Wear resistance of structural steels nitroded in cyclic-commuted discharge at limit modes of friction

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Abstract

The article discusses the method of conducting tribological studies at the limit modes of friction of nitrided and non-nitrided steels 20 and 45 in order to achieve a comparison of the results of laboratory tests with operational data. The relationship of structural phases in time is significantly influenced by the initial state of the surface and its physical and mechanical characteristics, pressure on the contact surface, sliding speed, and all these parameters for the limit mode of friction are closely related. Carrying out tests on the wear resistance of samples made of different materials and with significantly different characteristics of the surface layer at the same parameters of the test regime is impossible in most cases, since the obtained results are problematic to compare.

Keywords: nitriding, limit friction, wear

Statement of the problem and analysis of the latest research.

One of the directions of development of tribology is the development of methods of objective tribological studies of nitriding characteristics of surface layers on structural steels, depending on the requirements of further operation of nitriding facilities. [1-3].

For the objectivity of research on the wear resistance of nitrided surfaces, attention should be paid to the fact that post-modification characteristics should be compared with similar parameters of geometrically similar surfaces that were not modified. At the same time, both for one and for the other, they should be determined according to the same type of methodology. Only if these requirements are met, the results of the modification can be assessed as real and having scientific and practical significance. Indeed, in the event of the impossibility of meeting these requirements, the problem of finding a transition function between the results of experiments will arise. Comparison of parameters obtained under different conditions of their fixation can lead to conclusions that are highly unlikely to be confirmed in practice. One of the essential points of establishing experimental results is to ensure the conditions of experiments, which would correspond to the maximum extent similar to the characteristics of real operation [4]. Indeed, there is almost always a certain inconsistency of the conclusions formed on the basis of experiments, if the test conditions differed significantly from the real operating conditions. Finally, the time factor is not the least important, since it is possible to apply such operating parameters of the experimental installation for the study of wear resistance, in which the wear process over time would approach the values recorded in the operating mode. Then the duration of experimental research, taking into account the need to ensure the necessary reliability of their results, will be such that the need for the research itself for practice will disappear by itself.

The purpose of the work is to develop a methodology and criteria for evaluating experimental studies of the wear resistance of samples after their surface modification by nitriding in a glow discharge to achieve the results of laboratory tests that correspond to the real conditions of operation of parts.

Methodology of conducting experimental studies.

Experimental studies were carried out on a universal machine for testing materials for friction, model 2168UMT with some modernization of the friction unit, which is described in detail in the work [5]. Working out the modes of experiments was carried out on samples, the method of preparation of which is given in the same place. To check the possibility of further comparison of wear processes, objects with significantly different surface characteristics were selected: soft surfaces are represented by samples from steel 20 without modification, modified - from steel 45 after nitriding in a glow discharge. The latter before nitriding had a surface hardness of HV0.1 215, after modification HV0.1 700...730. Since liquid lubricant was supplied to the friction zone, the friction coefficient was fixed in the range of 0.05...0.12, which corresponds to the limit mode of friction.

Presentation of the main material and received scientific research.

The initial series of experiments was carried out on steel 20 samples without their modification. The hardness of the counterbody made of hardened steel was HRC 60. The speed and pressure were chosen within such limits that the temperature of the surface of the samples in the friction zone did not exceed 40˚C, and in combination with the pressure value, the constant presence of lubricant on the friction area would be ensured. At the speed of the relative movement of the sample V=1.8 m/s and the pressure of 10 MPa (this value turned out to be optimal, since more or less heavy wear is observed with it and there are no sticking phenomena), uniform wear is observed, and the value of linear wear is on average 15, 3 μm/km of path. The coefficient of friction ranged from 0.05 to 0.12, which in the experimental conditions corresponded to a friction force of 29.5 to 64.6 N. The dependence of the linear wear averaged over several samples per one kilometer of the path on the path is shown in Fig. 1.
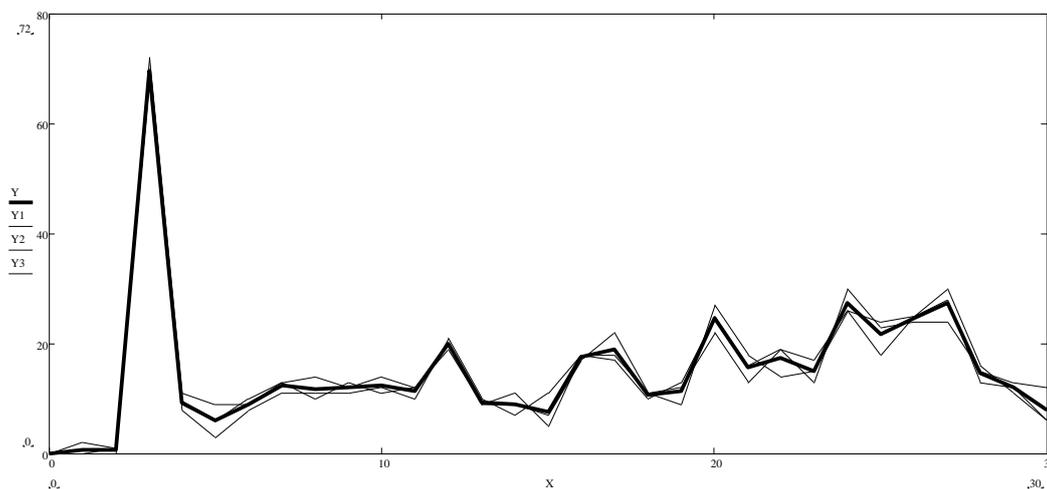
Fig. 1. Dependence of linear wear on the friction path of samples made of steel 20 non-nitrogenized at a pressure of 10 MPa, a speed of 1.8 m/s

In fig. 1, the friction path from 0 to 30 km is plotted on the horizontal axis, and the amount of wear in microns is plotted on the vertical axis (the main line is the amount of linear wear averaged over all samples, the thin lines are the average linear wear over groups of samples. From Fig. 1, it is clear the conclusion regarding the variable nature of the wear process itself is followed. In the first kilometers of the wear path, there is practically no wear, which can be explained by the fact that the samples were pre-loaded during the run-in process with a pressure of the order of 8 MPa. At the same time, a layer of compacted metal, a kind of slander, was formed on the future friction surface i.e., it strengthened on the surface. As this initial surface layer was removed, the process of intensive wear began. Further wear occurred according to the scheme of periodic surface compaction and destruction of this compacted layer. This explains the periodic fluctuations of both the coefficient of friction and the force of friction. Thus, from the above the first conclusion regarding the uneven character of wear follows formation of unmodified samples caused by constant structural transformations on the friction surface and the destruction of structures, the characteristics of which exceed the indicators of the surface hardness of the base of the samples. The same conclusion is confirmed in fig. 2 is a graph of the absolute wear of the samples depending on the traveled friction path (line markings are similar to Fig. 1).

The effect of surface compaction - slander when increasing the pressure is manifested in the increase of surface microhardness several times. For example, even for cast iron after treatment with a pressure of 1.2 MPa, the surface microhardness reached values of HV0.1 1000. It is not excluded that the constant presence of lubricant in the contact zone of the sample and the counterbody can contribute to the formation of metal-mineral structures, the processes of appearance and destruction of which also provoke unevenness wear [6].
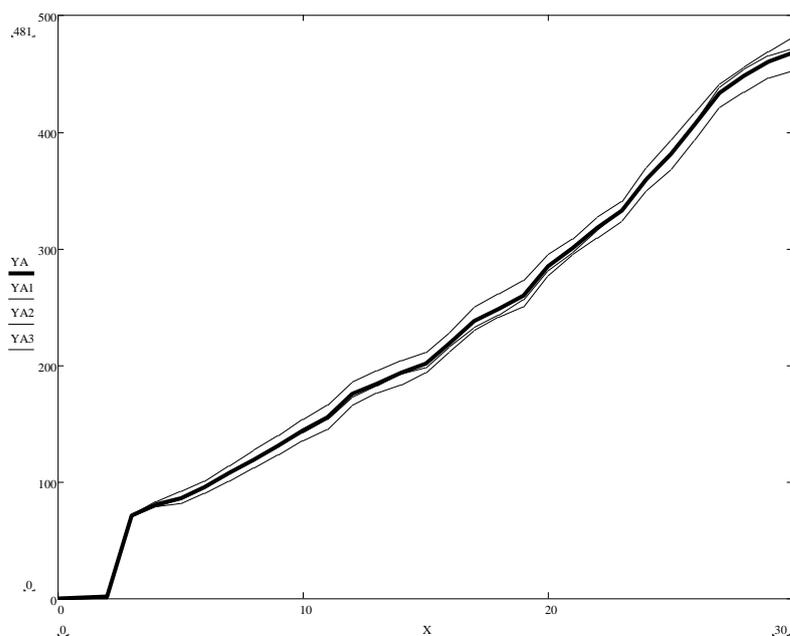
Fig. 2. Graph of the absolute value of linear wear of steel 20 samples

A change in the amount of pressure on the friction surface also significantly affects the wear process. The influence of the nature of the pressure change on the contact surface is confirmed by experiments with samples of unmodified steel 45. At an initial pressure of 10 MPa and a sliding speed of 1.8 m/s (that is, the parameters of the test regime completely coincided with those adopted for samples of steel 20) when reaching the path values 10 km of linear wear was practically not recorded. A stepwise increase in pressure by 2 MPa after each kilometer of the path up to 16 MPa also did not change the nature of the wear. At a pressure of 18 MPa, linear wear of 15-17 microns was observed in the next kilometer, but the wear stopped again in the next kilometer. After that (18 km of travel), the pressure was increased to 20 MPa, but no wear was observed. Thus, it follows from the foregoing that the surface of the sample is periodically compacted and strengthened, its destruction requires either a significant path of friction, or an increase in pressure to certain limits, which causes a frictional force sufficient for another change in the surface structure. In addition, it should be added that with the initial surface microhardness of HV0.1 215, after 20 km of the path and reaching a surface pressure of 20 MPa, the surface microhardness increased to the values of HV0.1 414. Subsequently, the pressure continued to be increased by 2 MPa for each new kilometer of the path, however linear wear was again not observed up to 26 MPa. At this pressure, at first wear increased intensively to values of 131-167 microns, and then the phenomena of seizing began. After the process began to be implemented at a pressure of 26 MPa, the surface microhardness increased to the values of HV0.1,856, i.e., in fact, the surface underwent mechanical modification. As for the nature of the pressure change on the surface, in the described experiment, the pressure increased according to a certain scheme (for example, by 2 MPa per kilometer of the path), its structural changes took place gradually. And in the next experiment with the participation of similar new samples and the counterbody, from the very beginning the pressure in the contact zone was set at the level of 24 MPa (at this pressure value, achieved by a stepwise increase in the previous experiment, linear wear was practically not fixed). Already in the first kilometer, the coefficient of friction increased rapidly to the values characteristic of adhesion, and the surface microhardness was HV0.1,892. In fact, at such a high pressure, the surface changed dramatically structurally, it is possible that these structural transformations led to the squeezing of the oil film from the contact zone and the nature of the friction process began to approach the regime of dry friction, which led to setting. The following experiment speaks about the role of the factor of the nature of the pressure change. On samples made of the same steel 45, the pressure from the very beginning changed according to the pattern of 2 MPa/km of the path and wear was practically absent, but already after 5 km the pressure was sharply increased to 20 MPa, which immediately led to the appearance of seizure phenomena, and the surface microhardness at the end of the experiment was HV0.1 838.

A parallel temperature control in the contact zone established that its value does not exceed 42°C immediately after stopping, and after 5-10 seconds after opening the contact, the surface temperature does not exceed 22°C. Thus, pressure was the decisive factor that influenced the nature of friction in these experiments, since the viscosity characteristics of the lubricant did not change significantly at the fixed temperature values.

The presence of a compacted layer on the surface as the main factor determining wear parameters was confirmed as follows. Without removing the sample from the stand, i.e. the basing conditions remained unchanged, a layer of 15-24 μm was removed with a fine sanding pad number 150 and number 500. Before that, at a pressure of 18 MPa, there was practically no linear wear on the 13 km path (only before grinding at different pressure values, the total path was 25 km). On the first kilometer after grinding, linear wear was recorded in the

range of 18-23 μm, on the next two kilometers it stopped again, then after similar grinding, the wear again amounted to about 10 μm with a gradual cessation, which once again confirms the above version of the influence on the nature of wear of the formation process compacted microstructures. It is interesting that the surface microhardness after grinding practically does not differ from the initial values.

The condition of the surface of the counterbody also significantly affects the course of the wear process. In the experiments described above, as already mentioned above, a hardened steel counterbody with a smooth surface (roughness parameter Ra 0.27) was used. The experiments described above were primarily time-consuming, for example even one series of steel 20 samples required, including time for temperature stabilization, measurements, etc., two full working days (15 hours). It is obvious that obtaining results that first of all meet the requirement of reliability of conclusions would require a time that cannot be considered real. This especially applies to those issues where obtaining operational data on the effectiveness of one or another method of modification and the technological parameters of its implementation is extremely necessary. Therefore, the next phase of the experiments were experiments in which the role of the mechanical component of wear was significantly increased. For this purpose, counterbodies were used, the surface roughness of which was artificially increased by sanding with a skin, a wheel, application of titanium and hard alloy on an electric spark unit, application of radial direction lines, etc. With the help of various methods of surface grinding, the roughness parameter Ra increased from a value of 0.2...0.3 μm to 0.5 μm when sanding with a leatherette by hand, to 0.37 μm when grinding with a circle on a grinding machine, and 1.15 μm when grinding with a circle on a grinding machine. After the application of titanium and hard alloy by the electric spark method, the roughness parameter exceeded 8 μm. The hardness of the surface after applying the coating by the electrospark method, depending on the polarity of the electrode, the brand of the implanted material, and the place of measurement (polished or fused surface) was HV0.1, 450...800, and higher values, as a rule, corresponded to the areas with subsequent grinding after implantation, which confirms the above-mentioned effect of surface sealing after grinding.

The graph of changes in linear wear of samples made of unmodified steel 45 (counterbody - modified by electrospark implantation, pressure 4 MPa, speed - 1.8 m/s) with observance of the curve designation system adopted in the previous figures is shown in fig. 3. As can be seen from this figure, at the beginning of the wear process, the mechanical wear component provides an incomparably greater intensity than in the previous experiments, and the pressure on the surface was significantly lower. The cutting ability of the counterbody leads to the destruction of surface structures, while preventing their compaction, but over time, as the microprotrusions on the surface of the counterbody become dull, the wear process becomes less and less intense, up to a complete cessation.
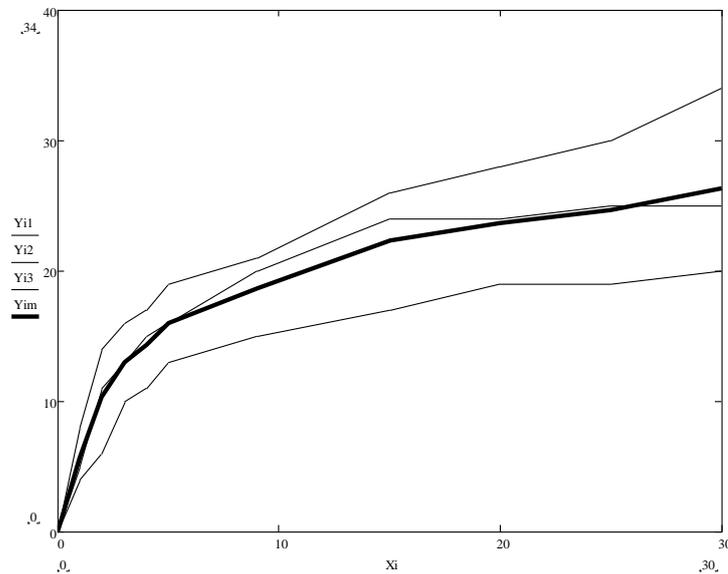
Fig. 3. Graph of changes in linear wear for a pair of samples made of unmodified steel 45; counterbody - implanted by the electrospark method

Results similar in content were obtained when using counterbodies, one of which was machined on a lathe with a VK8 cutter at a radial feed of 0.11 mm/rev, which provided a roughness parameter Ra of 2...3 μm. The intensity of wear on the first kilometer of the path at a pressure of 2 MPa was 8-10 microns for every 100 m of the path, but already at the beginning of the second kilometer this indicator decreased to the level of 1-2 microns per 100 m, and then to 1-2 microns/km.
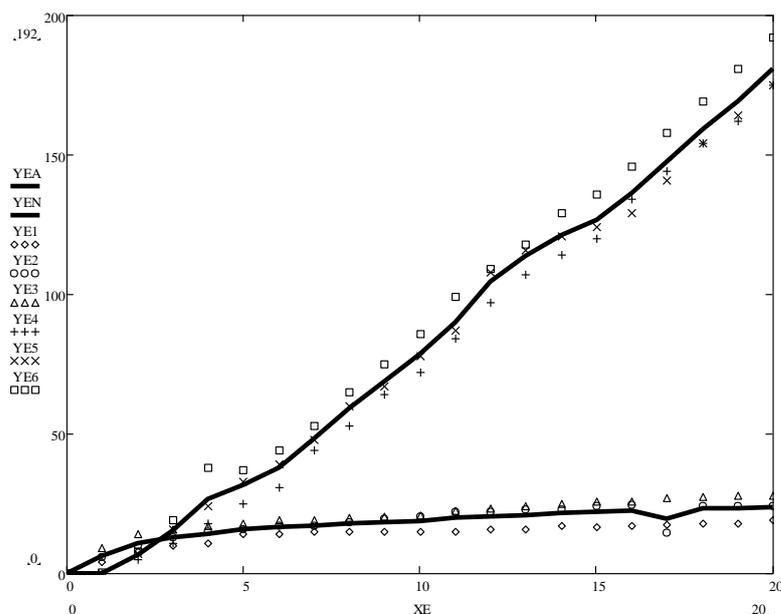
Fig. 4. Wear of nitrided (upper area) and non-nitrided samples (lower) due to the action of the mechanical component of friction (pressure 4 MPa, counterbody – VK8 hard alloy implanted by the electrospark method)

The nature of wear of nitrided samples in comparison with non-nitrided ones is shown in fig. 4. Nitrided samples (steel 45, surface microhardness HV0.1 466) were worn under the same conditions as those given above with the use of a machined counterbody, but the pressure was 4 MPa. As can be seen from the figure, the wear process for non-nitrogenized samples is traditional with the formation of compacted surface structures and practically stopping wear already after three kilometers of travel. Nitrided samples practically do not wear out in the first kilometer, since the strongest interlayer of the ε-phase comes into play. However, its thickness is insignificant, literally a few micrometers, so already in the next kilometers of the road, the process of wear begins with almost constant intensity. This is due to the fact that a really homogeneous interlayer of the γ′-phase and α-solid solution with sufficiently significant hardness indicators cannot be compacted and is removed due to the mechanical component of the wear process. Despite the fact that in the experiments, the results of which are shown in fig. 4, relatively little pressure was applied.

Further research developed in the direction of elucidating the influence of pressure on the wear process up to its large values. The results of this series of experiments are shown in fig. 5.
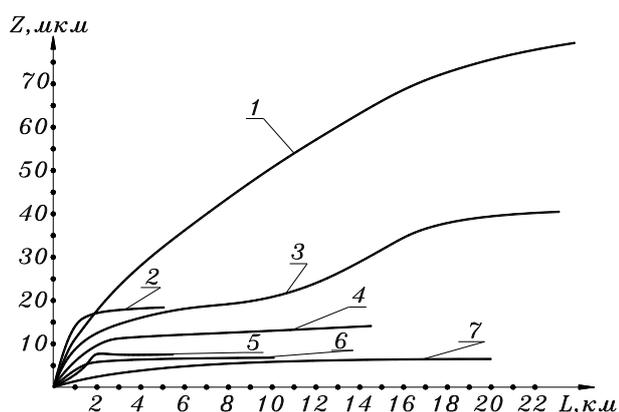
Fig. 5. Wear samples of nitrided steel 45 depending on the path at pressure in the contact zone and sliding speed: 1-65 MPa, 0.1 m/s; 2 – 50 MPa, 0.1 m/s; 3 – 120 MPa, 0.1 m/s; 4 – 80 MPa, 0.1 m/s; 5 – 40 MPa, 0.3 m/s; 6 – 65 MPa, 0.2 m/s; 7 – 20 MPa, 0.2 m/s

From fig. 5 follows the conclusion that at almost any pressure there comes a moment when the wear process practically stops, however, the way in which such stabilization is observed is different for different pressure values. The hypothesis that the wear process in conditions where the mechanical component of this process prevails is actually a combination of two competing processes - strengthening of the surface and destruction of this strengthened layer is confirmed by fig. 5. The harder the contact surface, the greater the

pressure threshold at which the compacted layer collapse phase occurs. However, the influence of pressure at its high values is extreme: in the demonstrated series of experiments, the wear process occurred most dynamically at a pressure of 65 MPa. At pressure values lower and higher than this value (at the same sliding speed), the intensity of wear was lower. An increase in the sliding speed leads to a decrease in the intensity of wear and an acceleration of the beginning of the stabilization phase, which can be explained by a decrease in the relaxation time of the surface layer compaction processes.

Conclusions

1. The wear process at extreme friction actually includes two competing processes: compaction of the surface layer with an increase in its microhardness and destruction of the surface layer with local adhesion of the surfaces.

2. The relationship of these phases in time is significantly influenced by the initial state of the surface and its physical and mechanical characteristics, pressure on the contact surface, sliding speed, and all these parameters for the limit mode of friction are closely related.

3. Carrying out tests on the wear resistance of samples made of different materials and with significantly different characteristics of the surface layer at the same parameters of the test regime is impossible in most cases, since the obtained results are problematic to compare.

4. Such test conditions should be considered promising, which can be applied to surfaces with different characteristics and provide results that are acceptable from the point of view of reliability, mutual comparison and time of their implementation

References

1.Kaplun V.H., Kaplun P.V. Yonnoeazotyrovanye v bezvodorodnыkh seredakh: monohrafyia / V.H. Kaplun, P.V. Kaplun. – Khmelnytskyi: KhNU, 2015.-315s.

2.Pastukh Y.M. Teoryia y praktyka azotyrovanyia v tleiushchem rozriade. Kharkov: NNTs KhFTY, 2006. – 364s.

3.Stechyshyna N.M., Stechyshyn M.S., Mashovets N.S. Koroziino-mekhanichna znosostiikist detalei obladnannia kharchovykh vyrobnytstv: monohrafiia / N.M., Stechyshyna, M.S.Stechyshyn, N.S. Mashovets. – Khmelnytskyi: KhNU, 2022.-181s.

4.Skyba M.Ie., Stechyshyna N.M. Koroziino-mekhanichna znosostiikist detalei obladnannia molokozavodiv / Kharchova promyslovist. Kyiv: NUKhT, 2019. №2. S97-106.

5.Stechyshyn M.S., Stechyshyna N.M., Martyniuk A.V. Kavitatsiino-eroziina znosostiikist detalei obladnannia molokozavodiv: monohrafiia. Khmelnytskyi: KhNU. 2018. 148s.

6.Zakalov O.V., Zakalov I.O. Osnovy tertia i znoshuvannia u mashynakh: navch. posib. Ternopil: TNTU im.. I.Puliuia, 2011. 322s.

Стечишин М.С., Люховець В.В., Стечишина Н.М., Лук'янюк М.В. Зносостійкість конструкційних сталей, азотованих в циклічно-комутованому розряді при граничних режимах тертя

У статті розглянута методика проведення трибологічнихдосліджень при граничних режимах тертя азотованих і не азотованих сталей 20 і 45 для досягнення порівняння результатів лабораторних випробувань з експлуатаційними даними. На взаємозв'язок структурних фаз у часі суттєвий вплив мають вихідний стан поверхні та її фізико-механічні характеристики, тиск на поверхню контакту, швидкість ковзання, причому всі ці параметри для граничного режиму тертя тісно пов'язані між собою. Проведення випробувань на зносостійкість зразків із різних матеріалів і зі суттєво різними характеристиками поверхневого шару при однакових параметрах режиму випробувань у більшості випадків неможливо, оскільки порівнювати отримані результати проблематично.

Кючові слова: азотування, граничне тертя ,знос