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

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Methodology and results of the study of physical, mechanical and tribological characteristics of nitrided inner surfaces of long holes

M.S. Stechyshyn, O.V. Dykha*, N.M. Stechyshyna, D.V. Zdorenko

Khmelnytskyi national University, Ukraine
**E-mail: tribosenator@gmail.com*

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Abstract

Created control device physico-chemical and tribological characteristics of nitrided internal surfaces of long holes, which is a hollow pipe with radial holes made at a certain distance from its ends to ensure the ratio of the height of the center of the sample to the internal diameter of the pipe from 0 to 10 or more, which differs in that the height of the samples simulates the depth of the longitudinal holes, and the samples themselves to facilitate their fixation and to ensure the absence of electric spark discharge near the ends, they are installed with a certain tension. At the same time, the length of the cylindrical sample is equal to the thickness of the pipe wall.Thus, each sample is nitrided from two ends, which makes it possible to nitride from the outside and from the middle of the model at almost the same temperature, as well as to compare the results of nitriding of two surfaces (external and internal). At the same time, the difference in conditions is only in the location of these surfaces - external or internal. All other factors that could affect the results of the modification are practically identical. However, nitriding in a glow discharge with a constant current supply does not ensure the treatment of the inner surface uniformly throughout the entire depth, and with significant ratios of length to diameter (more than 4), the inner surface of the hole remote from the ends is practically not nitrided. Therefore, a process technology and a device for quality control of anhydrous nitriding in glow discharge (BATR) of long holes with cyclically switched power supply of the gas discharge chamber have been developed.

Keywords: long holes, cyclically switched discharge, wear resistance, dry friction

Introduction

Practically all kinematic pairs of friction with translational movement structurally fall under 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 [1]. This indicator, accepted as a criterion of geometric ratios, is justified by the fact that the nitriding process of similar structural elements is similar in nature to a discharge with a hollow cathode [2]. From the theory of this process, it is known that the real field penetrates inside the holes to a depth of no more than two diameter sizes (if the holes are not round, then two smaller diameter sizes). The numerical criterion for assigning nitriding objects to the category of holes with a relatively small diameter in the number 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 to two.

Holes of a relatively small diameter in details should be considered through or blind holes, the ratio of the length of which to the diameter is greater than 2 - 4. The justification for these limits (a smaller value is for non-through holes) is that, as established in [1], the depth of the hole is two diameters, the intensity of the electric discharge field is only 0.02% of the intensity at the end of the hole. Taking into account this indicator, through holes whose length to diameter ratio is greater than three can be considered relatively small diameter holes, and for non-through holes - 1.5.

Literature review

Currently, in surface engineering methods, preference is given to the implementation of methods of controlled modification of surfaces based on the action of concentrated energy flows. Vacuum, ion and laser technologies, which are promising from the point of view of forming the structure and properties, have gained the greatest development. These methods of surface modification went through several stages, which led to the creation of a large number of technical solutions determined by both the specifics of the processes and the design features of the equipment used. One of the most developed and widely used in world practice is the method of anhydrous nitriding in a glow discharge. The paper [3] investigates the possibility of creating modified surface layers on austenitic stainless steels using low-pressure glow discharge nitrogen treatment, similar to sputtering, so that surface activation, heating, and nitrogen incorporation can occur in one step with a short duration. In work [4], it was established that with the help of appropriate treatment parameters, glow discharge nitriding can significantly improve the corrosion resistance of austenitic stainless steels, such as AISI 316L and AISI 202, compared to untreated alloys. In work [5], stationary helicon wave plasma with a small diameter (10 mm) was used for nitriding the inner part of a thin austenitic stainless steel tube. The results confirmed that the nitrided layer consists mainly of the austenite phase, iron nitride is not released. Given the successful control of the plasma discharge in a thin tube with a small diameter, this research paves the way for achieving high-performance nitride layers inside thin tubes. In work [6], the process of low-temperature plasma nitriding was proposed as a surface treatment to increase the technical durability of stainless steel tubes and nozzles. Various analyzes were performed to describe only the internal process of nitriding, from the inner surface of the pipes and nozzles to their depth in the thickness. The authors in the study [7] developed technological methods of pulsed ion-plasma nitriding of internal cylindrical surfaces using a hollow perforated anode. This leads to the formation of diffusion coatings consisting of areas of different chemical and phase composition. The purpose of the work [8] was to evaluate the possibility of nitriding deep holes of small diameter. The tests were carried out on cylindrical samples of unalloyed and low-alloyed steel with electro-drilled and mechanically hollow through and blind holes.

Attempts to nitride long holes in a glow discharge with constant power supply only confirm the above theoretical conclusions regarding the spread of the discharge in holes of relatively small diameter. At the same time, the inner surfaces of the holes near the ends are nitrided with acceptable quality, while when the distance from the end of the hole increases, the results of nitriding become less and less noticeable. Some improvement in the effects of the modification can be achieved by increasing the duration of the process. That is, the effect of ordinary furnace nitriding is manifested, but at the same time, the main advantage of nitriding in the glow discharge is eliminated - a significant reduction (by more than an order of magnitude) in the duration of processing [2] .

Thus, the task set in the work has, first of all, practical significance, since there are many options for its real production application. At the same time, one should take into account the fact that such a process has not been sufficiently studied, except for purely technological aspects [9]. A preliminary theoretical justification for the possibility of nitriding the inner surfaces of holes of a relatively small diameter can be the thesis of pumping nitrogen ions into the inner cavity of the hole due to the effect of their movement by inertia at the moment of changing the discharge voltage up to its complete disappearance during a cyclically switched discharge. Since, in the absence of an electric field, the ions will continue to move tangentially to the trajectory that took place at the moment of termination of the discharge, it becomes possible for them to reach the region of the hole cavity, where the field is practically no longer active. This phenomenon is especially characteristic of ions that fly into the hole in the vicinity of its center. At the same time, the trajectory of their movement is significantly straightened, the probability of collision of ions with the walls of the hole decreases, they fly a much longer path than it would be in the case of continuous power [10]. In this way, an excess concentration of nitrogen ions is created, which further 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 nitriding process of the inner surface should theoretically occur at a speed that practically corresponds to the conditions of processing open surfaces [11]. The influence of the physical foundations of the nitriding process on the contact interaction of modified friction surfaces is considered in [12]. The conducted analysis confirmed the determining importance of the structure and composition of the gas discharge environment.

Known works on the use of pulse discharge in nitriding processes in order to improve the mechanical and tribological properties of surface layers. In work [13], with the aim of optimizing the nitriding process, experimental studies of pulsed plasma nitriding of carbon steel DIN C45 (AISI C1043) were carried out using a direct current pulse glow discharge. The influence of gas composition, temperature, processing time and frequency on layer thickness and microhardness was studied. The obtained results are recommended for the optimization of the nitriding process and computer control of the process. In order to increase the tribological and properties of austenitic stainless steels in [14], the authors use plasma nitriding of the surface in pulse mode. It has been found that the wear rate is reduced by up to 90% compared to the base material when processed with a low duty cycle. It is shown that wear resistance and corrosion resistance can be significantly increased by reducing the pulse duty cycle. In work [15], samples of unalloyed steels were nitrided under fixed conditions using an alternating pulse current. It was established that the hardness and wear resistance increase significantly with an increase in the pulsed current. This study comprehensively explains the contribution of pulsed current to nitriding efficiency and plasma reactivity. In the study [16], a pulsed power supply is used for plasma nitriding to overcome the problems of direct current plasma nitriding. Therefore, the use of a pulsed power supply ensured: more accurate control of the nitriding process, post adjustment of the pulse width, avoidance of the phenomenon of arcing on the surface of the workpiece. Therefore, the advantages of using a pulsed discharge as a power source during nitriding are obvious, but its use for processing long holes has not been widely used.

The practical importance of solving the given problem is extremely great, since in mechanical engineering in almost all industries, many parts with holes of relatively small diameter are used, the inner surface of which is working and whose wear resistance is of fundamental importance for increasing the resource of products, their efficiency and the term of normal operation. Examples of such parts can be the inner surfaces of pneumatic and hydraulic cylinders, the inner surfaces of material cylinders of injection molding machines, the inner surfaces of plunger pumps of engine fuel equipment, etc.

Various technologies for modifying the internal surfaces of similar pairs are used: furnace nitriding, cementation, gas chrome plating, etc. But all of them have a number of important disadvantages: the fragility of the surface layers, the long duration of the saturation process during furnace nitriding (96 hours), the change in dimensions and the need for further finishing during cementation.

All the mentioned disadvantages are absent when using the technological process of nitriding in an anhydrous glow discharge. The part before the modification is processed in the finished dimensions, which significantly affects the cost of manufacturing parts. The process is an order of magnitude less long compared to the furnace process, and when using nitriding in anhydrous environments, it becomes possible not only to meet all the requirements of environmental safety, but also to significantly reduce the fragility indicators.

However, nitriding in a glow discharge with a constant current supply does not ensure the treatment of the inner surface uniformly over the entire depth, and with significant ratios of length to diameter, the inner surface of the hole remote from the ends is practically not nitrided. Therefore, the technology of the process of anhydrous nitriding in a glow discharge with cyclically switched power supply of the gas discharge chamber was developed.

Research methodology

To check the nitriding quality of the internal surfaces of long holes (to control the physico-mechanical and tribological characteristics of the nitriding layers), a device was created, which is a hollow cylinder in which 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 to nitride from the outside and from the middle of the model at almost the same temperature, as well as to compare the results of nitriding of two surfaces (external and internal). At the same time, the difference in conditions is only in the location of these surfaces - external or internal. All other factors that could affect the results of the modification are practically identical (Fig. 1).

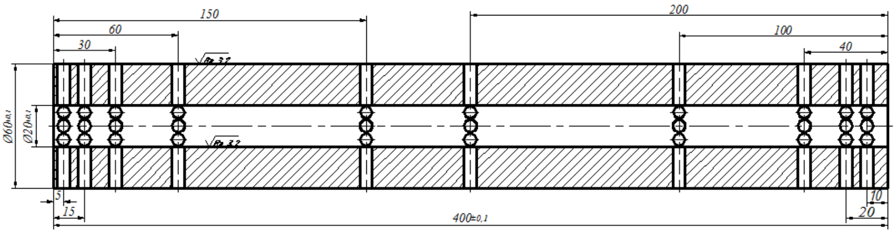


Fig. 1. Hollow cylinder for simulating nitriding of long holes

The presence of a series of radial holes creates the possibility of simultaneous nitriding of samples made of different steels at the same parameters of the technological process, which significantly speeds up experimental research. Full length model400 mm, hole diameter40 mm. Thus, the largest coefficient of the ratio of the length of the hole to its diameter was 10.

Nitridingwas carried out at the unit for anhydrous nitriding UATR-1. A nitrogen-argon mixture was used as a gas medium with a ratio of components by volume of 75% nitrogen and 25% argon. Samples made of steel 38X2MUA were installed in radial holes and held there due to a certain tension (Fig. 2). This achieved not only retention of the samples in the holes, but also the absence of burning near the ends of the samples, especially when fed with a direct current discharge. The appearance of this phenomenon is quite real, as it is observed even with gaps of the order of 0.5 mm. At the same time, the use of a similar method of fixing samples significantly simplifies the design of the model, eliminating from it devices such as screw clamps, collets, etc.

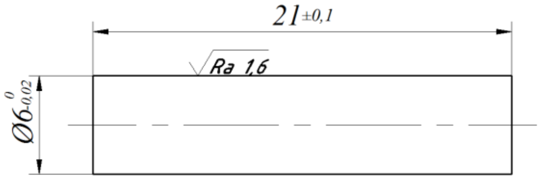


Fig. 2. Sample sketch

The parameters of the technological mode are presented in Table 1. In mode 1, cyclically switched discharge was used, and in mode 2, constant power supply of the gas discharge chamber was used.

Table 1

Technological parameters of nitriding

Mode number	Temperature,°C	Voltage, V	Pressure in the cell, Pa	Duration, hours	Features regime
1	560	730	160	6	The model is open from two sides
2	560	730	160	6	The model is open from two sides

The processing of nitriding results primarily involved measuring the surface microhardness on a PMT-3 microhardness tester. At the same time, 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 25, 50, 75, 100, 150, 200, 250, 300, 600, 1000 μm.

X-ray phase analysis of nitrided samples was performed on a DRON-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.

Experimental studies of samples for wear resistance were carried out on a universal machine for testing materials for friction, model 2168UMT. The material of the counterbody is steel SHX15 with a base hardness of HRC61; pressure in the contact zone P = 16 MPa; sliding speed v = 0.1 m/s; 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. The tests were carried out in the modes of extreme [8] and dry [9] friction, which is typical for many parts of mechanical engineering and agricultural machinery.

Research results

Table 2 shows the distribution of the surface microhardness of the internal end surfaces of samples made of 38X2MUA steel depending on the distance of their location from the ends of the model (pipes).

Table 1

Distribution of surface microhardness along the depth of the model

Mode No	Material	The microhardness of the surface is HV0.1 at the depth of the model								
		10 mm	20 mm	40 mm	100 mm	200 mm	250 mm	340 mm	370 mm	395 mm
1	38X2MUA	1098	1096	1097	1098	1097	1096	1098	1097	1098
2	38X2MUA	1100	1096	1090	1019	960	996	1050	1092	1090

For greater visibility, the data in the table. 2 are illustrated in fig. 3.

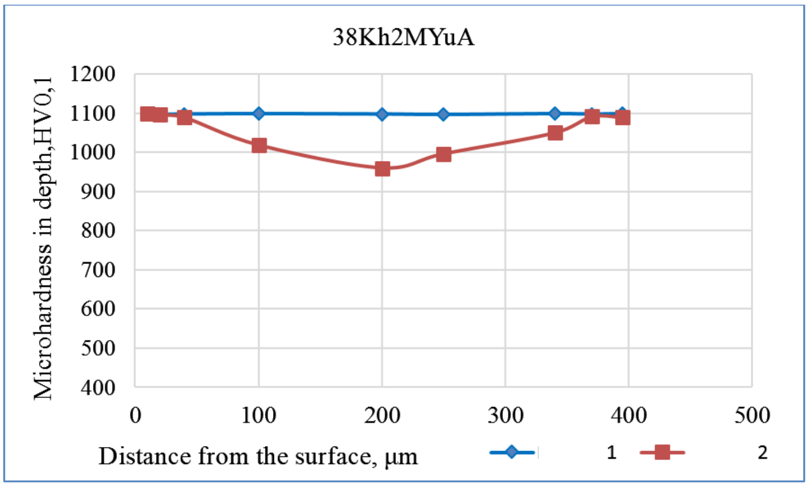
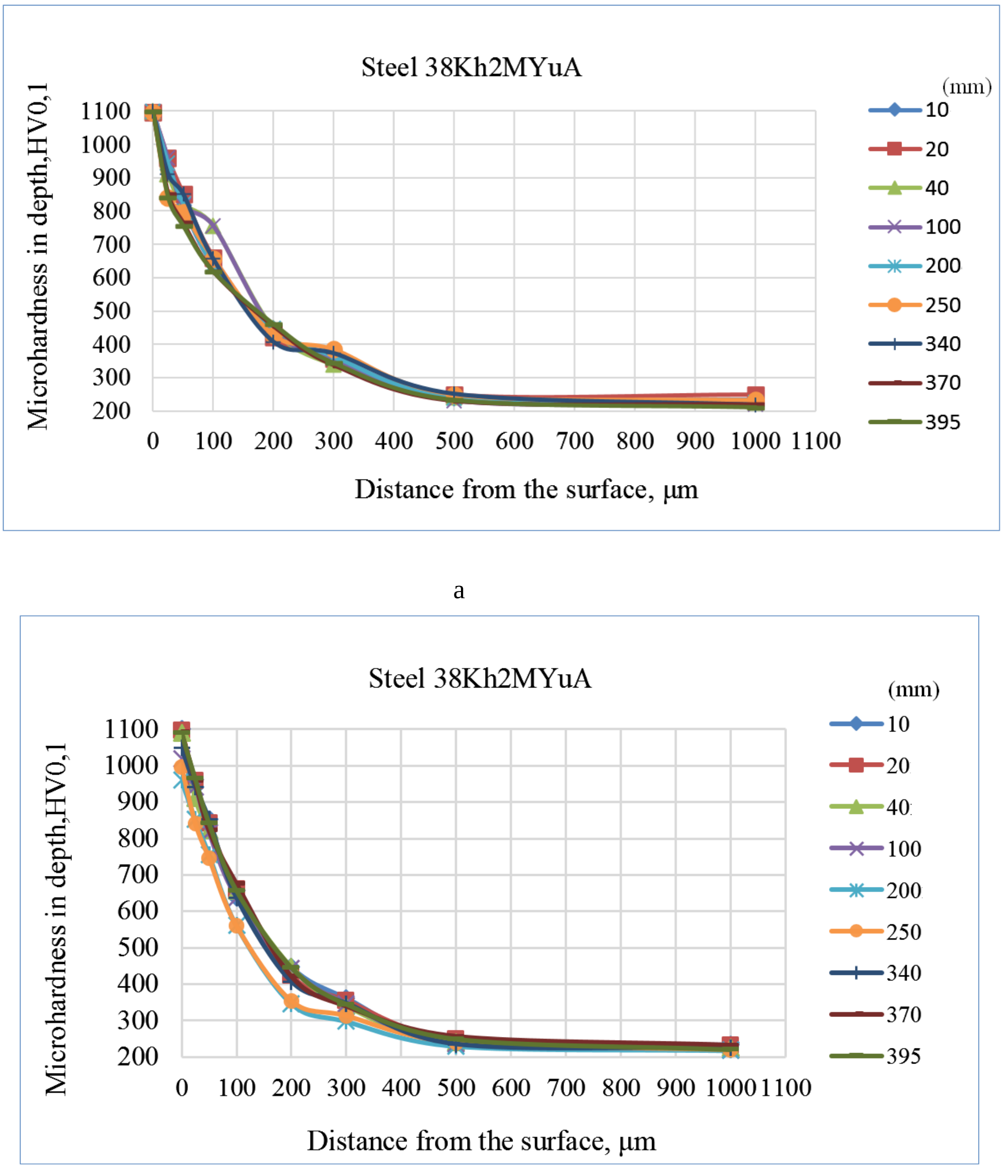


Fig. 3. Dependencies of surface microhardnesssteel 38X2MUA, nitrided in a glow discharge with cyclically switched and constant power supply for the inner surface of the sample

As can be seen from fig. 3, surface microhardness during nitriding in TSR (mode 1).along the height of the pipe, the modified layer of 38X2MUA steel, respectively, from the side of the inner ends remains constant, and during nitriding with direct current, it decreases and reaches a minimum for samples placed in the center of the pipe (mode 2).

A similar conclusion can be drawn from the analysis of the distribution of microhardness along the depth of the nitrided layer strengthened by nitriding in the glow discharge depending on the power supply mode of the gas discharge chamber (Fig. 4, a, b). During nitriding in a cyclically switched discharge, the distribution of microhardness over the thickness of the hardened layer is more uniform and practically the same for all samples along the entire length of the model. In addition, the value of microhardness in the thickness of the nitriding layer is higher during nitriding in a cyclically switched discharge than during constant power supply. Thus, for the sample placed in the center of the model (l = 200mm), the microhardness at the depth of the nitrided layer of 25, 50, and 100 μm was 852, 756, and 561 Pa, respectively, with constant feeding and 942, 822, and 638 Pa with nitriding in a cyclically switched discharge .



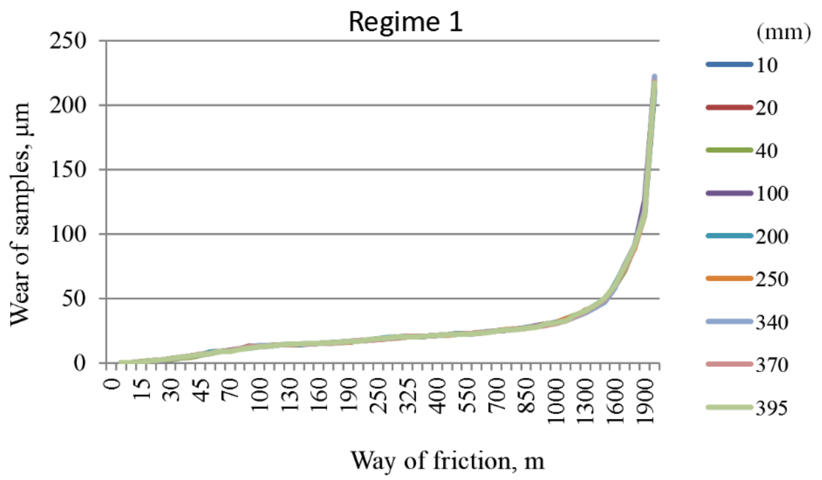
a

b

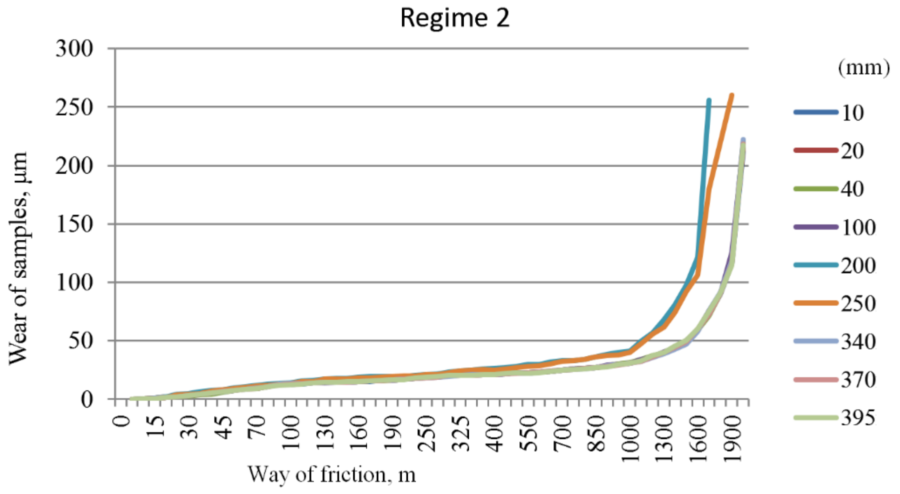
Fig. 4. Distribution of microhardnessfor nitrided steel 38X2MЮA: a – cyclically switched power supply; b - constant power supply

The study of the microhardness of the nitrided layers, its distribution along the depth of the nitrided layer (Figs. 3, 4) indicates the formation of highly nitrogenous phases during nitriding in the TSK. The obtained radiographs confirm this conclusion.

The results of tribological tests showed (Fig. 5) that nitriding in the TSR is a fairly effective way of strengthening the inner surfaces of long holes. Comparison of the wear resistance of 38X2MUA steel samples nitrided according to mode 1 and mode 2, depending on the height of their placement in the pipe, shows its significant increase (by 1.3...1.6 times) during nitriding in the TSR.



a



b

Fig. 5. Wear resistance of nitrided steel samples 38X2MIOA during dry friction depending on the friction path and their location from the ends of the pipe: a – TSR, b – direct current

Therefore, the use of the developed device makes it quite easy to assess the physico-mechanical and tribological properties of the internal surfaces of long holes depending on the distance of their placement from the end of the model hole.

Conclusion

Thus createda device for controlling the quality of nitriding of the inner surfaces of long holes, which is a hollow pipe with radial holes made at a certain distance from its ends to ensure the ratio of the height of the placement of the center of the sample to the internal diameter of the pipe from 0 to 10 or more, which is distinguished by the fact that the height of placement samples simulates the depth of long holes, and the samples themselves are installed with a certain tension to facilitate their fixation and ensure the absence of electric spark discharge near the ends. At the same time, the length of the cylindrical sample is equal to the thickness of the pipe wall.

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Стечишин М.С., Диха О.В., Стечишина Н. М., Здоренко Д.В. Методика і результати дослідження фізико-механічних та трибологічних характеристик азотованих внутрішніх поверхонь довгомірних отворів

Створено пристрій для контролю фізико-хімічних та трибологічних характеристик азотованих внутрішніх поверхонь довгомірних отворів, який являє собою пустотілу трубу з радіальними отворами виконаними на певній віддалі від її торців для забезпечення відношення висоти розміщення центру зразка до внутрішнього діаметра труби від 0 до 10 і більше, який відрізняється тим, що висота розміщення зразків моделює глибину довгомірних отворів, а самі зразки для полегшення їх фіксації та забезпечення відсутності електроіскрового розряду біля торців встановлюються з певним натягом. При цьому довжина циліндричного зразка дорівнює товщині стінки труби. Таким чином, кожний зразок азотується з двох торців, що дає можливість азотувати із зовні та з середини моделі при практично однаковій температурі, а також порівнювати результати азотування двох поверхонь (зовнішньої та внутрішньої). При цьому різниця в умовах полягає тільки в розташуванні цих поверхонь – зовнішнє чи внутрішнє. Всі інші фактори, які могли б впливати на результати модифікації практично ідентичні. Проте азотування в тліючому розряді при постійному струмові живлення не забезпечує обробку внутрішньої поверхні рівномірно по всій глибині, а при значних відношеннях довжини до діаметра (більше 4) внутрішня поверхня отвору віддалена від торців практично не азотується. Тому розроблена технологія процесу і пристрій для контролю якості безводневого азотування в тліючому розряді (БАТР) довгомірних отворів з циклічно-комутованим живленням газорозрядної камери.

Ключові слова: довгомірні отвори, циклічно-комутований розряд, зносостійкість, сухе тертя