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NITRIDING OF LONG-DIMENSION HOLES IN CYCLIC-SWITCHED DISCHARGE

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Abstract: The paper presents the results of the study of the surface microhardness and wear resistance of steel 45 nitrided in a hydrogen-free environment in a glow discharge with the gas discharge chamber powered by a cyclically switched discharge. The experiments were carried out on a model that is a hollow cylinder with holes drilled at a certain distance from the ends, into which samples of steel 45 were inserted with a certain tension. Thus, the ends of the samples outside and inside the cylinder were nitrided under practically the same technological conditions. Two options for nitriding the inner surfaces of the holes in a cyclically switched discharge were considered: a through hole (the ends of the cylinder are open) and a blind hole (one end of the cylinder is closed with a lid). For comparison, the results of strengthening the inner surfaces of the holes by nitriding with a constant current supply to the gas discharge chamber are given. The results obtained show the efficiency of nitriding of long-length through.

Keywords: cyclically switched discharge, nitriding, microhardness, long holes.

1. INTRODUCTION

Practically all kinematic friction pairs with translational motion of agricultural machinery structurally fall into the category of holes with a relatively small diameter, that is, the ratio of the length (depth) of the hole to its diametrical size exceeds the value of four. This indicator, adopted as a criterion of geometric ratios, is justified by the fact that the nitriding process of such structural elements is similar in nature to a discharge with a hollow cathode. From the theory of this process, it is known that in reality the field penetrates into the holes to a depth of no more than two diametrical sizes [1]. In this case, it is necessary to consider the fact that this indicator refers to the field boundary, where the intensity is only about two percent of the nominal value at the end of the hole. The numerical criterion for classifying nitriding objects into the category of holes with a relatively small diameter in the amount of four diameters applies to structures in which the holes are through. For blind recesses or holes, the value of the criterion can be reduced from 1.5 to 2 diameters [2]. Such holes include plunger pairs of fuel pumps of diesel internal combustion engines, material cylinders of thermoplastic automatic machines, etc. Attempts to nitride such structural elements in a glow discharge with constant power supply only confirm the theoretical conclusions given above [3]. A preliminary theoretical justification for the possibility of nitriding the internal surfaces of holes with a relatively small diameter can be the prediction of the possibility of pumping nitrogen ions into the internal cavity of the hole due to the effect of their inertial movement at the moment of changing the discharge voltage up to its complete disappearance in the case of a cyclically switched discharge (CSDC). Since the ions in the absence of an electric field will continue to move tangentially to the trajectory that took place at the moment of discharge interruption, it becomes possible for them to reach the cavity of the hole, where the field is practically no longer active. Thus, an excess concentration of nitrogen ions is created, which then drift into the depth of the hole, obeying the laws of diffusion. Since nitrogen ions are the main factor in the formation of nitrides, the process of nitriding the inner surface should theoretically proceed at a speed that practically corresponds to the conditions for processing open surfaces [4, 5].

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2. RESEARCH METHODOLOGY

To modify the surface of titanium alloys, low-temperature nitriding in a glow discharge in a hydrogen-free environment was used. Nitriding was carried out on the experimental installation "UATR-1", which was developed by the Podolsk Scientific Physics and Technology Center (PNFTC) at Khmelnytskyi National University [1,2]. One of the ways to improve the quality of modification of steel surfaces of parts and tools by nitriding in a glow discharge is the introduction of a cyclically switched discharge (CSCD). The introduction of CSCD does not require the creation of fundamentally new equipment, it is enough to carry out the process of modifying existing installations. The essence of modifying existing installations is to introduce a discharge switch into the discharge power circuit, which would form a signal of the required configuration, both in form and in duration of the signal itself. Taking into account the frequency of the switching process, the most promising design option for the switch is its electronic version. To implement the process of modernization of existing installations, it is proposed to introduce a discharge switch into the discharge power supply circuit between the capacitive-inductive filter units and the sensor of the discharge control and management system. To check the quality of nitriding of the internal surfaces of long holes, a device was created, which is a hollow cylinder in which a series of radial holes are drilled at different distances from the end. Samples made of different steels are inserted into these holes. Thus, each sample is nitrided from two ends, which makes it possible, firstly, to nitride from the outside and from the inside of the model at practically the same temperature, and secondly, to compare the results of nitriding of two surfaces, with the difference in conditions being only the location of these surfaces - external or internal. All other factors that could affect the modification results are practically identical. To simulate blind holes, the upper end of the model was closed with a lid. Studies of the microstructure, surface microhardness and its distribution along the depth of the nitrided layer were carried out on specially prepared metallographic sections. To produce the sections, control samples were cut in the diametrical plane after nitriding. In order to prevent the layer from chipping and deviation from the plane of the analyzed surface ("section blockage"), the samples were fixed in special mandrels (clamps) with copper foil gaskets, after which the studied surfaces were subjected to grinding, polishing, washing and etching. Etching of the samples to reveal the structure of the modified layer was carried out using a 3% alcoholic solution of nitric acid HNO3. To determine the quality of the surface layer and the structure of the internal layers of the modified steel samples, a microstructural analysis of metals was performed. Microsections with a ground and polished smooth surface were examined in a MIM-10 optical microscope. The study of the microstructure of nitrided surfaces was carried out on "straight" and "oblique" sections. Measurements of the thickness of the nitride zone were carried out using a metallographic microscope MIM-10, which allows for visual observation and photography of the microstructure of metals, as well as quantitative analysis of the phase and structural composition of steels using a semi-automatic built-in device. The thickness of the nitride zone of the modified layer was calculated as the arithmetic mean of the measurement values taken at 50 points of the sample studied.

Processing of the nitriding results primarily involved measuring the surface microhardness on a PMT-3 microhardness tester. In this case, the surface microhardness was studied not only on the ends of the samples, but also along the depth of the modified layer. Microhardness measurements were performed at a distance from the surface of 0, 25, 50, 100, 200, 300, 500 microns. X-ray phase analysis was carried out on a general-purpose X-ray diffractometer DRON-3 in filtered iron anode radiation, in the angle range $2\theta = 20 \div 100^{o}$ with a scanning step of 0.1^{o} and an exposure time of 10 s. X-ray imaging was performed from the flat ends of cylindrical samples subjected to nitriding to the depth of the modified layer.

The studied nitriding modes:

1. Temperature T = 560 °C, process duration τ = 6 h, gas mixture composition – 75% nitrogen and 25% argon, voltage U = 760 V, current I = 0.8 A, frequency f = 1.5 kHz, waveform – rectangular, duty cycle (ratio of cycle period to signal duration) – 2, chamber pressure p = 160 Pa, Discharge cyclically switched. The cylinder is open on both sides.

2. Temperature T = 560 °C, process duration τ = 6 h, gas mixture composition – 75% nitrogen and 25% argon, voltage U = 730 V, chamber pressure p = 1.2 torr. Glowing discharge with constant power supply. The cylinder is open on both sides.

3. Temperature T = 560 °C, process duration τ = 6 h, gas mixture composition – 75% nitrogen and 25% argon, voltage U = 760 V, current I = 0.8 A, frequency f = 1.5 kHz, signal shape – rectangular, duty cycle (ratio of cycle period to signal duration) – 2, chamber pressure p = 160 Pa. The discharge is cyclically switched. The cylinder is closed on one side.

4. Temperature T = 560 °C, process duration τ = 6 h, gas mixture composition – 75% nitrogen and 25% argon, voltage U = 730 V, chamber pressure p = 1.2 torr. Glowing discharge with constant power supply. The cylinder is closed on one side.

The choice of nitriding modes is due to the fact that although the literature contains data on nitriding of open and closed long holes with constant power supply [6, 7], as well as hardening of open holes in CCR [8, 9] for some steels, there are no results of studies of the effect of nitriding on the hardening of the internal surfaces of closed (blind) holes. Therefore, to compare the effectiveness of hardening of such holes with power supply in CCR, the results of their study with constant power supply for holes in steel 45 are presented.

3. RESULTS AND DISCUSSION

As can be seen from Fig. 1, the distribution of microhardness along the depth of the nitrided layer during CCR hardening for all samples of the open model is practically the same. At the same time, the microhardness at the ends of the samples placed at different heights of the model is also the same. In contrast, for an open model during nitriding with a direct current supply for samples placed at a distance from the end more than two diameters of the inner hole, the microhardness decreases both at the end and along the depth of the nitrided layer. The lowest microhardness is for samples placed in the vicinity and in the center of the length of the model (Fig. 2).

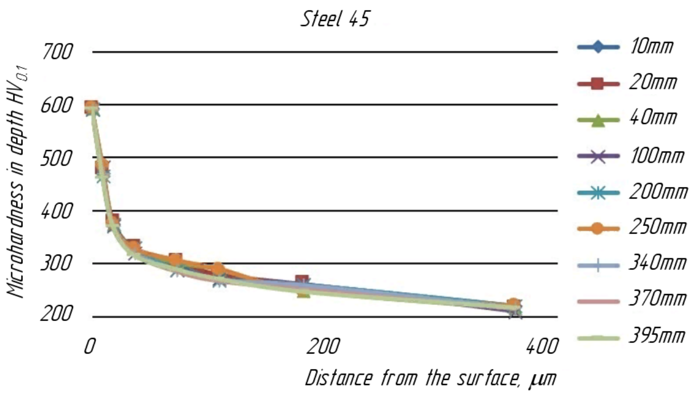

Fig. 1. Distribution of microhardness along the depth of the nitrided layer of steel 45 depending on the distance of the sample from the end of the model in a glow cyclic-commutated discharge (through hole).

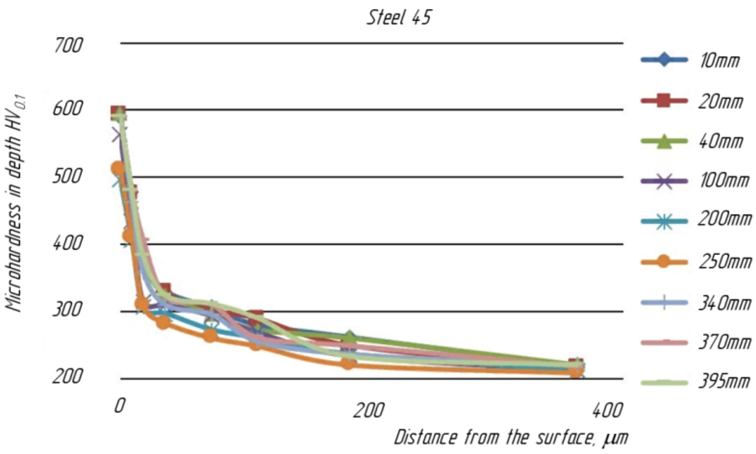

Fig. 2. Distribution of microhardness along the depth of the nitrided layer of steel 45 hardened by direct current depending on the distance of the sample from the end of the model (through hole)

For them, the microhardness decreases by approximately 100 HV0.1. The results of X-ray phase analysis indicate a sharp decrease in the content of the ε - phase in the near-surface layer.

A somewhat different picture is seen in nitriding in the CCR and in nitriding with direct current of blind holes (the upper end of the model is closed with a lid). In nitriding in the CCR, the microhardness of the hardening of the nitrided layer along its depth decreases more smoothly compared to nitriding with direct current (Fig. 3). For samples nitrided with direct current, the microhardness decreases sharply already at a height of their placement of 1.5 internal divmeters of the model and reaches 200…300 HV0.1. In practice, samples placed in holes at a distance of more than 200 mm from the open end of the model (half of its length) are not nitrided (Fig. 4). On the other hand, in nitriding in the CCR, holes located at a distance of more than 300 mm can be considered as such (Fig. 3).

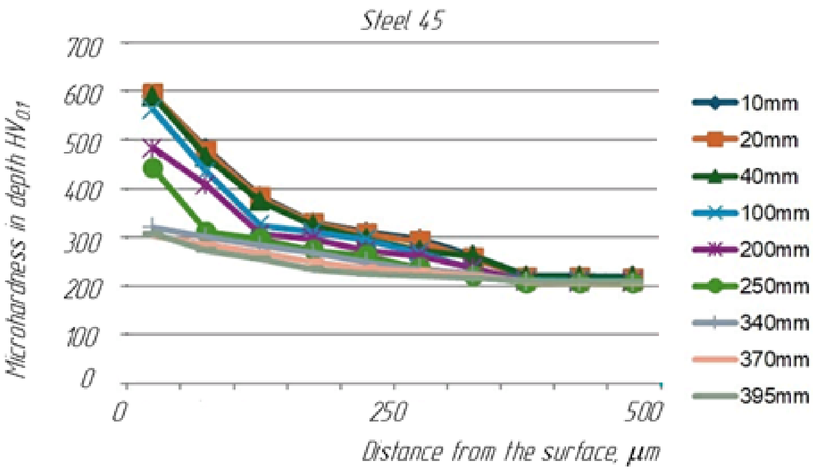

Fig. 3. Distribution of microhardness along the depth of the nitrided layer of steel 45 depending on the distance of the sample from the end of the model in a glow cyclic-commutated discharge (blind hole).

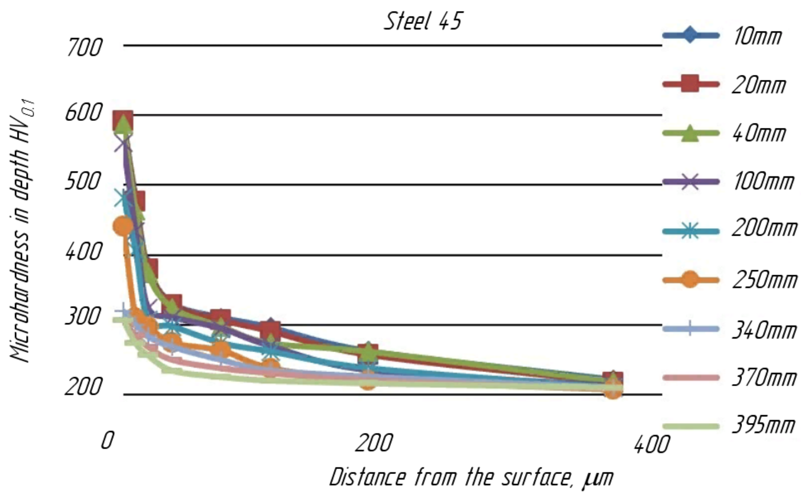

Fig. 4. Distribution of microhardness along the depth of the nitrided layer of 45 steel hardened by direct current depending on the distance of the sample from the end of the model (blind hole)

When friction, especially dry, plays a decisive role in surface microhardness. Physicochemical characteristics of surface layers determine the intensity and durability of parts and friction units under various types of wear: corrosion, corrosion-mechanical, cavitation-erosion, abrasive, etc. As can be seen from Fig. 5, the best results of surface microhardness are obtained for all samples placed along the entire length of the model when nitriding in the DCR for an open hole (mode 1). When nitriding open holes with direct current (mode 2) in the vicinity of the ends of the model at a distance of 1.5 internal diameter of the pipe we have the maximum possible for steel 45 microhardness (600 HV0.1), and then it begins to decrease and reaches a minimum in the center of the model (Fig. 5).

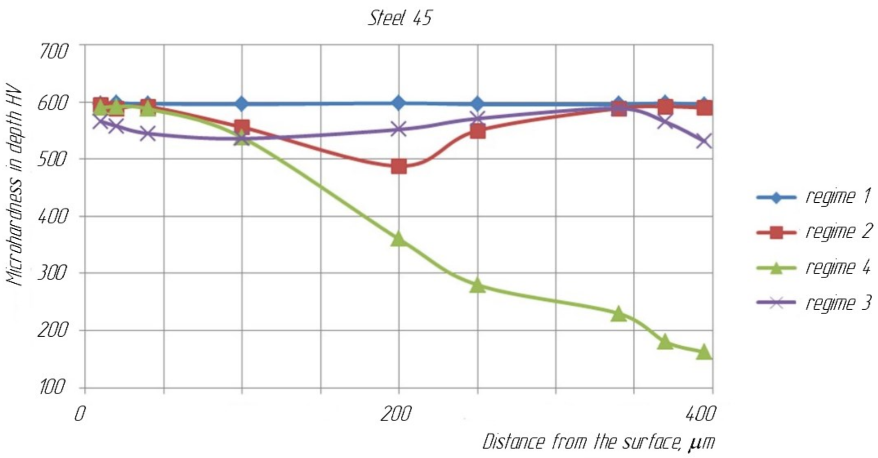

Fig. 5. Graphs of studies of the microhardness of steel 45, nitrided in a glow discharge with constant and cyclic power supply for the inner surface of the holes depending on the height of their placement in the model.

The dependence of the surface microhardness of the samples on the length of the model when they are nitriding in the CCR looks somewhat more complicated. The decrease in microhardness at the beginning of the open end of the model (Fig. 5) requires additional research, and the decrease in its values near the closed end of the model is explained by the reflection of nitrogen ions and atoms from the pipe cover. The same applies to the maximum value of microhardness at a distance of up to 1…1.5 of the inner diameter of the model. Analysis of nitriding of blind holes with a constant current supply of the gas discharge chamber showed an extremely low hardening efficiency (mode 4 in Fig. 5). Nitriding occurs only at a distance of HV0.1 from the open end of the model.

4. CONCLUSIONS

The most effective method of nitriding the internal surfaces of open (through) long holes is their hardening in a hydrogen-free glow cyclic-commutated discharge. For closed (blind) long holes, nitriding in a CCR is also effective compared to hardening with a direct current supply, but requires further research in the direction of studying the influence of frequency, duty cycle and waveform..

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