had a disc shape with a diameter of 49 mm. The coating was deposited on the rolling side of the disc. The test was done on the AMSLER installation presented in Fig. 2.

Figure 2: *The AMSLER contact fatigue installation*

In the test one of the samples is static and the other one has a rotational movement around its axis. Different combinations of contact material were used: material base – material base and sample with coating – sample with coating.

The lubrication regimes used for the test were limit and mixed using an oil with a SAE 5W-30 (9,3 – 12,5 cSt) viscosity specific for internal combustion engines. The test was carried out for a period of 30 hours, the loading force had a value of 177 N and the velocity of the moving sample was 375 turn/min.

3. The test results

In the cam/ cam follower mechanism the wear takes form of abrasive marks, plastic deformations in the material which leads to accumulations and cracks which can lead pitting and spalling. In the first phase, abrasion wear marks represent the grinding process of the surfaces and their smoothening. This process is usually determent by the tougher material.

In table 2 are presented the mechanical properties of the deposited material and for the base material.

Table : Mechanical proprieties of materials

Proprieties	40Cr130	18MnCr11
Young Modulus	220 [GPa]	200 [GPa]
Tensile Strength	1750 [MPa]	1158 [MPa]
Yield Strength	1450 [MPa]	1034 [MPa]
Hardness	490 [HB]	335 [HB]
Poisson Ratio	0,3	0,29
Density	7700 [kg/m^3]	7800 [kg/m^3]

3.1. The obtained results for the limit lubrication regime

Lubrication in limit regime implies a small quantity of lubricating substance between the contact surfaces. This fact leads to a deficient bearing capacity of the lubricating film, which is accompanied by high thermal phenomenon's, pronounced plastic and elastic deformations and the possibility of material detachment which lead to abrasive wear. Also the surface layer fatigue is more pronounced which leads to material accumulations and cracks caused by the shear stresses. Due to the high thermal regime the adhesive wear is more intense and can lead to scuffing.

Below are presented the results obtained from the SEM analysis on the rolling surface and in cross section of the samples.

In Fig. 3 is presented a SEM image of the rolling surface of the sample made of 18MnCr11 steel alloy. The magnification at which the image was made is 100X. During the fatigue test in limit lubrication conditions to the samples without coating scuffing appeared. On their surface can be observed abrasive marks and plastic deformations. The abrasive marks are caused by the contact between the asperities of the surfaces and also by the abrasive particles detached from the two surfaces. The plastic deformations are caused by scuffing, thermal stresses and abrasive wear.

Fig. 4 shows at a magnification of 500X signs of surface failure due to contact fatigue. This fact is highlighted by the presence of multiple spalls. The spalls are produced by cracks which are initiated in the material and propagate to the surface.

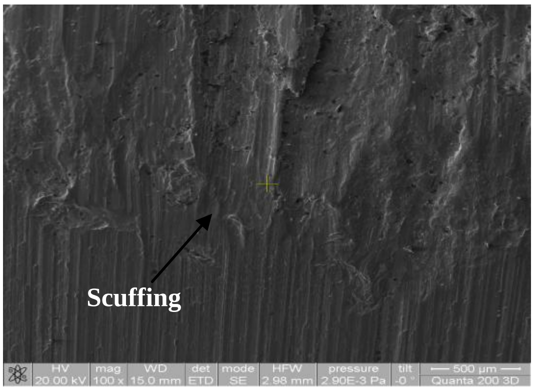


Figure 3: *Scuffing marks on the rolling surface of the samples without coating*

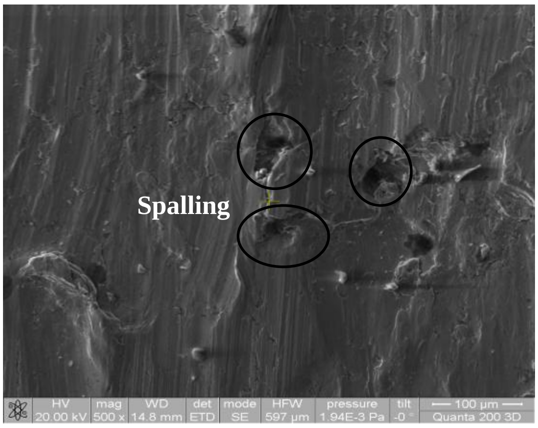


Figure 4: *Multiple spalling caused by the shear stress*

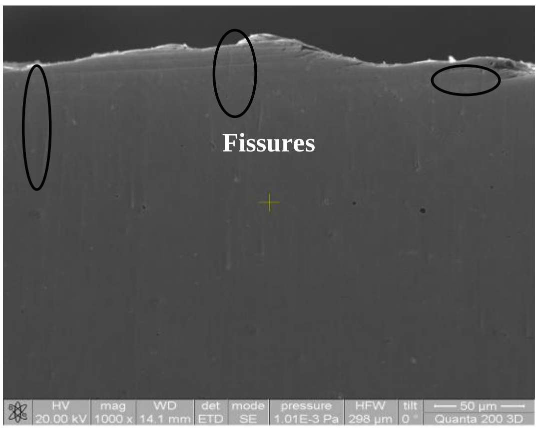


Figure 5: *SEM image in cross section which shows multiple cracks initiated on the surface and in the material*

Fig. 5 presents the cross section of the same sample. Multiple cracks are present in the image. The cracks initiated on the surface propagate downward in the material and are cause by plastic deformations. The cracks parallel to the surface and inside the material are cause by the shear stress and tend to propagate to the surface.

In fig. 6 is present the spectral analyses of the base material and the elementary chemical composition.

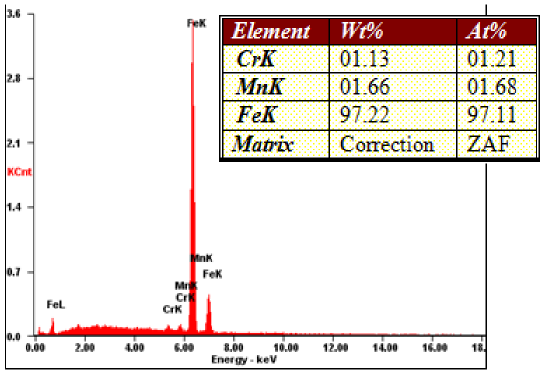


Figure 6: *Spectral analyses of the 18MnCr11steel alloy*

In Fig. 7 is presented an image of the rolling surface of the sample with coating. After the 30 hours contact fatigue test abrasive wear marks are presents which are caused by the smoothing of asperities.

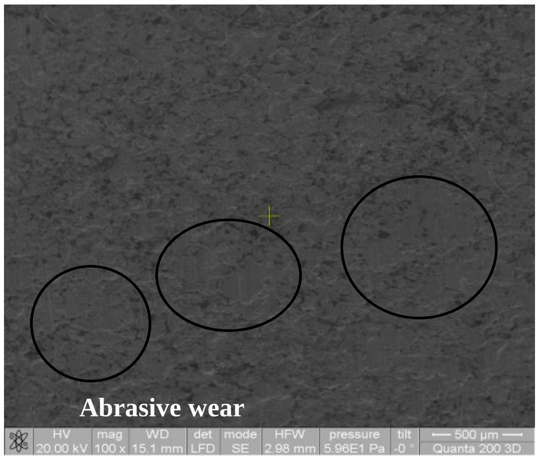


Figure 7: *SEM image of the rolling surface for the sample with coating*

Fig. 8 shows the sheared asperities after the grinding process of the surfaces to achieve a leveling of the asperities and the nominal working regime. The shearing of the asperities can also indicate the fatigue of the material.

Image 9 and 10 show specific aspects of contact fatigue as: cracks and spherical concentrations. Another aspect shown in the pictures is the thermal influenced zone at the interface between the coating and base material.

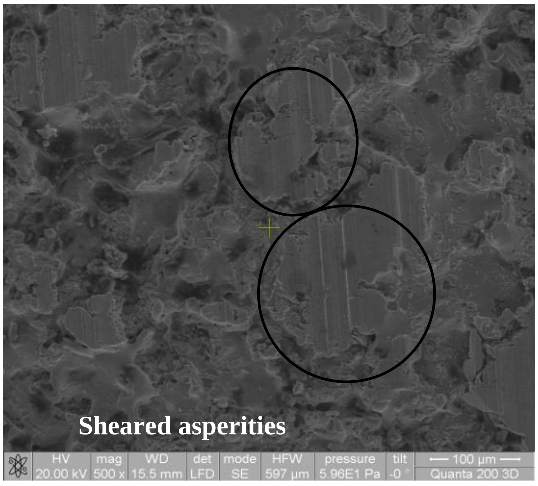


Figure 8: *SEM image of the sheared asperities*

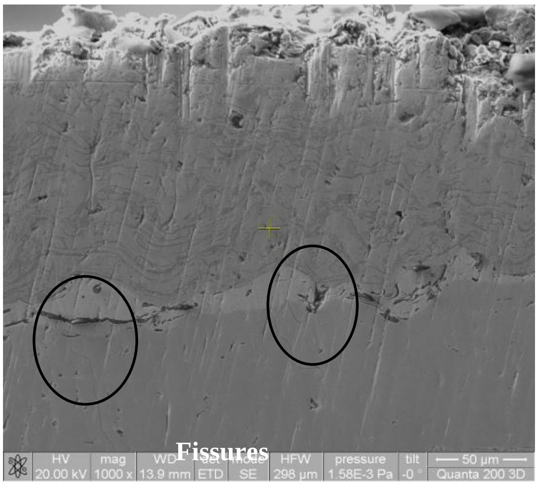


Figure 9: *Cracks at the interface due to shear stresses*

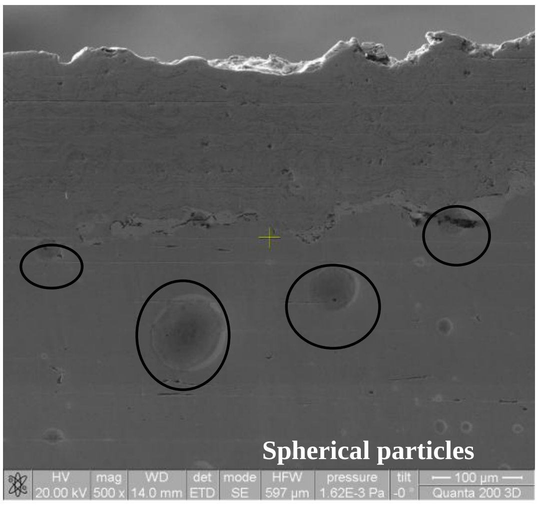
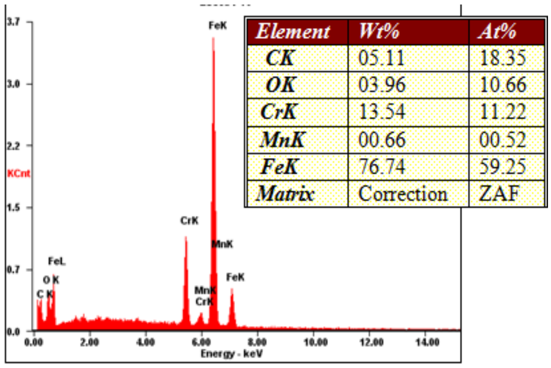


Figure 10: *Spherical concentration of material*

The cracks which appear in Fig. 9 are initiated at the interface between the base material and coating and propagated in the deposited layer. This happens due to the shear stresses at the interface between the two materials. These stresses also cause spherical concentration of the material at the interface.

In fig. 11 is presented the spectra analyses of the deposited coating and its elementary chemical analyses.



Element	Wt%	At%
CK	05.11	18.35
OK	03.96	10.66
CrK	13.54	11.22
MnK	00.66	00.52
FeK	76.74	59.25
Matrix	Correction	ZAF

Figure 11: *Spectral analyses of the 40Cr130 coating*

3.2. The results of the test in mixed lubrication condition

Mixed lubrication conditions lower the friction coefficient and enhance the functioning of contact surfaces. The pressure distribution in the lubricating film depends on the surface asperities. The heat generated by the friction of the surfaces is dissipated more efficiently by the lubricant. Nevertheless elastic and plastic contacts still exist between the surface asperities.

In fig. 12 is presented the rolling surface of the mobile sample after the contact fatigue test in mixed lubrication conditions.

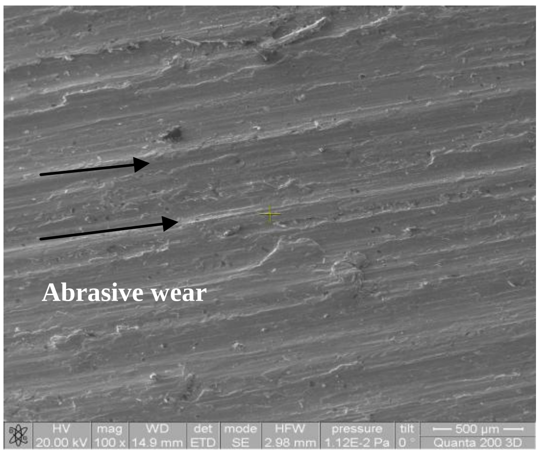


Figure 12: *Image of the rolling surface in mixed lubrication conditions*

Fig. 12 also show less pronounced abrasive wear marks then the marks present on the sample without coating subjected to friction in limit lubrication conditions. This fact is due to the higher minimum thickness of the lubricant film. Fig. 13 shows the rolling surface at a higher magnification. On this image multiple abrasive wear marks are present and also signs of contact fatigue.

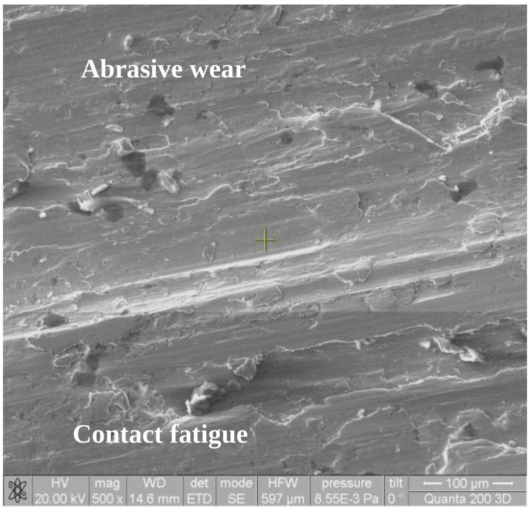


Figure 13: *SEM image of the rolling surface for the sample without coating at a magnification of 500X*

In fig. 14 is presented a cross section in the sample without coating subjected to contact fatigue in mixed lubrication conditions. In the upper left corner a crack can be observer which initiated on the surface and propagated in the material. This crack is due to the fatigue of the material.

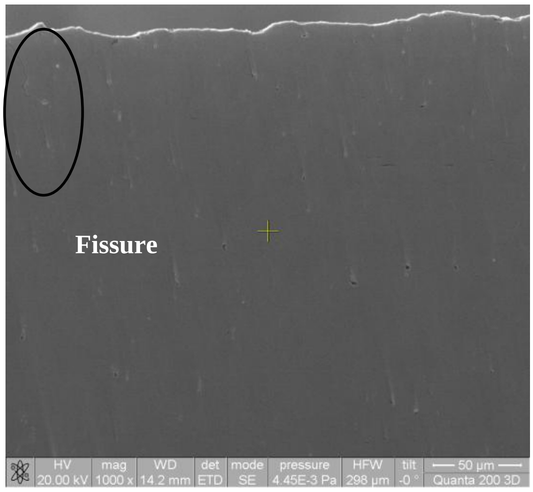


Figure 14: *SEM cross section image of the sample without coating*

Fig. 15 show a SEM image of the rolling surface of the sample with the 40Cr130 metallic coating subjected to friction in mixed lubricating conditions. The image show abrasion marks due to the shearing of the surface asperities in the grinding process. Fact also presented Fig. 16 at a higher magnification. The grinding marks are less obvious due to the higher size of the lubricant film.

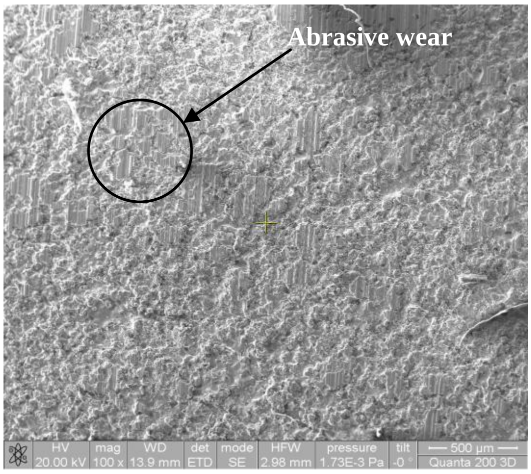


Figure 15: *SEM image of the rolling surface of the deposited coating*

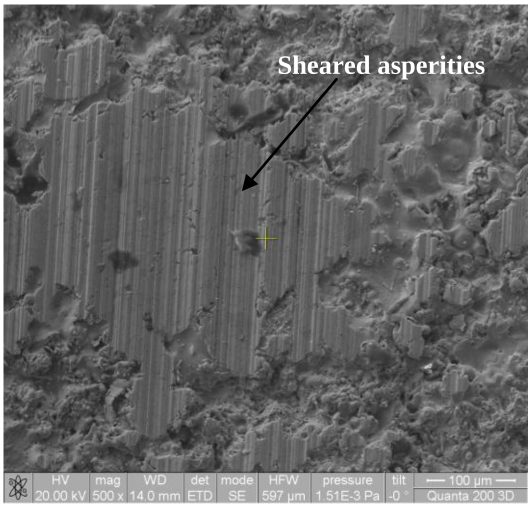


Figure 16: *SEM image of the rolling surface at a 500X magnification*

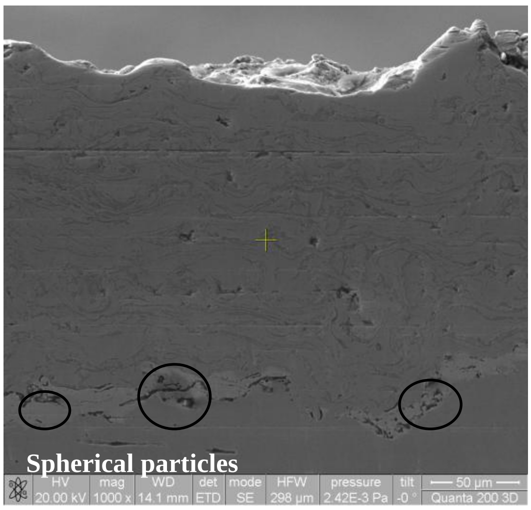


Figure 17: *SEM cross section of the sample*

In fig. 17 is presented a cross section of the sample with coating. The only fatigue signs in the image are the spherical concentrations present at the interface between the base material and the deposited coating.

Conclusions

This paper followed the contact fatigue behavior of a 40Cr130 steel alloy deposited in electric arc on an 18MnCr11 base material.

The samples were analyzed by electron microscopy to highlight the effects of contact fatigue following the test.

In limit lubrication conditions the samples without coating showed extreme adhesive wear phenomenon (scuffing). The sample with coating showed fatigue wear characteristics but behaved better then the uncoated sample.

In mixed lubrication conditions the sample without coating showed extensive fatigue wear characteristics but behaved well to the 30 hours test.

The best behavior is present in the sample with coating in mixed lubrication conditions. The fatigue wear present on the sample is minimal and the coating presented a very good adhesion to the base material.

References

[1] Gwidon W. Stachowiak and Andrew W. Batchelor, *E n g i n e e r i n g T r i b o l o g y*.

[2] W.A. Glaeser and S.J. Shaffer, *Contact Fatigue*, ASM Handbook, Volume 19: Fatigue and Fracture.

[3] Bo Alfredsson, *A Study on Contact Fatigue Mechanisms*, ISSN 1104-6813.

[4] Per Lindholm and Fredrik Svahn, *Study of thickness dependence of sputtered-carbon coating for low friction valve lifters,* Wear 261 (2006) 241–250.

[5] A. Ramalhoa and J.C. Miranda, *The relationship between wear and dissipated energy in sliding systems,* Wear 260 (2006) 361–367.

[6] Nagaraj Nayaka, P.A. Lakshminarayanan, M.K. Gajendra Babu and A.D. Dani, *Predictions of cam follower wear in diesel engines*, Wear 260 (2006) 181–192.

[7] Daisuke Yonekura1, Richard J. Chittenden and Peter A. Dearnley, *Wear mechanisms of steel roller bearings protected by thin, hard and low friction coatings,* Wear 259 (2005) 779–788.

[8] C. Jaoul, O. Jarry, P. Tristant, T. Merle-Méjean, M. Colas, C. Dublanche-Tixier and J.-M. Jacquet, *Raman analysis of DLC coated engine components with complex shape: Understanding wear mechanisms*, Thin Solid Films 518 (2009) 1475–1479.

[9] J.S. McQueena, H. Gaoa, E.D. Blacka, A.K. Gangopadhyayb and R.K. Jensenb, *Friction and wear of tribofilms formed by zinc dialkyl dithiophosphate antiwear additive in low viscosity engine oils, Tribology International 38 (2005) 289–297.*

[10] J. de Vicentea, J.R. Stokesb and H.A. Spikes, *Lubrication properties of non-adsorbing polymer solutions in soft elastohydrodynamic (EHD) contacts, Tribology International 38 (2005) 515–526.*

[11] J. Durany, G. Garcla and C. Vfizquez, *Numerical computation of free boundary problems in elastohydrodynamic lubrification*, Department of Applied Mathematics, University of Vigo, Campus Marcosende, Vigo, Spain, Elsevier.

[12] J. Molimarda, M. Querryc, P. Vergneb, I. Krupkac and M. Hartl, *Calculation of pressure distribution in EHD point contacts from experimentally determinated film thickness, Tribology International 38 (2005) 391–401.*

[13] Anders Pettersson, *High-performance base fluids for environmentally adapted lubricants*, Tribology International 40 (2007) 638–645.

[14] Tsunamitsu Nakaharaa and Kazuyuki Yagib, *Influence of temperature distributions in EHL film on its thickness under high slip ratio conditions, Tribology International 40 (2007) 632–637.*

Acknowledgements

We thank to SC Plasma Jet SA for the support in the plasma jet deposition of the analysed layer from this paper.

I give thanks to the Faculty of Mechanics for the support and for making available the science of materials and Materials Science laboratories for performing the necessary tests for the paper.

I give thanks to the Faculty of Mechanics for the support and for making available the science of materials and tribology laboratories for performing the necessary tests for the paper.