CONTACT-FATIGUE RESISTANCE OF PM STEEL WITH HARD COATINGS

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Abstract

Hard coatings applied by the Physical Vapor Deposition method often provide very good mechanical properties, especially when applied to metal parts that are mentioned to withstand certain level of wear. In this study, TiN coating combined with deep rolling were applied to the investigated steel samples, prepared by powder metallurgy and subjected to contact-fatigue stress. Computational analysis of stress states in samples by the finite element method helped to reveal the behavior and formation of fatigue failures when loading samples. The results, processed in the form of fatigue curves, probabilistic Weibull curves using metallography and electron microscopy, showed a positive effect of the used coatings and their combination with other surface treatments on the contact-fatigue strength of the examined samples. Microscopic study also showed the different mechanisms of crack formation and of crack propagation rate due to contact loading of material with a laser hardened surface, which has an obvious impact on material lifetime.

Introduction

The expansion of powder metallurgy and especially the production of new materials allow their application in specific conditions. It is all about materials that are exposed when using higher stresses. In many cases this is not enough, so the methods of further modifications in order to resolve this issue, or simply increase the service life of the parts, are still in development. In specific cases, if a stress concentrates itself on the material surface (fatigue, abrasion resistance...) strengthening of the surface can help. The methods are well known. [1] We divide them into thermochemical, thermal and mechanical. [2] In some cases it is necessary to test the procedures for new materials eventually the unconventional materials, including in some cases, PM materials. Recently, these materials are used in cases of fatigue stress, resp. rolling contact fatigue stress. Mechanical compacting is one of the practices that meet these requirements. There are many literary references [3,4] confirming this. Mostly the methods of shot peening or deep rolling were used. Also the sinterhardening effect is well known and well described in the literature, for example [5-8]. It is therefore necessary to subject the PM materials to these technologies and map their behaviour and determine the conditions under which their use is acceptable. Their use is known from the literature [9-11], including work of our own [12]. Surface hardening is one of the methods suitable for increasing resistance against contact fatigue [12].

The following article describes the two simple methods for their effects on consolidation and structural changes in materials made by PM technology

Material and methods

In this study, samples made by the powder metallurgy method from steel pre-alloyed powders of the CrL and CrM type from Höganäs were used. The preparation process took place by adding the required amount of graphite before the sintering process, thus creating sets of samples containing 0,3% C. After the addition of HWC type lubricant, samples were compacted under 600 MPa to form disc specimens of dimension ϕ 30 x 5 mm. Then they were sintered in controlled atmosphere (90% N_2 +10% H_2) at 1120 °C/60 min. The sintering atmosphere was freezed before sintering - dew point of -57 °C. Samples were placed into a retort with a mixture of Al_2O_3 with addition of 1% C to avoid possible undesirable oxidation and decarburization of sample surfaces.

In the case of deep rolling we use an equipment for testing the contact fatigue, Axmat type - Fig. 1A,B, where we exchanged balls for rolls (3 pieces - about 5 mm in diameter and 5 mm in length).

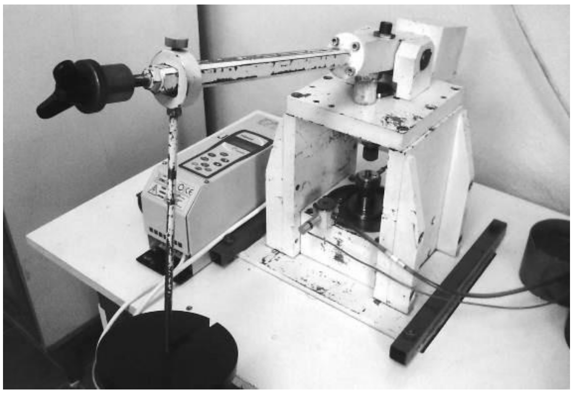

Fig. 1A. View of AXMAT device transformed into device for deep rolling

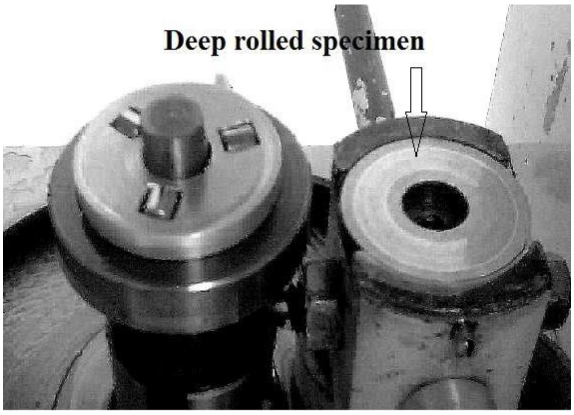

Fig. 1B View of assembly for deep rolling

Rollers were placed in a cage. In addition, it was necessary to change the speed of equipment that has constant 1420 rpm to 230 rpm. That we have reached by the involvement of frequency converter power supply into the circuit of asynchronous induction motor, which spins spindle with roller tool in Axmat device. The frequency of the electrical network during the rolling was set to 8 Hz, which after calculation using the familiar relation:

$$n_s = \frac{(60.f)}{p}. \quad (1)$$

where n_s means revolutions count of stator, f means current frequency, p represents number of electric motor pole pieces, gives the resulting speed of 230 rpm. Deep rolling was performed with a constant force of 1100 N (time varies) to achieve the same value of surface roughness Ra.

The samples deep-rolled and coated by TiN after tests were subjected to metallographic-microscopic analysis, hardness and micro-hardness measurement and to rolling-contact fatigue test.

Results and discussion

To obtain an image of the stress distribution under the contact surface in the test equipment, a simulation contact model was created, in which calculations were performed on the basis of the Finite element method (FEM). This model represents a situation that is typical for our device for examining contact fatigue - AXMAT, ie it is the contact of 1 ball of an axial bearing with the plane of the surface of the base material of the sample. The calculation assumes a steel ball with a diameter of 3.969 mm with a Young's modulus of 210,000 MPa and an investigated sintered material whose Young's modulus of elasticity is reduced to an average of 140,000 MPa due to porosity. A static force of 500N acts on the steel ball in all cases. For the accuracy and comparability of the results of the calculations, a suitable and effective level of cross-linking of the model assembly is necessary, which will ensure that the calculation will be sufficiently accurate but will not take up too much computer computing time [13].

The model prepared in this way was modified using selected mechanical material properties to simulate not only the porosity of the material, but also the existence of a hard coating on the surface in the form of TiN on base material is in Fig 2. The resulting stress level values are in MPa.

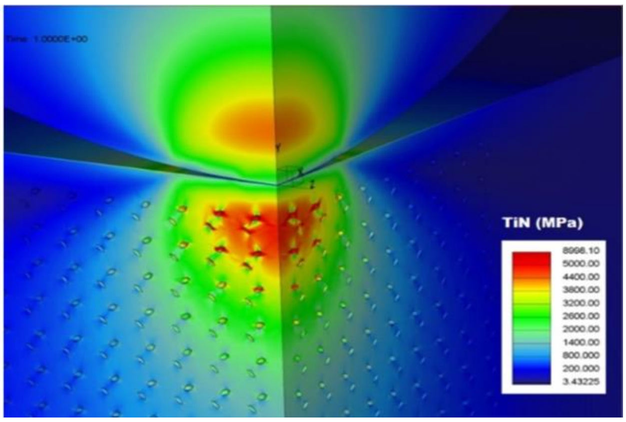

Fig. 2. Analysis of the stress field distribution in the contact of the tested material coated with TiN

According to the simulations, the presence of TiN coating should have the effect on this stress distribution. This finding may be another factor that most likely influenced the results of contact-fatigue tests on these materials. If a thin layer of hard coating had a higher ability to absorb and redistribute the applied load to the interior of the material so as to reduce the maximum Hertz stresses in its surface layers, then a positive effect of such a coating on the resistance of contact fatigue can be expected.

Metallography of a sample of CrL + 0.3% C and CrM + 0.3% C with TiN coating - Fig. 3, showed that the basic structure under the coating was not affected and showed that the coating thickness did not exceed more than 2 microns in this case. Nevertheless, the coating is continuous and evenly deposited.

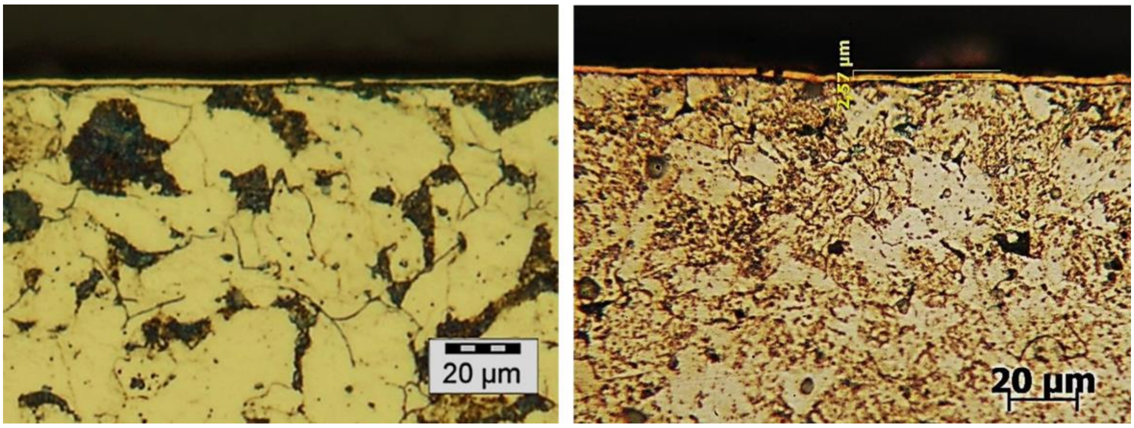

Fig. 3. Microstructure of CrL+0,3%C and CrM+0,3%C and appearance of TiN coating

For the TiN coating, EDX analysis of the elements in the electron microscope at the coating site was also viewed from above to verify the chemical composition and correctly identify the type of coating.

Contact-fatigue tests of materials and their variations with different treatments of functional surfaces, which took place using the AXMAT test station, showed a significant difference in results with respect to the method of surface treatment used. A graphical representation of the results of contact-fatigue tests in the form of Wöhler curves on a semi-logarithmic scale for carbon variants of base materials without any surface treatment were already published by us [12].

Subsequent mechanical surface treatments of these samples had a debatable effect on the results of contact fatigue. Rolling of functional surfaces to some extent also strengthened the surface, but reduced its roughness.

A graphical representation of the contact fatigue results for TiN-coated samples is shown in Fig. 4. This coating was applied to CrL + 0.3C and CrM + 0.3C samples. It is clear that the results of the TiN coating are better than in the case of the DLC coating, which is mainly due to the greater thickness and adhesion of the coating.

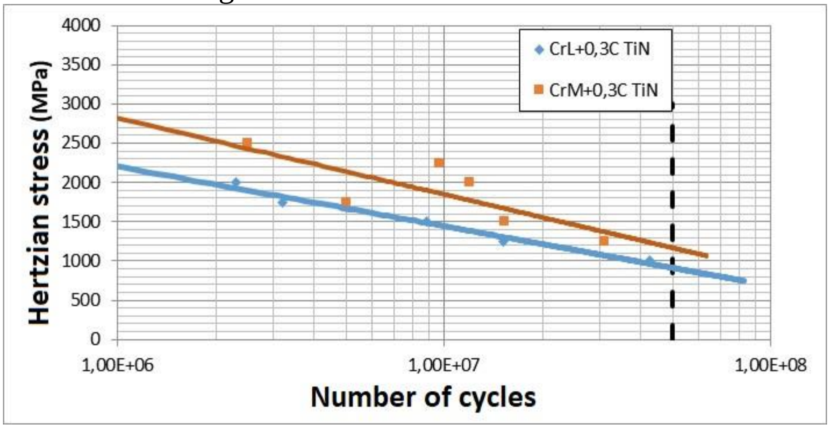

Fig. 4. Contact fatigue results for the TiN coated surface

The results of the contact-fatigue tests themselves are similar to the values of the contact fatigue limit, which is clearly summarized in the following table. 1. There is a clearly visible difference between the influence of individual surface treatments on the resulting value of the contact fatigue limit with respect to the value of 50.10^6 cycles passed.

For Wöhler damage analysis only three representative sample finishes were selected to perform this method, given the amount of samples available and the time available. This method for determining the lifetime at the 10 and 50% significance levels was performed on samples after plasma nitriding, laser hardening and TiN-coated samples. All samples in the required number of 15 pieces were tested for contact fatigue at an applied stress of 1500 MPa.

Table 1 Rolling-contact fatigue results

	CrL+0,3%C σ_c (MPa)	[%]	CrM+0,3%C σ_c (MPa)	[%]
Samples without treatment	660	10 0	1154	10 0
TiN	900	13 6	1200	10 4

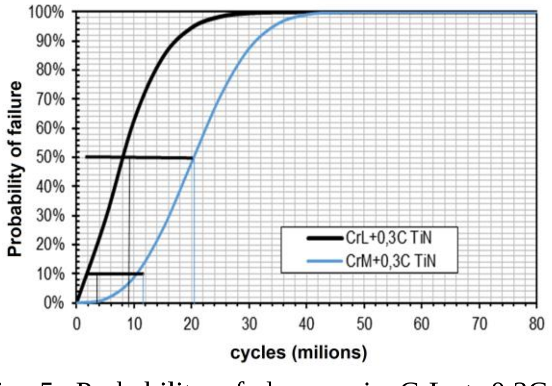

Fig. 5. Probability of damage in CrL + 0.3C and CrM + 0.3C samples with TiN coating

It is clear from the graphs in Figure 5 that even though the samples were loaded with the same 1500MPa stress level and had the same surface finish in the series, they always differed to some extent in the achieved life value and thus the Weibull probability function has more or less inclined course. This slope then also indicates the variance of the properties of the samples with respect to contact-fatigue resistance. The steeper the curve, the smaller the variance of the sample properties is achieved and thus the more accurate the result. This fact then testifies to the homogeneity of production conditions and the quality of surface treatment of the examined samples.

Conclusions

Based on the analyses performed on specimens, the following conclusions can be summarized:

1. It has been assumed that the factors that affect the resistance of the material to contact fatigue cannot be simply specified on the basic properties of the material, such as hardness or surface quality in terms of roughness. It is clear that the state of the microstructure has a more significant effect, and this is doubly true for materials produced by powder metallurgy, for which the presence of a certain degree of porosity is a priori assumed.

2. Preliminary measurements have shown suitable values for the porosity and hardness HV 10 of the samples, which generally do not differ much from sample to sample and are in good agreement within each type of material.

3. Surface treatment of the surface by rolling has proven to be an effective tool for reducing the surface roughness of the samples, which is secondarily associated with an increase in the hardness of the surfaces of the treated samples. Nevertheless, the results of the contact-fatigue tests did not show significant improvements in the contact fatigue resistance, which can be attributed to the existence of residual stresses in the surface layers of the material after the roll deformation strengthening process.

Acknowledgment

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