INFLUENCE OF ROUGHNESS IN DLC FILMS ADHESION ON CILINDRIC METALLIC SURFACES

Valdair José Pimentel
valdair.pimentel@hotmail.com

Leonardo Todorowicz
Mechanical Engineering Post-Graduate Course (PG-Mec), Universidade Federal do Paraná (UFPR), 81531-980, Brazil
todorowicz@creapr.org.br

Sílvio Francisco Brunatto
Departament of Mechanical Engineering, Universidade Federal do Paraná (UFPR), 81531-980, Brazil
brunatto@ufpr.br

Jairo Müller Wolff
Engineering Post-Graduate Program (PIPE), Universidade Federal do Paraná (UFPR), 81531-980, Brazil
jairomuller@terra.com.br

Abstract. *The present paper proposes an study of the influence of roughness on DLC (diamond like amorphous carbon) films adhesion deposited on Cr thin film enhanced ABNT M2 steel cilindrical samples. Tempered samples were coated with PECVD (Plasma Enhanced Chemical Vapor Deposition) method. Different roughness profils were obtained by grinding. The samples were cleaned with hydrocarbons base-solvent under ultra-sound effect. For such study two methods was applied. The first one was a optical evaluation of the hardness printing and the second one was the determination of the film adhesion by scratch test. Two other tests were used as suport of samples characterization, one was the roughness evaluation and the other was the coating thickness determination. After heat-treatment, samples present average hardness of 60 ± 2 HRC. The results indicate the cleanness process exert significant influency on the film adhesion. This effect is higly roughness dependent, since it was observed film adhesion failure tendency caused by the residues remained at the roughness.*

Keywords*: DLC, roughness, scratch test, PECVD*

1. INTRODUCTION:

Nowadays the interest of metal mechanic industries in applying Diamond-like carbon (DLC) films are in connection with protective materials and solid lubricants, because of their excellent tribological properties such as low-friction coefficient even in dry atmosphere, high wear resistance (not only of the coated body but also of the counter body) and high hardness. Some special applications such as cutting tools [5,11,14] and dies [9,10] are examples of these beneficial qualities. In order to avoid a premature wear makes necessary find out a substrate surface finishing that provide the best adhesion for industrial applications. Normaly high roughness means high superficial stress, high punctual pressure contact and these factors lead to an acelerated wear and lose of the primary properties. The present study aims to show what is the influence for three diferent cylindrical surface finishings prepared with robust industrial machinery in order to obtain a Rz~ 0.6 µm and ~5.3 µm on adhesion of the coating. An intermediate surface was obtained using a sandpaper n°. 120 with ~1.5 µm. A method was used to improve the the adhesion of DLC on the substrate with an interlayer [1,2,3,4,8,13] of Cr.

2. CLEANING PROCESS:

Before the process the samples were previouly cleaned with an industrial equipament for large production scale based in a isoparaphinic hydrocarbon media under vaccum and ultrasonicaly enhanced to simulate a mechanic action through the shock waves created. This action aims a better cleaness quality by removing the organics and inorganics contaminants, such as oils and extern particles harmful to the coating process.

3. COATING:

The coating process used was PECVD whith a Cr interlayer enhanced the adhesion between DLC and the surface of an ABNT M2 steel. The samples were coated obeying a satelitar movement to provide an uniform deposition. During the process the surface to be coated was ways perpendicular to the ion bombardment.

4. THICKNESS:

This evaluation was made by a CSM grinding equipament called Calotest and it consists on grinding a sphere with 25.4 mm against the coated part. The result was 2.08 μm and an ilustrative picture is shown at figure 1. For all the samples the thickness were around 2.00 μm and 2.10 μm.

Figure 1 - Grinded Calotte

5. ROUGHNESS:

To evaluate the roughness before and after coating was applyed a Mahr equipment model Perthometer Concept. The figure 2 and 3 shows the roughst profile before and after coating. The table 1 compare the results for all the measured samples and in this study is not possible to confirm what is described by Jiang and Arnell [6] because the roughness after coating is very slightly modifyed except for the rougher sample which after coated had a smoother finishing.

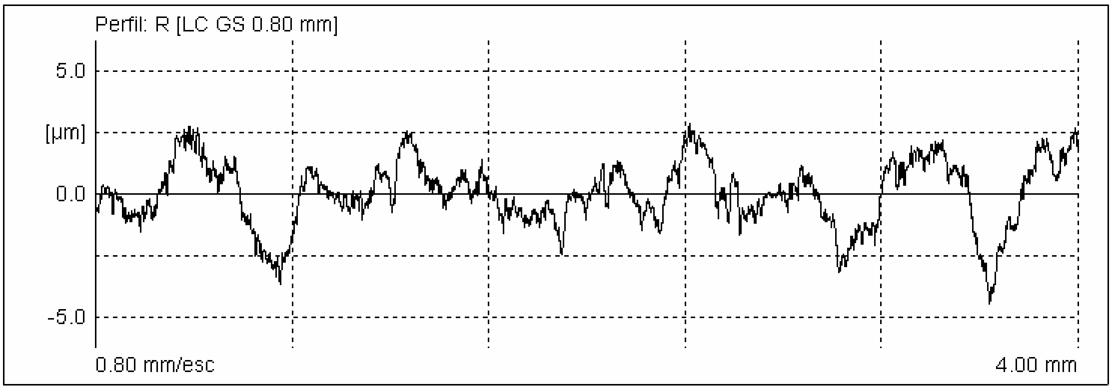

Figure 2 - Profile Rz=4.82 μm before coating

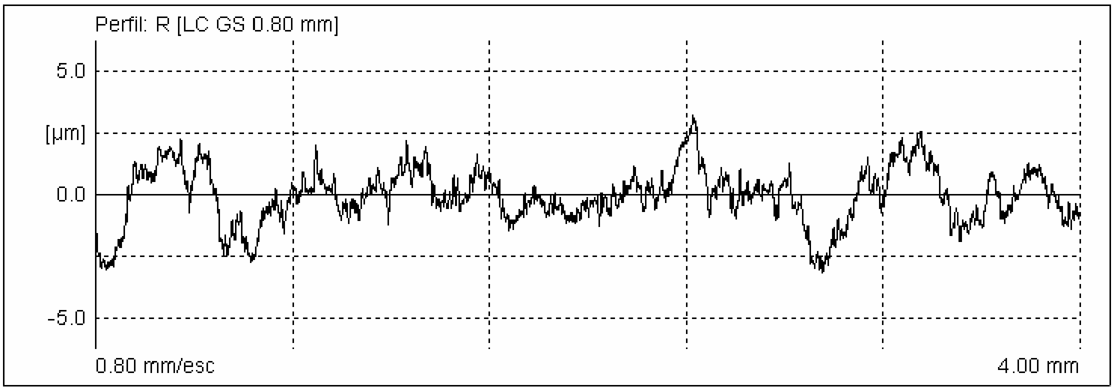

Figure 3 - Rz=4.67 μm after coating

Table 1 - Roughness Comparison Before vs. After Coating

Description	Rz Before Coating (**µm**)	Rz After Coating (**µm**)	Difference %
Sample 01	0,56	0,97	73,21
Sample 02	0,67	0,89	32,84
Sample 03	0,59	0,79	33,90
Sample 04	1,61	2,29	42,24
Sample 05	1,54	2,20	42,86
Sample 06	1,59	2,03	27,67
Sample 07	5,58	4,75	-14,87
Sample 08	4,82	4,67	-3,11
Sample 09	5,61	4,75	-15,33

6. VISUAL EVALUATION:

Under a microscopy magnifying of 100x was evaluated how good in general had the DLC coating covered the surface. Clearly is possible to observe, figure 4, small places where there is no coating specialy on the Rz= 1.5 µm and Rz=5.3 µm. This is due to the internal stresses and the critical profile where the peaks act as stress concentrators as citated per Per Lindholm [7].

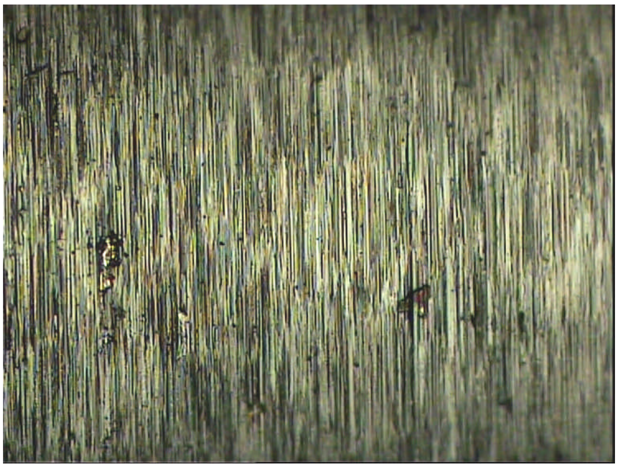

Figure 4 - Failures on the Coating by Visual Evaluation

7. SCRATCH TEST [12]:

Using the Revetest from CSM Instruments with a diamond identer of 200 µm radius was performed the test with the normal force starting with 10 N and ending with 50 N. A linear increase was applyed on a track with 10 mm long and with a displacement speed of 200 mm/min [15]. By the analylisis shown at figure 5, 6 and 7 was possible to identify that just with small forces the Rz~1.5 µm and Rz=5.3 µm failled. The failure cause can be explained through the brocken up of the peaks during the applying of the force and as a consequence of that the stiff coating is drifted up and peel off. At the end of the track there is quite any covered surface. However, by the Rz=0.6 µm the main failure occurs on the boundaries of the track where exists a sudden deformation due to the indentor track form and this summed to the britleness character of the coating cause the flaking.

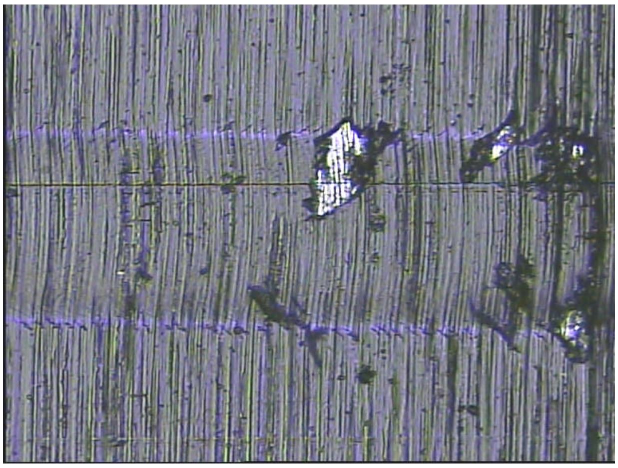

Figure 5 – Scratch on sample with Rz=0.6 µm at 36.00 N

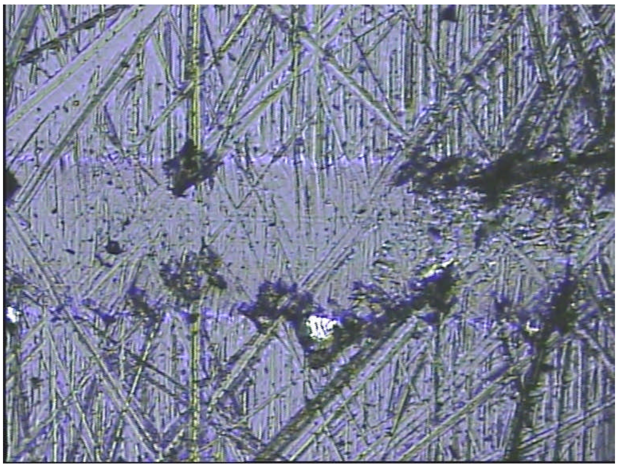

Figure 6 - Scratch on sample with Rz=1.5 µm at 25.00 N

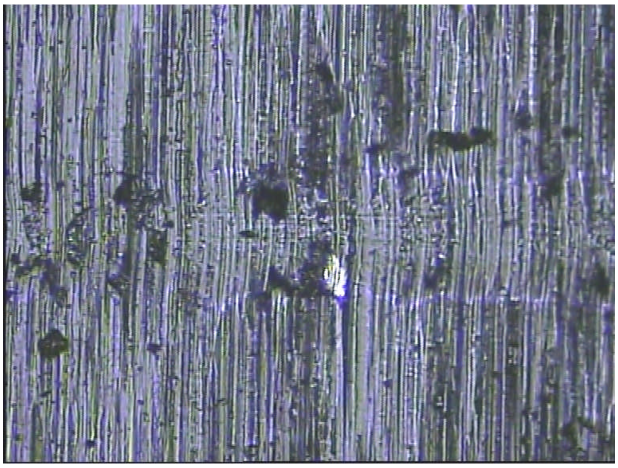

Figure 7 - Scratch on sample with Rz=5.3 µm at 15.00 N

8. HRC PRINT EVALUATION:

After the print with a HRC identer loaded with 150 N was evaluated unter microscopy the behavior of adhesion. In order to get this information the boundary formed between the print out and the original surface musst be under flakings analysed. As shown at figure 8 the sample with Rz=0.6 µm has any failure point, totaly contrary to the other two bodies which were observed diferent failure modes. For a Rz=1.5 µm the cause of the rupture was related to the crossing point of valleys caused previously by the sandpaper because even for points out of the region of deformation influence, crack and delamination were found, figure 9. The last case at figure 10, Rz=5.0 µm, the main problem was the deformation of the print nearby region, where in part happened a DLC rupture (only superficial) and also some points of delamination until the substrate. Because of a homogeneus grinding by the last case the roughness is quite continous and for this reason the result was a generalized crack on the coating.

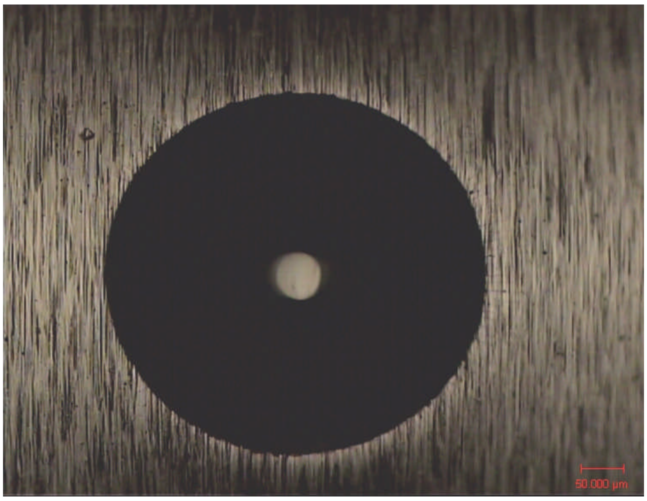

Figure 8 – HRC print on sample with Rz=0.6 µm

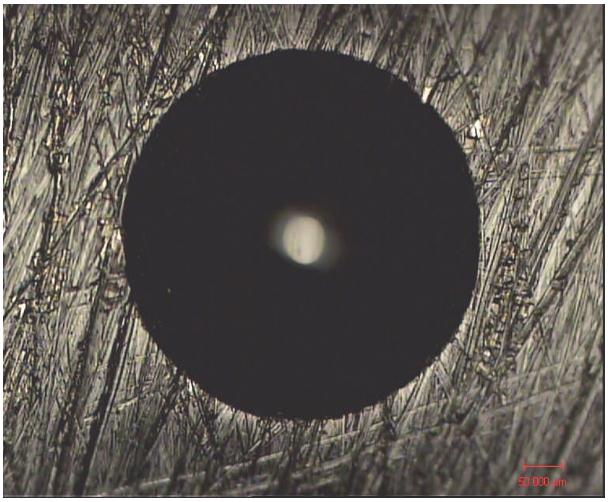

Figure 9 - HRC print on sample with Rz=1.5 µm

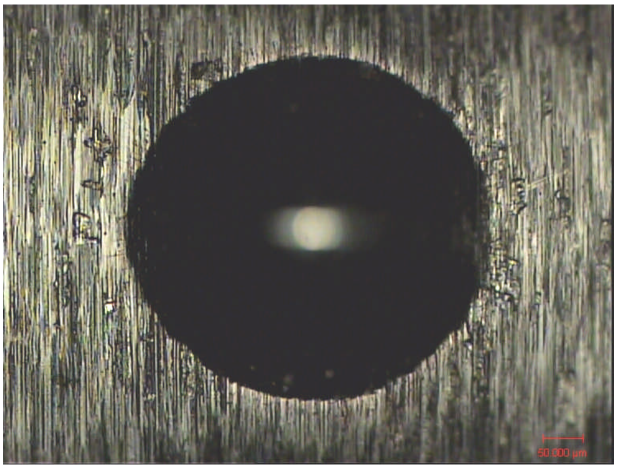

Figure 10 - HRC print on sample with Rz=5.0 µm

9. CONCLUSION:

The deposited coating follow the same profile as the body before. It was proved that the adhesion of the body had high influence by the roughness on a reverse way i.e., rather higher the Rz lower is the adhesion. Another hipothesis would be the efficiency of the cleaning process depedent on the roughness and a direct influence in adhesion caused by the passivation of some regions of the samples, but it was not the aim by this study.

10. REFERENCE:

[1] M.D. Bentzon, K. Mogensen, J.B. Hansen, C. Barholm-Hansen, C. Traeholt, P. Holiday, S.S. Eskildsen, Metallic interlayers between steel and diamond-like carbon, Surf. Coat. Technol. 68/69 (1994) 651–655.

[2] H. Chen, M.L. Nielsen, C.J. Gold, R.O. Dillon, J. DiGregorio, T. Furtak, Growth of diamond films on stainless steel, Thin Solid Films 212 (1992) 169–172.

[3] K.L. Choy, E. Felix, Functionally graded diamond-like carbon coatings on metallic substrates, Mater. Sci. Eng. A 278 (2000) 162–169.

[4] M.P. Delplaucke-Ogletree, O.R. Monteiro,Wear behavior of diamond-like carbon/metal carbide multilayers, Surf. Coat. Technol. 108–109 (1998) 484–488.

[5] H. Hanyu, Y. Murakami, S. Kamiya, Y. Kondoh, The improvement of cutting performance in semi-dry condition by the combination of DLC coating and CVD smooth surface diamond coating, Surf. Coat. Technol. 200 (1/4) (2005) 1137–1141.

[6] Jiaren Jiang, R.D. Arnell, The effect of substrate surface roughness on the wear of DLC coatings, Wear 239 2000 1-9

[7] Per Lindholm, Stefan Björklund, Fredrik Svahn, Method and surface roughness aspects for the design of DLC coatings, Wear 261 (2006) 107–111

[8] H.P. Lorenz, Investigation of TiN as an interlayer for diamond deposition on steel, Diamond Relat. Mater. 4 (1995) 1088–1092.

[9] M. Murakawa, N. Koga, T. Kumagai, Deep-drawing of aluminum sheets without lubricant by use of diamond-like carbon coated dies, Surf. Coat. Technol. 76–77 (2) (1995) 553–558.

[10] H. Ohmori, K. Katahira, M. Iwaki, J. Komotori, M. Mizutani, F. Maehama, Investigation of substrate finishing conditions to improve adhesive strength of DLC films, CIRP Ann. 54 (1) (2005) 511–514.

[11] B. Podgornik, S. Hogmark, O. Sandberg, V. Leskovsek, Wear resistance and anti-sticking properties of duplex surface treated forming tool steel, Wear 254 (11) (2003) 1113–1121.

[12] B. Podgornik, J. Vizintin, Influence of substrate treatment on the tribological properties of DLC coatings, Diamond Relat. Mater. 10 (2001) 2232–2237.

[13] F.J.G. Silva, A.P.M. Baptista, E. Pereira, V. Teixeira, Q.H. Fan, A.J.S. Fernandes, F.M. Costa, Microwave plasma chemical vapour deposition diamond nucleation on ferrous substrate with Ti and Cr interlayers, Diamond Relat. Mater. 11 (2002) 1617–1622.

[14] T.C.S. Vandevelde, K. Vandierendonck, M.V. Stappen,W.D. Mong, P. Perremans, Cutting applications of DLC, hard carbon and diamond films, Surf. Coat. Technol. 113 (1/2) (1999) 80–85.

[15] H. Zaidi, A. Djalmai, K. J. Chin, T. Mathia, Characterization of DLC coating adherence by scratch testing. Tribology International 39 (2006) 124-128

11. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.