ROLLING CONTACT FATIGUE AND WEAR OF CrL AND CrM MODE POWDER METALLURGY STEELS

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Abstract

Contact fatigue properties of sintered steels type CrM and CrL with addition of 0,3-0,7 %C were examined on the device type „pin on disc“ and confronted with wear tests on the same principle. Achieved outcomes are better for CrM material; the higher carbon content the better they are. Fatigue strength ranges from 925 - 1410 MPa and is consistent with the value of hardness. Dry wear tests show that the wear is dependent on the hardness of carbide particles (microhardness) and not on macrohardness of material. These causes wear of indentor. Between values obtained from tests of contact fatigue and wear testing is not possible to find relevant compliance. Both rupture mechanisms are based on breaches of other principles, particularly the PM materials are in the mode of wear that is not sufficiently explored.

Keywords: *Contact fatigue, Pulver metallurgy, Wear, Microstructure, TEM studies.*

1. Introduction

Nowadays, the use of sintered materials in mechanical engineering practice attracts growing attention. The situation has been improved by the fact that we successfully produced, also powders of Astaloy CrL and CrM type by Höganäs have been added and they exhibited the preparation and processing of the properties which are useful in manu-facturing of highly stressed machine components such as gears. It is also necessary to know specific characteristics of properties that result from the way of stress. These include the primary resistance to contact fatigue and wear. The research in this field is kept for economic reasons so it can be put straight into practice. The results, which were hitherto achieved in this area were mainly related to systems based on Fe-Ni-Cu-Mo-C, where the properties are strictly examined with regard to engineering requirements [1-4], for example effect of quenching and tempering, carbonitriding, or cementation eventually plasma nitriding. As a comparative base, material was used only in the classical version of sintering. In recent years, an intensive study of the properties of CrL and CrM materials [5-11] is in progress, including the study of contact fatigue. Similar reasoning applies to research on wear although there is research on the sintered materials slightly behind [12-15].

The present work aims to assess the strength of these two types of material to contact fatigue and wear. Accurate quantitative results directly applicable in practice are not a priority. In addition to qualitative comparison we are interested primarily in mechanisms of rupture, as well as other symptoms that accompany stress. For wear holds this idea as well. It should be noted that the wear of powder materials is not always consistent with normal experience, as is showed by results of other authors, but also our own. The results achieved in the material processed in traditional way (ie pressing and sintering) are used as a reference base for assessing the impacts to be studied under the project of the Ministry of Education and SAS Vega 1/0464/08 "Tribological aspects of sintered materials damage with an emphasis on contact fatigue and wear". Initial achievements have already been published [17-19].

2. Experimental Material and Procedure

The materials used for testing were iron powders fy Höganäs comp. type CrL (Fe - 1.5 Cr-0, 2 Mo) and CrM after adding of 0.3% C and 0.7% C 0.5% with the type of solid lubricant HW, the compacted specimens of ϕ 30 x 5 mm dimensions were pressed. The used compaction pressure was 600 MPa.

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The specimens were sintered in the atmosphere consisting of 90% N_2 + 10% H_2 at 1120 ^{O}C for 60 minutes. The atmosphere was freezed out (condensation point -57 °C) to prevent possible oxidation of specimens. Against possible decarburization, specimen were also put into dusting powder of Al_2O_3 + 5% C. Cooling after sintering was done under a protective atmosphere, in dusting powder, outside of the furnace. Once made, they were mechanically adjusted to ϕ 28 mm with a ϕ 10 mm central opening. Both sides of the surface were grinded, mainly due to flatness, which is very important for a balanced load. Also eliminating of undesirable phenomena on the surface occurred after sintering (slight cementation) was prevented at the same time. Thus prepared samples (O_2 content in the powder was 0.156%, after sintering for powders with 0.3% C it was about 0.105%, for the powders with 0.7% C it was approximately 0.081%), were subjected to standard tests of hardness, metallographic analysis and testing of contact fatigue on the device type AXMAT - Fig. 1a. The frequency was about 500 cycles / sec. We used lubricant - gear oil SAE 80th Mogul. The results are presented in the contact fatigue SN curve obtained from about 10 measurements. The test was terminated by pitting occurrence, while lifetime was compared to the value of 50.10^6 cycles.

3. Results

There were four variants of materials used for testing see Table 1, where chemical composition and main reached attributes obtained after sintering can be seen. The structure view of materials, Fig. 2a, b, c, d, corresponds to the given chemical composition and to cooling rate after sintering, that was app. 0.3 °C /sec. It is in concordance with observations of quoted authors and with CCT diagrams for this type of steels as well [16]. Other mechanical properties were not studied because are well and sufficiently known, and published. The hardness measurement and metallographic analysis done by us, do not deviate from the standards achieved. for particular materials described Life time results for particular materials described by S-N diagram are presented in Fig. 3. To compare the endurance of individual tested materials the life-time limit has been set to 50.10^6 cycles. The fatigue strength values are in 925 – 1410 MPa range. When compared to the measured hardness values, one can see a good correlation between fatigue strength and hardness, which is about 5.6 ± 0.1. The metallographo-microcopic breakage analysis of shown sintered steels has revealed that the surface defects of a pitting shape occur as a result of contact stress straining.

Tab. 1

Chemical composition and reached attributes of examined materials

Mat.	Composition	γ (g.cm^{-3})	HV_{10}	Structure
1. CrL	Fe-1.5Cr-0.2Mo-0.3C	7.01	168	ferit + pearlite
2. CrL	Fe-1.5Cr-0.2Mo-0.7C	6.99	203	fine pearlite
3. CrM	Fe-3Cr-0.5Mo-0.3C	7.00	227	upper/lower bainite
4. CrM	Fe-3Cr-0.5Mo-0.7C	6.98	253	upper/lower bainite

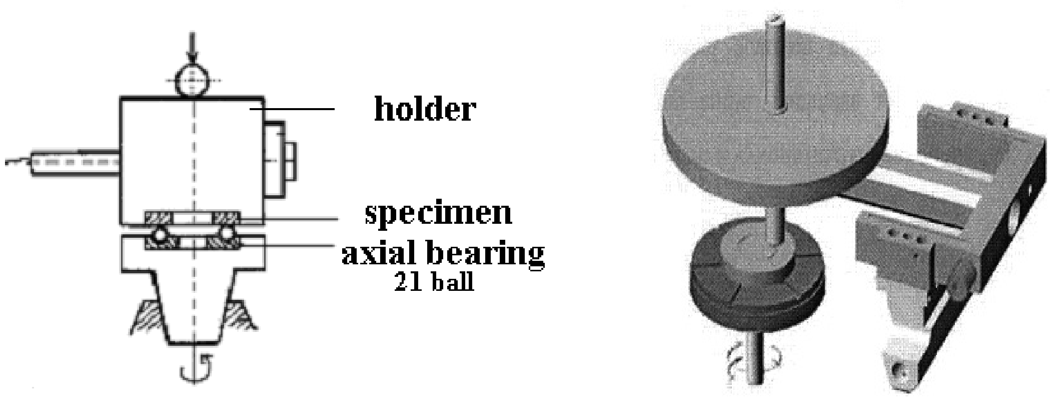


Fig. 1 Devices for contact fatigue testing – AXMAT and CSM (principle)

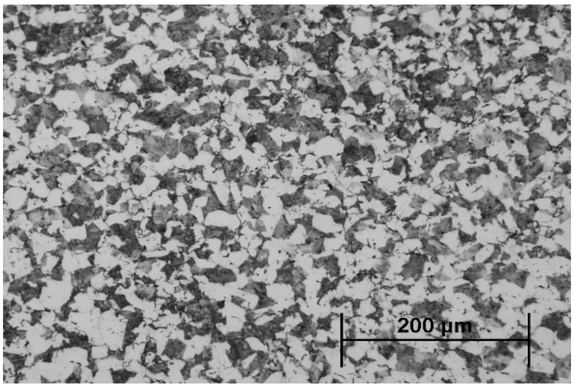


Fig. 2 a. Microstructure of CrL +0.3C

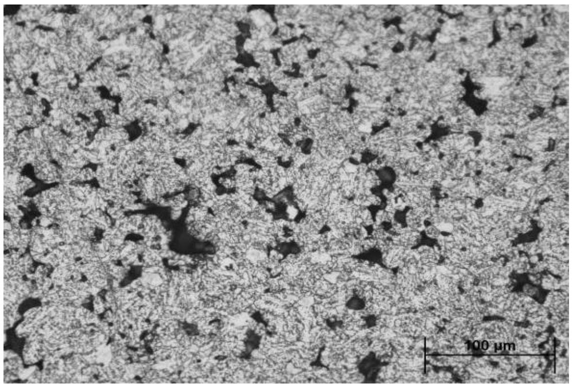


Fig. 2c Microstructure of CrM+0.3C

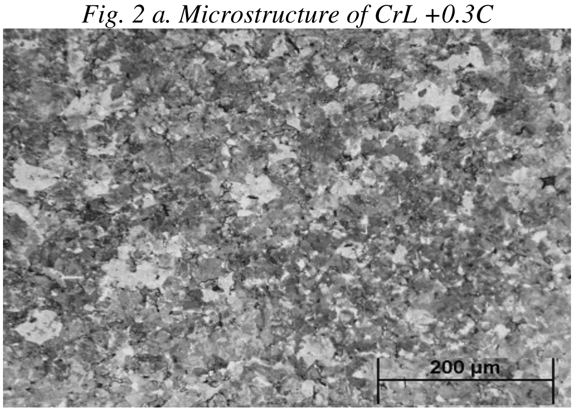


Fig.2b. Microstructure of CrL+0.7C

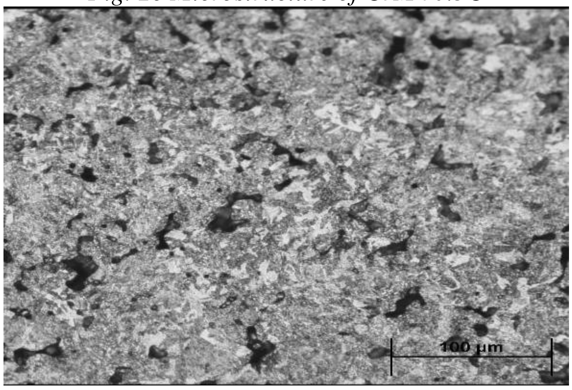


Fig. 2d. Microstructure of CrM+0.7C

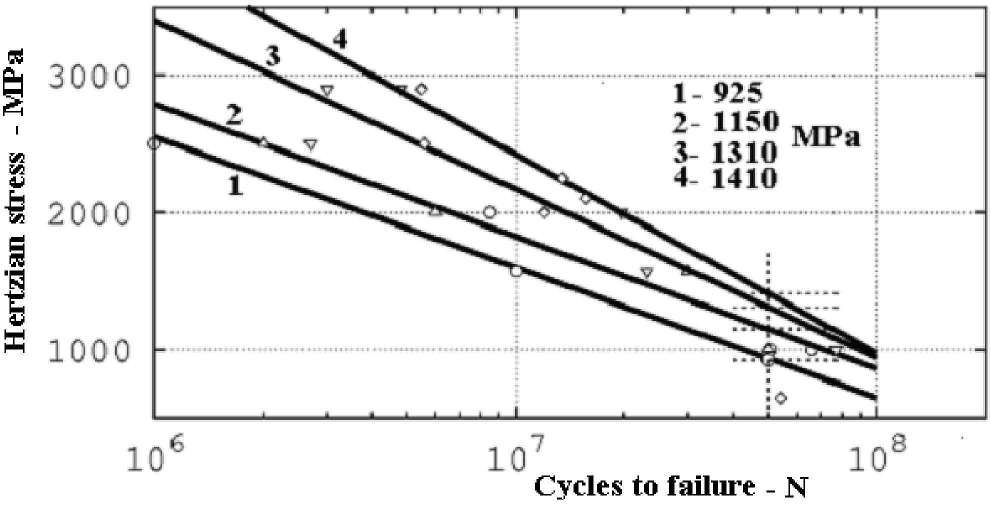
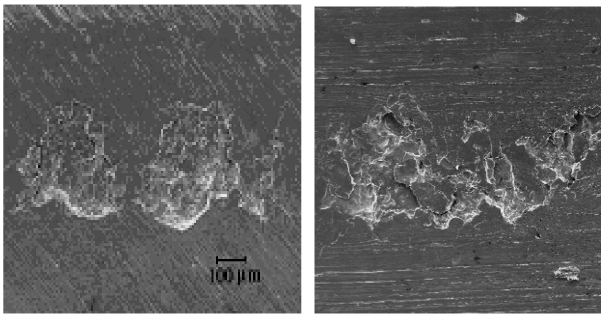


Fig. 3. Contact fatigue tests of sintered materials of CrL and CrM type

The difference comparing to wroughts is primarily given by the frequency of their occurrence in the running track. Wroughts usually have one pitting. In the case of sintered materials, in many cases, continuous sequences in running track are created. Their number and size, inter alia, relate to the testing using the methodology of the tests. If the system is based on vibration level measurement (as Axmat device), it is obvious that the level boundary setting plays an important role. The pitting observations showed that the shape and size, depending on the chemical composition in these four cases, did not differ, Fig. 4 a,b.

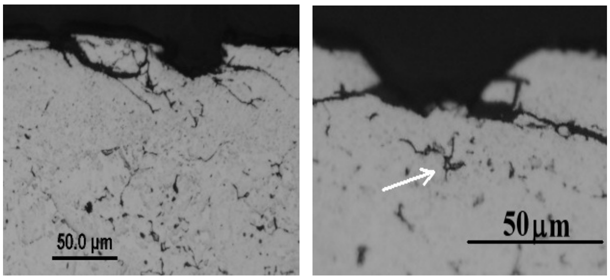
The impact of contact straining on the studied „simple sintered "steels can be divided into two phases. The first one is given by tribological abrasion; the movement of steel balls with 62 HRC hardness on the surface of sintered material with hardness is considerably lower (168 - 253 HV).



a) CrL+0.3C b) CrM+0.7C

Fig. 4. Pitting appearance

This results in smoothing out the surface roughness reduction at the track. The second phase is given by tribologic-fatigue manner that leads to nucleation of cracks, their joining and consequently in crumbling off materials from the surface – pitting formation. The microscopic study of through pitting cross sections has expressly showed that for all examined materials pitting were generated on the surface, irrespective to their chemical composition and their structure. There were not observed any undersurface cracks, even in places of maximal Hertzian stress, Fig. 5.



a) - CrL+0,3C, b) - CrM+0,3C

Fig. 5. Pitting cross section

Occasionally there have been observed cracks in places of maximal Hertz stresses, unless this places contained a secondary particle which caused, with given tension, local decohesion. If the spread of cracks would take place strictly on the interparticle connections, the depth of pitting must have been about 150 μm, the average size of powder. In fact, the depth on whatever tested material is only about 30 μm.

Surface profile measurements validate this fact. For example, for material type 3, as Fig. 6 illustrates, on the curves of three measurements performed on specimen, it can be seen that an average value of pitting depth after correction (polynomical rank 1) was app. 24 μm at track width 706 μm for specimens 1 and 29 μm for track width 818 μm for a specimen 3. We have not investigated this phenomenon in more detailed way however, it is possible to give two presumptions. Pitting depth of 30 μm is around a value of maximum Hertz stress levels below the surface. For our terms the depth is ranging from 22 μm at a stress of 1000 MPa to 32 μm at a stress of 1500 MPa. The principle of higher Hertz stress in places below the surface is probably also valid for the PM material, but is likely to occur when cracks formed on the surface gets into the depths. The crack is spreading, on a short section, paralel to the surface. In second case, one can also consider the impact of additional stress induced by pressure of lubricant in the pores of the material.

In principle, a tribological testing method pin – on-disc can be divided into three groups, according to the outcomes, Fig. 8. Either wear occurs only on indentor, or material, or on both indentor and material in the same/varying measure.

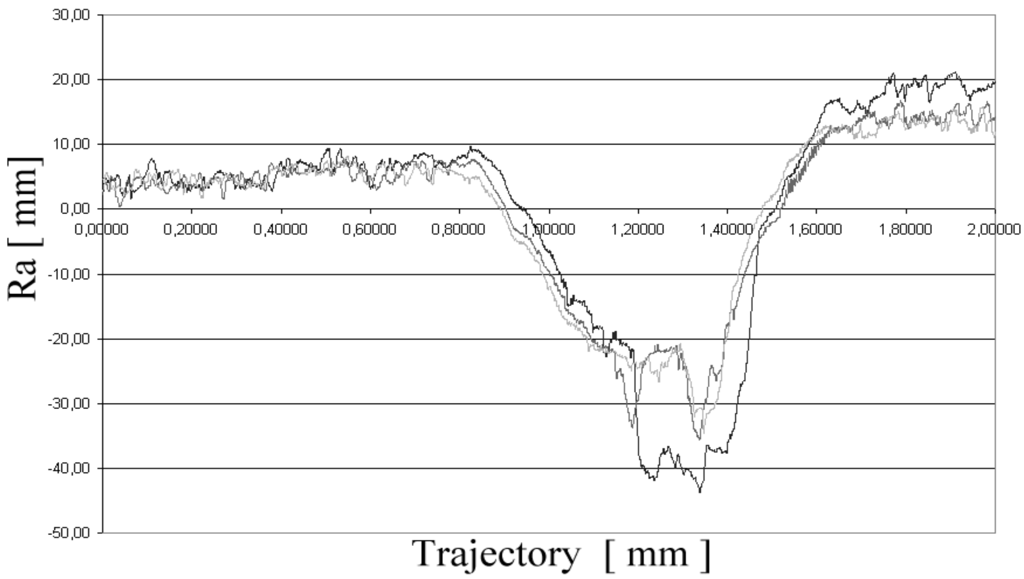


Fig. 6. Profil measurement of track

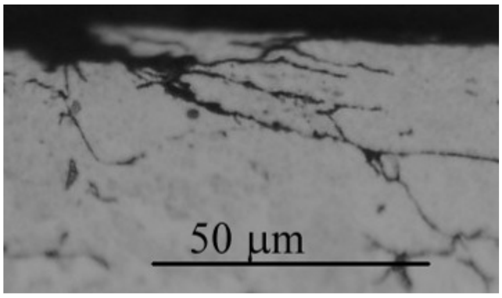


Fig. 7. Delamination of powder particle

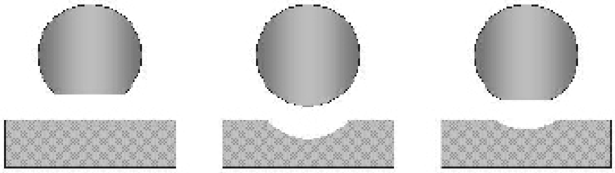


Fig. 8. Possible tribo test manners of wear out of indentor and material

Tests showed that although there is a big difference between the hardness of the indentor and tested material (62 HRC vs. 168 - 253 HV10) the wear took place according to the third option, wear of specimen as well as indentor. Results of tribological tests are given in Fig. 9 a, b. The amount of dry friction coefficient (average) copies hardness values of material. Tests in the lubricant showed very small differences. A fundamental difference lies in the fact that in lubricant, the friction coefficients do have almost constant value from the outset. In dry con-ditions this ratio evolves as seen by comparing Fig. 10a,b. Also there is a tendency of equa-lization of this value. Wear expressed by height / depth of material removed is in Fig. 9b. Two aspects are obvious from the picture. Firstly, the wear con-sists, as already stated, from the material wear and wear of the indentor. As shown in the graph, when tested under dry indentors wear is prior, so that for materials 2 and 4 (carbon content is 0.7%) it is almost 100%. This is evidenced by microscopic observation of worn indentor and traces on the material - Fig. 11a, b. The figure shows that the wear of indentor create area of 1215 µm diameter, while the material in the wear track was not highly worn out (still visible traces of grinding). Using of approximate conversion (decrease of Ra in this place - Ra after grinding was 0.9 µm) showed that it is about 0.3 µm. What at first glance looks like a worn surface, are adhered particles from the worn indentor. Materials 1 and 3 - carbon content of 0.3% C, exhibit much higher wear. It appears, that the dry wear has its specificity. Logic says - the softer material the higher wear. Probably it is necessary to distinguish between macro and microhardness in relation to the hardness of indentor. The wear of indentors is caused by carbide particles deposited in the matrix.

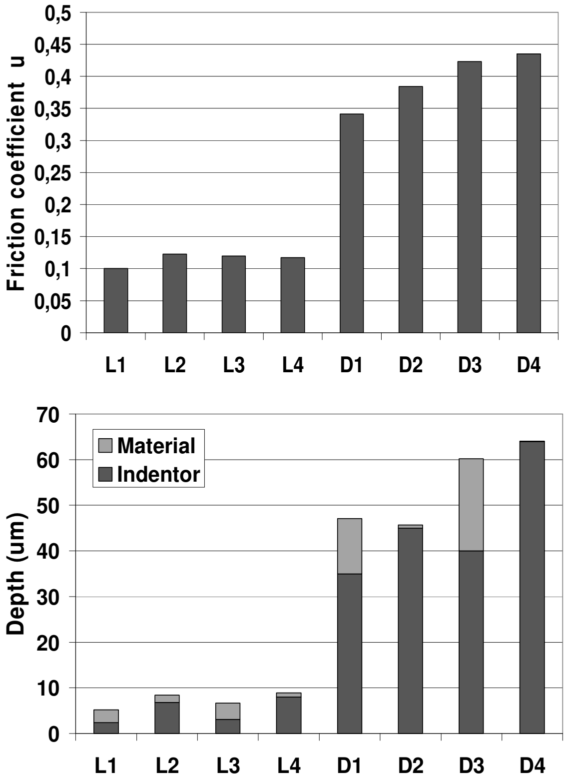


Fig. 9 a,b Friction coefficient versus trajectory on air and in lubricant

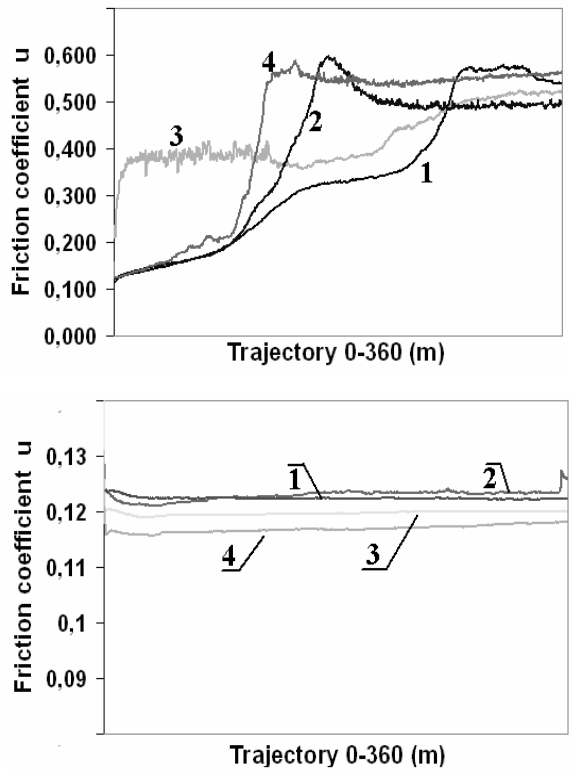


Fig. 10 a,b Dependence of friction coefficient on run trajectory, on dry and in lubricant

They do have much higher hardness than the hardness of the material is. This factor also contributes role of pores, as the place where they can be collected, and can change the nature of friction. Microhardness of carbide particles will mainly depend on both the carbon and chromium content, the size, but also the nature of their exclusion, concentration distribution, etc. Wear in the lubricant is small, so it is difficult to express fundamental position. Wear of indentor can be calculated from geometrical dimensions. The same is theoretically possible to do for specimen, using the width of material traces. Logically should be the width of track as big as the area diameter on indentor. The reality is that in many cases, these two values are diametrically opposed (for material - CRM +0.3 C- Fig. 12 a, b track width is 37 µm and indentors worn area is 250 µm).

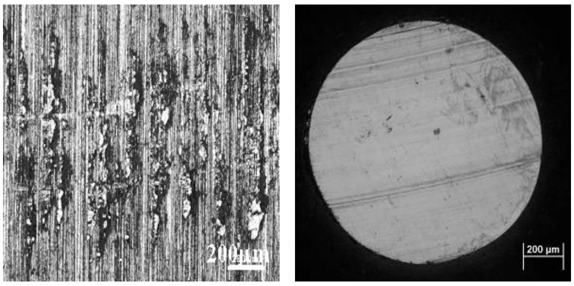


Fig. 11a,b Specimen /track/ and indentor wear CrM+0.7C

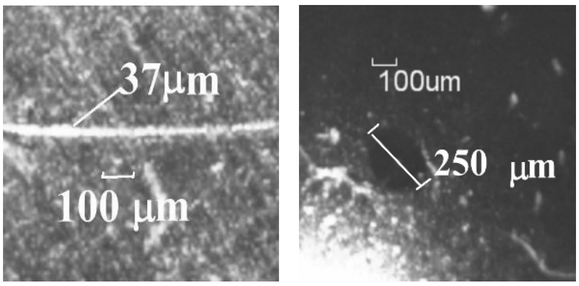


Fig. 12a,b Specimen and indentor wear

4. Conclusions

Contact fatigue and tribological properties of sintered steels of type CrL and CrM with 0.3 and 0.7% C, were detected using the pin-on-disc method. The results showed that:

1. Absolute values of fatigue strength for four described materials will range from 925 – 1410 MPa for the value of 50.10^6 cycles.

2. Achieved values correspond to the values of hardness resulting from the structure that resulted from methods and parameters of the specimen preparation. These values can be changed in a wide range and thus positively affect the contact fatigue resistance.

3. The mechanism of the contact fatigue damage is given by creation of pitting on the running track. Their origin is given by the mechanism of crack creation, which originated on the surface, and is related to frequency and distribution of pores. Occasionally we saw crack nucleation at the max. Hertz stress depths.

4. From the fractographical savour (that participate on anaclastic processes) point of view, it can be stated that in addition to ductile and fragile facettes on the anaclastic faces also striae mechanisms of rupture were observed.

5. The wear tests showed the fact despite the large difference in hardness of the indentor and specimen, (62 HRC versus 143-253 HV10), higher wear of indentor occurs.

6. The higher was the microhardness of its carbidic particles, the smaller was the wear of the material itself. Therefore, this result was achieved not only when tested on dry but also when tested in lubricants (contact fatigue tests) it can be concluded that both damage mechanisms do have different principles, and that wear itself has a minor function in contact fatigue tests.

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