Problems of Tribology, V. 28, No 1/107-2023, 20-24

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2023-107-1-20-24

Wear resistance of structural steels nitrided in a cyclically switched discharge with dry friction

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Received: 20 December 2022: Revised: 25 January 2023: Accept:20 February 2023

Abstract

The paper examines the method of conducting tribological studies in the dry mode of friction of nitrided and unhardened structural steels 20 and 45 in order to achieve comparable results of laboratory tests with operational characteristics. Preliminary studies of anodized steels of the same steels indicate that under conditions of extreme friction it is extremely difficult, and in some cases impossible, to use such values of specific pressure on the friction surface, at which it would be realistic to compare the results obtained for different samples made of different brands materials and processed using various technological processes. Since during the tests, constant lubrication of the friction zone was ensured, a layer of lubricant was present on the friction surface up to a certain pressure value, which led to extremely small indicators of linear wear. However, depending on the characteristics of the modified surface, there was a critical value of pressure at which the layer of lubricant was squeezed out of the friction zone, which led to instant adhesion of the surfaces. Thus, the study of wear resistance in the dry mode of friction ensures a significantly higher productivity of experiments.

Unlike experiments with limit friction, dry friction can be used for different steels at the same pressure value, which eliminates the problem of comparability of results and contributes to the objectivity of conclusions regarding the effectiveness of various modification processes.

According to the results of previous experiments, such a compromise pressure value can be 16 MPa.

Another important phenomenon for the analysis of the influence of the modification results on the wear resistance characteristics of the surface is established - the effect of relaxation processes in the near-surface layers, which have already acquired structural transformations under the influence of pressure in the friction zone.

For all steels, there is some slowing down of the intensity of wear after a break with a gradual return to the intensity characteristic of a certain brand of steel. The reason for such a phenomenon can only be the relaxation of stresses and the equalization of the characteristics of the structure in the near-surface layers. At the same time, the result is the strengthening of the surface, which explains the decrease in the intensity of the wear process. over time, as the strengthened layer breaks down, the indicators of the surface condition become equal to those before the break and the intensity of wear is restored.

Key words: nitriding, dry friction, limit friction, wear.

Statement of the problem and analysis of the latest research

The metal surface should be considered as a special variety of defects that destroys the periodicity of the solid body. This thesis is confirmed by the fact of significant acceleration of chemical reactions in the presence of solid catalysts on the surface. The boundary layer, the structure of which differs from the base of the solid body, can interact more actively with external factors that stimulate surface modification. At the same time, it is the presence of a real surface that is the stimulus due to which most of the physical or chemical processes of the interaction of a solid body with the environment take place.

The near-surface layer should be considered as a three-dimensional structure, which differs from the solid body itself, since within several atomic layers it may include atomic nodes different from the atomic nodes of the main volume. However, one should not forget that the near-surface layer is a crystalline structure for which two-dimensional periodicity is preserved. Thus, violation of the indicated natural periodicity of near-surface layers inevitably affects all characteristics of the surface as a whole, including its ability to resist wear. This circumstance was noted to a greater or lesser extent in classic works on tribology, but there is no coverage of the research results, on the basis of which it would be possible to form practical methods of experiments to find the tribological characteristics of the wear resistance of metals.

It is known that during the adsorption of gases, a monomolecular adsorption layer is formed - a monolayer, and the degree of integrity of the monolayer at low pressure values is proportional to the adsorbate pressure in the gas medium. If gas molecules, in the presence of a strong chemical or physical bond, do not have the opportunity to move on the surface, then we get localized adsorption with the formation of an adsorption complex.

Chemisorbed and physically sorbed gas particles on the surface differ in the type of electronic bond between the adsorbate and the base. If the electronic state of the adsorbed molecule undergoes significant changes up to the formation of chemical bonds with the surface, then we are talking about chemisorption. If the molecule is held on the surface by van der Waals forces, then this type of adsorption refers to physical adsorption. The upper limit for physical adsorption is only 0.6 eV. The chemisorption energy is usually within 1...8 eV [1]. If the energy of a molecule of the external environment is several electron volts, then it will already be able to overcome the potential barrier of the near-surface layer and the conditions for chemical sorption or chemical reaction appear [2]. It is obvious that the mechanical impact on the surface changes the parameters of adsorption phenomena, which also affects the wear processes.

From the above follows the conclusion about the importance of taking into account the parameters of the wear process on the objectivity of the results of the conducted research. This especially applies to their analysis and formation of practical recommendations.

The work [3] analyzed the results of research on wear resistance, which were obtained under conditions of extreme friction. The main conclusion from the analysis was that any wear process is a combination of successive compaction of near-surface layers and their removal. At the same time, the test parameters are of decisive importance, which must be selected taking into account the material and the preliminary treatment of the surface. The results of the experiments show that, under conditions of extreme friction, it is extremely difficult, and in some cases impossible, to use such values of the specific pressure on the friction surface, at which it would be realistic to compare the results obtained for different samples, made of different grades of materials and processed with various technological processes. Since during the tests, constant lubrication of the friction zone was ensured, a layer of lubricant was present on the friction surface up to a certain pressure value, which led to extremely small indicators of linear wear. However, depending on the characteristics of the modified surface, there was a critical value of pressure at which the layer of lubricant was squeezed out of the friction zone, which led to instant adhesion of the surfaces. The presence of compaction and structural transformations of the surface is evidenced by the fact that with a gradual increase in pressure, it was possible to reach relatively high values of the critical pressure. An attempt to immediately conduct tests on new samples at a pressure close to these critical values inevitably caused seizure of the surfaces. The reason for such a phenomenon could only be the gradual compaction of the surface and its strengthening associated with a change in the structure of the near-surface layer. The above and the impossibility of an objective comparison of test results obtained at different pressures explain the need to switch to the scheme of experiments with dry friction.

The purpose of the work is to develop the methodology and criteria for the evaluation of experimental studies of the wear resistance of samples after nitriding in the cyclically switched discharge (CSD) in order to achieve the results of laboratory tests that correspond to the real conditions of operation of the parts.

Methods of conducting experimental research

In order to ensure the independence of the energy parameters of the regime without hydrogen nitriding in the glow discharge (HNGD), the installation was modernized: a block of heating elements was installed in the gas discharge chamber, and a power supply unit from an independent source and also a switching and control unit of the cyclically switched discharge were added to the electrical circuit.

Experimental studies of samples for wear resistance were carried out on a universal machine for testing materials for friction, model 2168УМТ. The friction scheme is “disc – finger”; contact type – plane-on-plane sliding (the end of the cylindrical sample slides on a flat metal disk; the material of the counterbody is steel 100Cr6 with a base hardness of HRC61; pressure in the contact zone p = 16 MPa; sliding speed v = 0.1 m/s [4].

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 C22 without modification, modified - from steel C45 after nitriding in a glow discharge. The latter before nitriding had a surface hardness of HV0.1 215, after modification HV0.1 700...730 [5].

The controlled parameter is linear wear h, which was determined as a change in the linear size of the sample, measured normal to the friction surface, as a result of passing a section of length l.

BATR was carried out on an industrial unit of УАТР, which corresponds to the diode-type model. A power supply unit from an independent source, as well as a switching and control unit for a cyclically switched discharge, have been added to the scheme. In addition, the installation is additionally equipped with heating elements placed in the gas discharge chamber, which made it possible to arbitrarily change the energy parameters - the voltage U, and the value of the current density j (the ratio of the current to the total area of the cage and suspension) [6].

Metallographic studies of nitrided samples were performed after etching in a 3% alcoholic solution of nitric acid. The thickness of the nitride zone was measured on an RX50M microscope. Microhardness was determined on a DuraScan-20 microhardness tester under a load of 1.0 N, with fixation of microhardness values both on the surface and at a distance from it of 0; 25; 50; 100; 200; 300; 500 microns.

The thickness of the nitride zone was measured using a MIM-10 microscope, which allows quantitative analysis of the phase and structural composition of nitrided surfaces.

X-ray phase analysis of nitrided samples was performed on a ДРОН-3 diffractometer in filtered radiation of an iron anode in the range of q angles from 20° to 100° with a scan step of 0.1° and an exposure time of 10 s. X-ray imaging was carried out from the surface to the depth of the nitrided layer.

Presentation of the main material and received scientific research

The results of preliminary tests are shown in Figure 1. It follows from Figure 1 that in the dry friction mode, the intensity of the wear process increases significantly, which means a significant increase in the productivity of experimental studies. Thus, one experiment in the mode of extreme friction lasted for weeks, and in the dry mode it was possible to perform it in several shifts. In addition, the thesis regarding the decisive influence of pressure on the intensity of wear on the friction surface was confirmed: the same indicators of linear wear d were achieved with an increase in pressure with a significantly smaller friction path L. The brand of the material and the initial values of its physical and mechanical indicators in combination with the available modification surfaces also significantly influenced the intensity of wear. Thus, for steel 41CrAlMo7 nitrided in the glow discharge, the intensity of wear is almost an order of magnitude lower compared to steel C22. Similar data were obtained in [7].

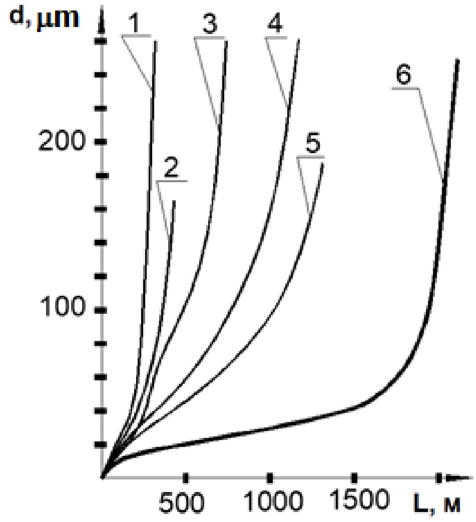

Fig. 1. Dependence of linear wear on the path of friction and pressure: 1 – steel C22, p=16 MPa; 2 – steel C45, p=16 MPa; 3 - steel C22, p=10 MPa; 4 – steel 41Cr4, p= 16 MPa; 5 – steel C45, p= 10 MPa; 6 – steel 41CrAlMo7, p= 16 MPa

In contrast to the methodology of experimental research with extreme friction, in the dry friction mode, results can be achieved at the same pressure values for almost all steels, which excludes the issue of comparability when analyzing the results of research. The importance of this provision is evidenced by the comparison of wear curves for the same steels at different pressure values (Figure 1). Since the same value of linear wear for the same material, but at different pressures, is achieved with significantly different values of the friction path, establishing the relationship between the listed factors would pose a certain problem.

Curves in fig. 1 also confirm the effect on the wear intensity of the physical and mechanical parameters of the surface and its modification. Thus, steels with higher physico-chemical characteristics (41Cr4 and 41CrAlMo7), as well as steels that have undergone a certain modification treatment, wear out under the same conditions (pressure and speed of relative movement) with a lower intensity of wear, which in the graphs corresponds to the angle of their inclination.

The effect of structural transformations of the surface is confirmed by Figure 2, which shows the results of fixation of linear wear with a small interval of the friction path. The wear schedule in this case is a stepped curve of periods of formation of strengthened structures on the surface, when wear is practically absent, and periods of destruction of these surface structures.

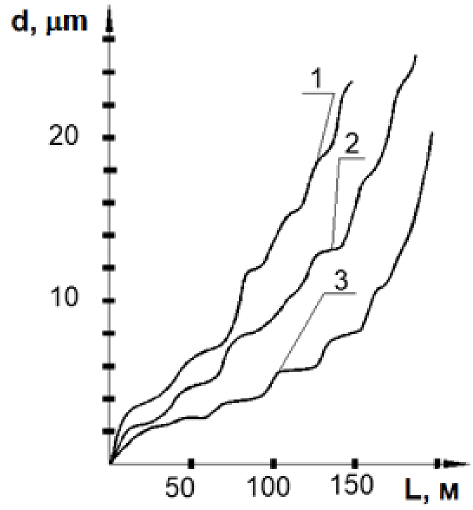

Fig. 2. Character of surface wear in the initial period: 1 - steel C22, 2 - steel 41Cr4, 3 - steel 41CrAlMo7

For modified surfaces, this phenomenon is especially characteristic in the initial period, when the nitride and internal nitriding zone wears out.

Another important phenomenon for the analysis of the influence of the modification results on the wear resistance characteristics of the surface is established - the effect of relaxation processes in the near-surface layers, which have already acquired structural transformations under the influence of pressure in the friction zone.

Black dots on curves 2, 4, 6 show the points when wear resistance tests were suspended and resumed the next day (Figure 3). For all steels, a certain slowdown in wear intensity is noted after a break with a gradual return to the intensity characteristic of a certain brand of steel (Figure 3). The reason for such a phenomenon can only be the relaxation of stresses and the equalization of the characteristics of the structure in the near-surface layers. At the same time, the result is the strengthening of the surface, which explains the decrease in the intensity of the wear process. over time, as the strengthened layer breaks down, the indicators of the surface condition become equal to those before the break and the intensity of wear is restored.

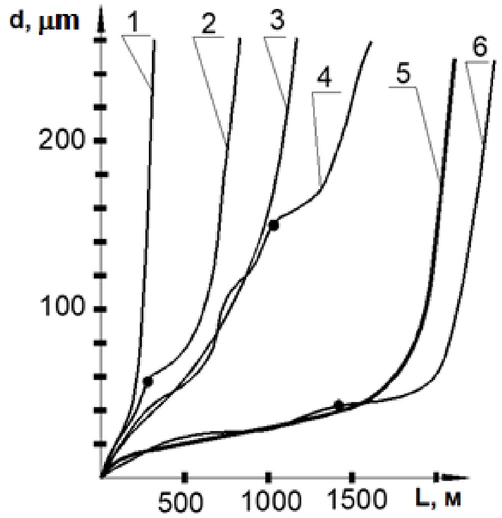

Fig. 3. Effect of relaxation structural transformations of the surface: 1, 2 – steel C22; 3, 4 – steel 41Cr4; 5, 6 – steel 41CrAlMo7 (points for stopping the tests are marked with dots)

Conclusions

Thus, the study of wear resistance in the dry mode of friction ensures a significantly higher productivity of experiments. Unlike experiments with limit friction, dry friction can be used for different steels at the same pressure value, which eliminates the problem of comparability of results and contributes to the objectivity of conclusions regarding the effectiveness of various modification processes. According to the results of previous experiments, such a compromise pressure value can be 16 MPa. The effect of relaxation transformations of surface structures has been established, on the basis of which it is recommended to carry out research on wear resistance during one continuous session.

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Стечишин М.С., Скиба М.Є., Мартинюк А.В., Здоренко Д.В. Зносостійкість конструкційних сталей, азотованих в циклічно-комутованому розряді при сухому терті.

У роботі розглянута методика проведення трибологічних досліджень при сухому режимі тертя азотованих і незміцнених конструкційних сталей 20 і 45 з метою досягнення порівнюваних результатів лабораторних випробувань з експлуатаційними характеристиками. Попередньо проведені дослідження аотованих цих же сталей свідчать про те, що в умовах граничного тертя надзвичайно важко, а в деяких випадках неможливо використовувати такі значення питомого тиску на поверхню тертя, при яких реальним було б співставлення результатів, одержаних для різних зразків, виготовлених з різних марок матеріалів та оброблених за допомогою різних технологічних процесів. Оскільки в ході випробувань забезпечувалось постійне змащування зони тертя, то до певного значення тиску на поверхні тертя був присутній шар мастила, що призводило до надзвичайно малих показників лінійного зношування. Проте в залежності від характеристик модифікованої поверхні існувало критичне значення тиску, при якому шар мастила витискувався із зони тертя, що приводило до миттєвого схоплювання поверхонь. Таким чином, дослідження зносостійкості при сухому режимі тертя забезпечує суттєво більшу продуктивність експериментів. На відміну від експериментів при граничному терті сухе тертя може застосовуватись для різних сталей при однаковому значенні тиску, що виключає проблему порівнянності результатів та сприяє об’єктивності висновків стосовно ефективності різних процесів модифікації. За результатами попередніх експериментів таким компромісним значенням тиску може бути 16 МПа. Встановлене ще одне важливе явище для аналізу впливу результатів модифікації на характеристики зносостійкості поверхні - ефект релаксаційних процесів в приповерхневих шарах, які вже набули структурних перетворень під дією тиску в зоні тертя. Для всіх сталей відмічається деяке сповільнення інтенсивності зношування після перерви з поступовим поверненням до інтенсивності, характерної для певної марки сталі. Причиною такого явища може бути лише релаксація напружень і вирівнювання характеристик структури в приповерхневих шарах. При цьому наслідком є зміцнення поверхні, що і пояснює зниження інтенсивності процесу зношування. з часом, По мірі руйнування зміцненого прошарку, показники стану поверхні стають рівними з тими, що були до перерви і інтенсивність зношування відновлюється.

Ключові слова: азотування, сухе тертя, граничне тертя, знос.