THE EFFECT OF PVD COATING ON ROLLING CONTACT FATIGUE OF SINTERED MATERIAL

Tomáš CHOVANEC, Jozef ČERŇAN *,
Faculty of aeronautics, Technical university of Košice, Rampová 7, 041 21 Košice
**Corresponding author*. E-mail: jozef.cernan@tuke.sk

Summary. Paper describes changing properties of the coated samples according to the contact fatigue as a specific phenomenon causing damage to the surface of stressed materials by cyclical stress changes and the emergence of so-called piting on the surface. The aim of the work is to explore the impact of using TiN and CrN PVD coatings to extend the life of sintered materials, which are currently widely replacing traditional materials compact also in highly stressed applications. For coating was used sintered material Astaloy CrL with 0.3% C and TiN coating and also material Astaloy CrL + 0.7% C coated with CrN. Roling contact fatigue was assessed on the device type Axmat according to service life up to 50.10^6 cycles. The test results were evaluated in the form of S-N curves and further described by Metalographic-microscopic analysis as well as by the respective mechanical tests.

Keywords: rolling contact fatigue; sintered steels; PVD coatings

1. INTRODUCTION

In recent decades, efforts are being made to replace compact materials with materials produced by powder metallurgy technology. This offers a significant reduction of economic cost, weight reduction, as well as various new types of alloys. Their recent development is well advanced to the extent that, their applicability has been extended to cases of strong static and dynamic stress. The dynamic development of some industries (aerospace, automotive, railway) called for a significant extension of the use of sintered materials. One of the areas where these sintered materials have been applied, were products subject to so-called rolling contact fatigue [1-3]. Low resistance of sintered materials to rolling contact fatigue has been the subject of extensive research that leads to use of various surface finishes. At first classical methods (cementation, nitriding) and further use of very hard coatings [4-7], that proved to be very effective in their application for bulk materials. This problem is widely solved in the world and brought a number of positive results [3-10].

2. METHODOLOGY OF TESTS

Two sets of samples were prepared from the same basic pre-alloyed powder from Höganäs. It was a powder Astaloy CrL™ having the composition of Fe-1.5% Cr-0.2% Mo. Samples were prepared by adding graphite with different amount - either the 0.3 and. 0.7% C. To improve the compressibility was lubricant of type HWC added. The samples were pressed in a hydraulic press in the die at 600 MPa, and had a diameter of ∅30 mm and thickness of 5mm. They have had sintered in a furnace with a protective atmosphere of composition 90% N_2 10% and H_2. The atmosphere was freeze-drying - dew point of -57 ° C before entering the furnace to remove moisture. Sintering was carried out at a temperature of 1120 °C for 60 minutes. After sintering the samples were machined to a size of ∅ 28 mm with a center hole ∅10 mm. For attaining the flatness were the surfaces of samples from each side grinded. Each set consisted of 10 samples. The first set of samples had the composition Fe 1.5Cr + 0.2Mo +0,7C and the surface was covered with a layer of TiN with a thickness of 2 microns. Surface of samples were deep rolled before using in the AXMAT station. The second set had the composition: Fe + 1.5Cr + 0.2Mo + 0.7C and surface were coated with CrN. Before the coating the surface of the second set of samples was laser hardened with a beam width of about 4 mm. After hardening, the samples were finely grinded. CrN layer had a thickness of 2.5 microns. Each sample in both sets was treated on both sides. Contact fatigue tests were carried out on the device type AXMAT whose appearance and principle is shown in Figure 1a, b.

Fig. 1 a,b Principle of testing node and AXMAT device

It is a device of the "pin on disc" type, operated at a 500 rpm/min. Inside this device was used thrust ball bearing STN 51102 with bearing balls in the cage (12 pcs, ∅ 3.969 mm). The tests were conducted while supplying the lubricant (gear oil SAE Mogul 80), which was continuously purified. An integral part of the test device has a piezoelectric vibration sensor, which interrupted the test after the preselected size of the surface damage in the form of Pitting. Metalographic-microscopic analysis was performed using as optical microscope Neophot 21, as well as using a scanning electron microscope MIRA 3. For mechanical testing was the measurement of micro-hardness used.

3. TEST RESULTS

Metallographical analysis of both materials CrL + 0.3C and 0,7C indicates the presence of ferrite-pearlite - Figure 2a, b. Proportion of pearlite answers in both materials to carbon content. Moreover, in CrL+0,7C material was in the laser hardened surface observed bainite structure.

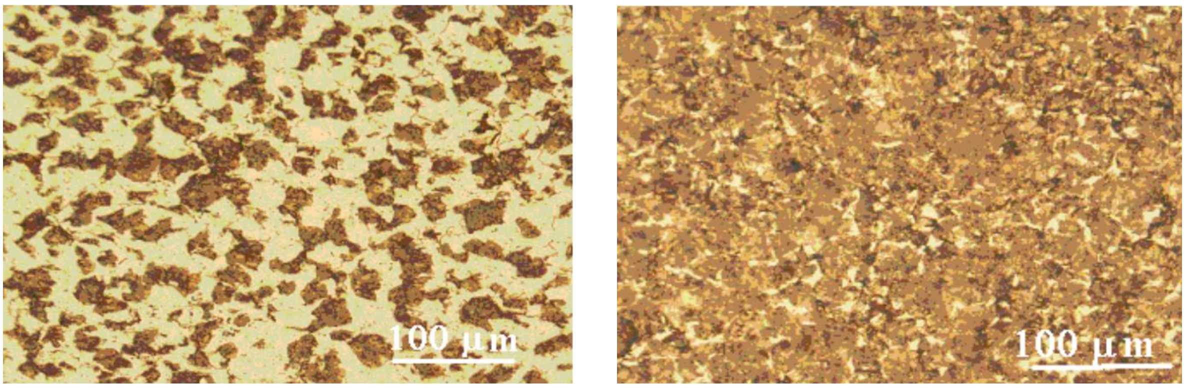

Fig. 2 a,b Ferritic-pearlitic structures of investigated materials

It was also found that during deposition of PVD coatings, no chemical-thermal change occurred in both types of materials, to preserve the original structure of ferrite-pearlite. In cross-section at Fig. 3 a, b are seen on the surface the TiN respectively CrN coating layer.

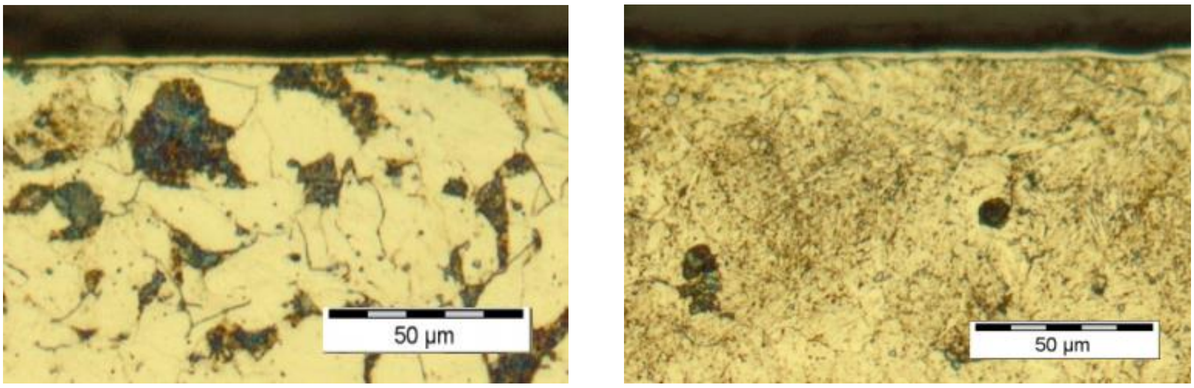

Fig. 3 a) Sample CrL+0,3C with TiN layer and b) sample CrL+0,7C with CrN layer

As will be seen shortly in contact fatigue testing, both coatings due to its high hardness are very fragile, resulting in the cracking at the point of orbit from rolling balls. The presence of these coating have been verified, excluding metallographic analysis in cross section, by the quantitative - EDAX analysis by the scanning microscopy. The results are shown in Fig. 4 a, b, in which the top right of the score values include the composition of the elements. Thereby confirming their composition.

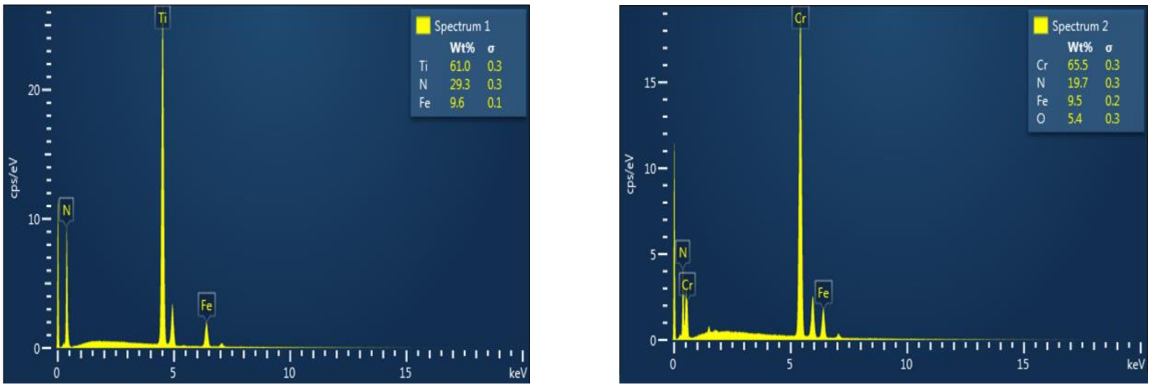

Fig. 4 a) EDAX analysis of chemical composition of TiN coating, b) CrN coating

Measurement of microhardness (HVm method was used) had the task of assessing the impact of surface treatments carried out on these samples after a cross-section of the material. The measurement was performed from the surface to the center of the sample at length intervals of about 50 microns. The results of measurement for the material CrL + 0.3C - TiN are shown in Fig. 6a and for material CrL + 0.7C - CrN in 6b. Two curves shown in this figure correspond to the micro-hardness measurements from one the other side of the sample. As shown the course of the hardness is almost identical. The hardness of the surface is logically higher than the average hardness of the sintered material that represents ferrite-pearlite microstructure over the cross section of the sample piece. This is about 150 ± 10 units HV0. 05. Higher hardness below the surface to a depth of about 150 microns is determined by the influence of the deep rolling of the material surface, which can be characterized as cold plastic deformation. The same applies to the material CrL + 0.7 - CrN - see Fig. 7. Higher hardness at the surface is given by the influence of laser hardening, which on the surface has changed the structure of ferrite-pearlite structure to the upper bainite. As is clear from the results, the hardness of the upper bainite values on the order of about 300 HV0.05 units and higher, and the hardness of the base ferrite-pearlite microstructure due to the higher carbon content and therefore the proportion of the perlite is approximately 210 HV0.05.

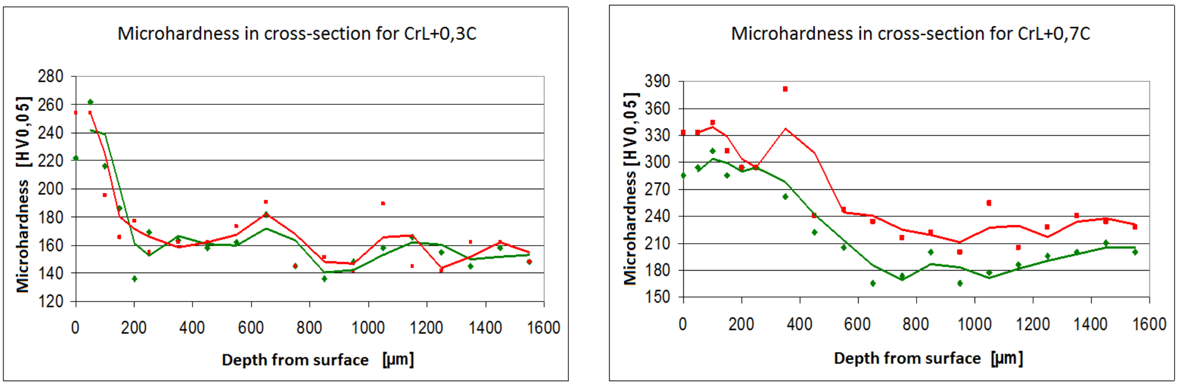

Fig.6a,b Microhardness behavior in cross section of samples with TiN and CrN

The test results of resistance of materials against contact fatigue that is actually their life is determined in the form of Wöhler curves, which compares the number of cycles that take place in damage to the test sample according to the Hertz stress. Figure 7 are stress-number curves for materials CrL + 0.3C and CrL + 0,7C without deposited coatings. These curves serve us as a source of reference data. Of these, we subtracted the size of the border tensions, which we have established to the value of 5.10^7 cycles. This limit (life) has been for the material CrL + 0.3C only in sintered state after deep rolling 700 MPa and for the material CrL + 0,7C after laser hardening (surface with bainitic structure) is 900 MPa.

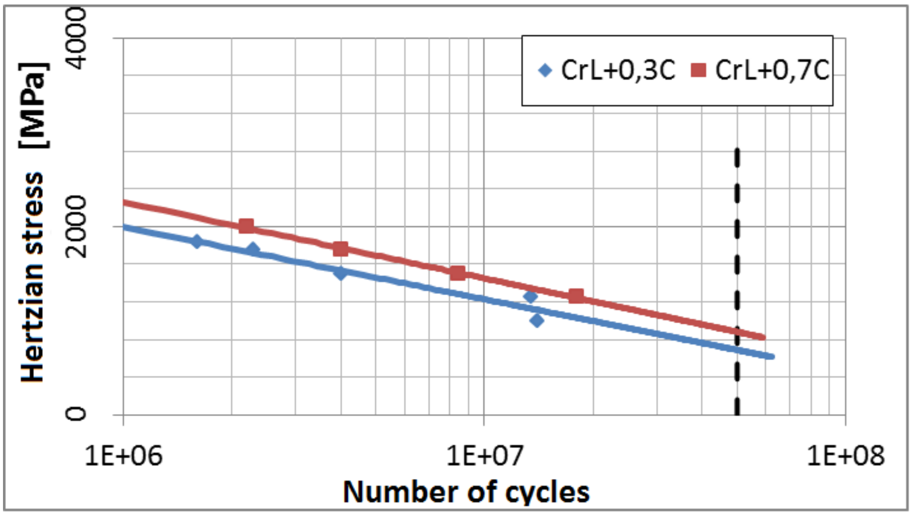

Fig. 7 Wöhler curves of investigated materials in sintered state

The effect of coating on the rolling contact fatigue results are expressed as shown in Figure 8, b. As is visible results in fatigue life of the material with the TiN coating to the value of 50.10^6 cycles increased to a value of 900 MPa, which is an increase of about 22% compared the same material without the coating. For the material coated with CrN the lifetime limit for 50.10^6 cycles is about 1080 MPa, which represents an increase of 17%. Although this increase is not as high as that achieved in other cases that have been published for example [7], we can accept them because they give us the basis for modification of technological preparation of samples. Both results are approximately the same, so it can be stated, that the essential role in both cases played the hardness ratio of the base material, the thickness of the coating and the adhesion of the coating to the base material. One of the main reasons, which appears to be a priority is the thickness of the coating. Such thin coatings are not able to overlay porosity of the sintered steels.

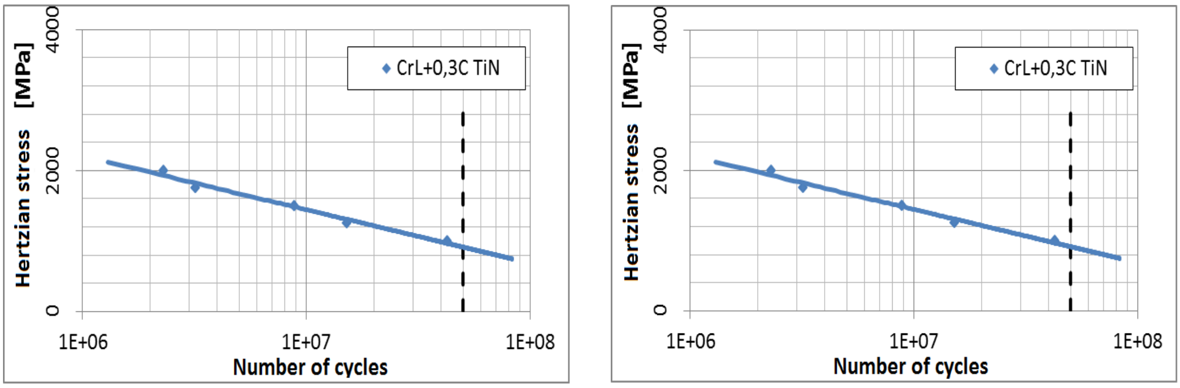

Fig.8a,b Wöhler curves of investigated materials after coating by TiN resp. CrN

Rolling contact fatigue in both of these materials and coatings was carried out by the traditional way, i.e. by cracking of coating, the occurrence of cracks that started to appear on the surface of the matrix. Connecting of these cracks leads to the formation of Pitings – i.e. the crumbling of the material from the surface of orbit. These phenomena were easily observed, and are presented on the following Figures 9a, b, showing the extent of their shape and size.

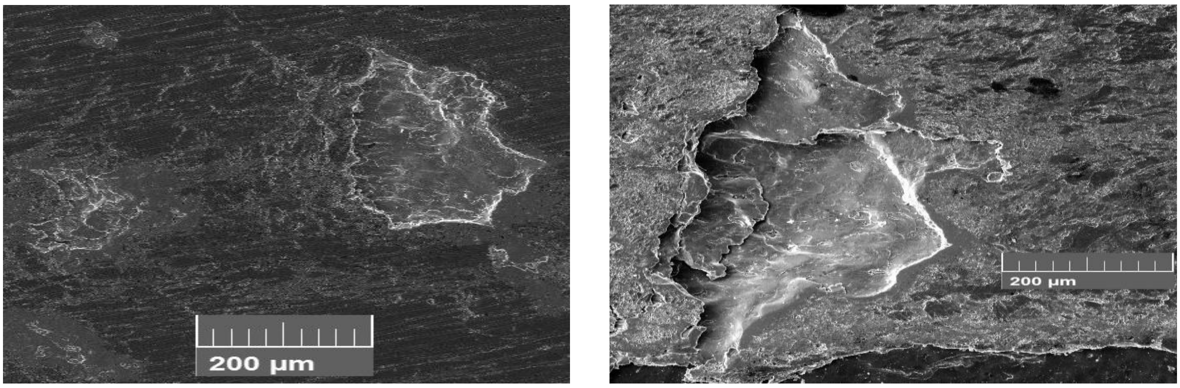

Fig. 9 a, b Appearance of pittings in track on investigated materials

Metallographic analysis reveals that pittings were developed by the crack initiation at the surface as a result of the stress concentration in the areas of cracked coating. Figure 10 shows the place of flaking coating. In the cross-section is again visible as the cracks are propagating inside the material from of this area. Cracks spread interparticly at an angle of 15-30°. Combining of these cracks, ultimately leads to the formation of Piting and thus to shorten the service life, respectively to its complete loss.

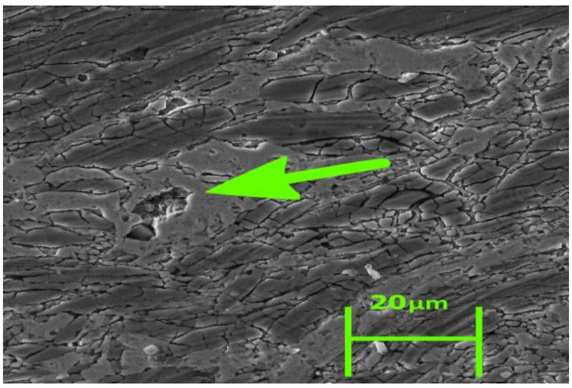

Fig. 10 Flaking TiN coating

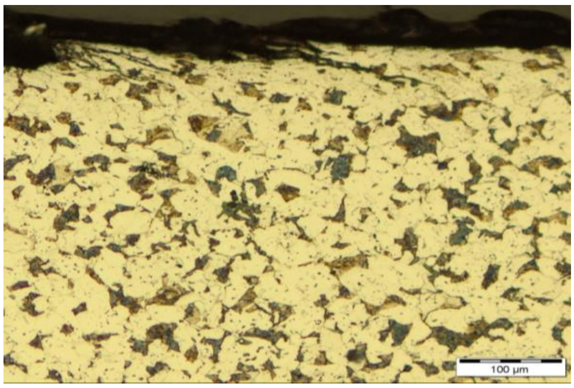

Fig. 11 Initiation of surface cracks

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4. CONCLUSIONS

On the basis of carried out tests, it can be stated as follows:

1. Both types of coatings TiN and CrN have a positive effect on the resistance of the sintered steels to rolling contact fatigue.
2. This positive impact has been far less than was achieved with similar coatings on the same material.
3. The reasons which have a majority in this case, are represented by the adverse synergistic effect resulting from the fragility of hard and relatively thick coating and by his problematic adhesion to the basic material.
4. Nevertheless, by properly selected combination of modifications parameters that were used for sintered steel, it can be possible to achieve increased rolling contact fatigue resistance. This requires, however, not basic research, but extensive development works.

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