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Research of the vacuum thermocyclic nitrogen process in a plasma pulsing glow discharge

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Abstract

As a result of the studies, the regularities of the influence of vacuum thermocyclic nitriding in a pulsating glow discharge plasma parameters on the microhardness, the diffusion saturation depth, the magnitude and distribution of residual stresses in the hardened layers of steel surfaces are established. Based on the use of expert assessment methods and the results of a series of screening experiments, optimization criteria (endurance limit and corrosion resistance) and controlled factors for mathematical modeling of the formation of strengthened ion-nitrated surface layers are determined. A mathematical model of the technology of the formation of reinforced surfaces of the vacuum thermocyclic nitriding in a pulsating glow discharge plasma according to the criteria of endurance and corrosion resistance is obtained. An analysis of the studies showed that there are no general conclusions and recommendations on the selection of optimal technological parameters of the vacuum thermocyclic nitriding in a pulsating glow discharge plasma that would be used for the practical application of this technology. These circumstances confirm the need for further study of the vacuum thermocyclic nitriding in a plasma of a pulsating glow discharge of vacuum thermocyclic nitriding in a pulsating glow discharge plasma technology and the feasibility of its optimization.

Key words: vacuum thermocyclic nitriding, mathematical model, technological process, plasma, pulsating glow discharge

Relevance of the research topic

Analysis of literary sources and recent research, as well as patent information search showed that the wide use of vacuum thermocyclic nitriding technology in pulsating glow discharge plasma is limited by the lack of research on the interrelationship of factors that determine the course of the process of vacuum thermocyclic nitriding in pulsating glow discharge plasma and generalizing conclusions and recommendations for choosing technological parameters of this technology. These circumstances confirm the relevance and necessity of studying the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge.

Formulation of the problem

Most of the reasons for the destruction of structural elements of parts of machines and mechanisms are related to their cyclic strength, namely thermomechanical fatigue, which is expressed in the gradual accumulation of damage in the material under conditions of simultaneous exposure to variable loads, aggressive environment and temperature. This leads to the appearance of a fatigue crack, its development and the final destruction of the material. One of the important and promising directions in solving problems related to increasing the resistance to thermomechanical fatigue of structural elements is the use of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge. In order to effectively analyze the mechanism of phenomena and control the technological process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge, it is necessary to identify the interrelationship of the factors that determine the course of the process.

Analysis of recent research and publications

Based on the theory of thermocyclic fatigue and the phenomenon of anomalous mass transfer during impulse impact at the Institut problem micnosti imeni G.S. Pisarenka of the National Academy of Sciences of Ukraine developed the technology of accelerated nitriding in a glow discharge with a cyclic temperature change due to the periodic supply of discharge voltage. The technology of ion-plasma thermocyclic nitriding is protected by patents of Ukraine and has no analogues in domestic and international practice [1-4].

With the help of the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge, it is possible to process various parts. For example, crankshafts, sleeves of internal combustion engines, gears of various modules, screws of extruders, shafts, stamps, molds, long parts with holes, etc. Ion nitriding is used for processing cast iron and various steels and alloys: structural and tool, martensitic aging, corrosion-resistant, chromium and chromium-nickel steels of the ferritic and austenitic class, etc. A promising new technology for strengthening titanium, refractory metals - niobium, molybdenum.

The new technology is synthesized on the basis of three theories, phenomena and effects: theory of thermal fatigue; discrete-pulse input of energy in heat technologies; of the effect of anomalous mass transfer under the action of impulse deformations. The effect of anomalous mass transfer is provided by thermal stresses arising due to cyclical changes in process temperature. The theory of thermal fatigue determines the conditions for obtaining values of thermal stresses sufficient to accelerate the diffusion of nitrogen into the metal, but safe so as not to damage the product. The discrete-pulse input of energy provides an increase in the heating rate by 2...5 times, which allows to increase the thermal stress and, accordingly, the rate of nitrogen diffusion [1-4].

The technology of accelerated nitriding in a glow discharge with a cyclical change in temperature due to the periodic supply of discharge voltage is based on the "three whales" - an effective solution to a complex of interrelated scientific and methodological problems on the border of thermomechanics, metallophysics and thermophysics [1-4]. The technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge should be considered as an alternative to classical cementation followed by quenching. It should be emphasized that the American standard ASTM A 706 limits and prohibits quenching and finishing machining due to technical difficulties and increased cost. The new technology does not require finishing mechanical processing [1, 2, 4].

The main feature of the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge is the use of the effect of anomalous mass transfer of nitrogen in the surface of the processed part by creating a field of thermal stresses in the surface layer due to the cyclic inclusion and exclusion of the glow discharge. Taking into account the acceleration of mass transfer during thermal cycling due to the occurrence of thermal stresses, it was decided to develop a chemical-thermal treatment technology based on the classical ion nitriding technology, which works in isothermal mode all over the world. The technology of ionic nitriding is attractive for improvement because the global trend is to reduce the duration of chemical-thermal treatment, which is one of the most energy-intensive in mechanical engineering. Previous attempts to create a technology of thermocyclic ion nitriding gave positive results. [1-4]:

The technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge does not use furnace devices. Compared to furnace nitriding, ion nitriding has the following advantages [1-4]: it accelerates diffusion processes by 0.5-2 times; allows obtaining a diffusion layer of adjustable composition and structure; characterized by slight deformations of products and a high class of surface cleanliness; makes it possible to nitride corrosion-resistant, heat-resistant and martensitic-aging steels without additional processing; significantly reduces the total time of the process by reducing the time of heating and cooling the cage; has high efficiency, increases the coefficient of electricity use, reduces the consumption of saturating gases; non-toxic and meets the requirements for environmental protection.

Ammonia is used in the world practice of nitriding. The ecological advantage of the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge consists in the rejection of the use of ammonia. Processing is carried out by a glow discharge in a mixture of argon and nitrogen. This also eliminates the negative effect of hydrogen on the core of the part - hydrogen embrittlement and hydrogen corrosion. The replacement of classical gas nitriding in an ammonia environment with the technology of vacuum thermocyclic nitriding in plasma of a pulsating glow discharge in a mixture of nitrogen and argon provides a 10-fold reduction in the duration of processing [1-4]. Unlike chemical-thermal treatment, the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge does not create continuous heating of the part, but provides heating of only the surface layer to the depth necessary for its strengthening. Heating occurs due to the energy of the glow discharge, so there is no need to use furnaces [1-4].

The difference between the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge and the classic technologies of chemical-thermal treatment, which use isothermal mode: the process of chemical-thermal treatment is accelerated by 2...6 times; due to the absence of furnace devices and thorough heating of the part, as well as due to pauses in the power supply during the half-cycle of part cooling, the cyclic nature of the high-speed discrete energy input, the acceleration of diffusion processes, the processing time is reduced by 2-3 times, electricity costs are reduced, and the energy consumption of the technology is reduced by 10 times [1-4].

Thus, the cyclic nature of the heating of the product makes it possible to reduce the required power of electrical power sources by 2-5 times, which refers the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge to the energy-saving category. The technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge increases the hardness of the surface by 20%, does not change the shape and dimensions of the part, as well as the roughness of the surface. Therefore, it is used as a finish, without final mechanical processing. This greatly simplifies the technological process of production while increasing the durability and wear resistance of the part by 4 times, the limits of multi-cycle fatigue by 25% [1-4].

One of the important and promising directions in solving problems related to increasing the resistance to thermomechanical fatigue of structural elements is the use of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge. However, the wide use of the technology of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge is limited by the lack of determination of the relationship of the factors that determine the course of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge and the lack of recommendations for the selection of technological parameters of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge. These circumstances confirm the need for further study of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge.

The purpose of the article is to provide an analysis of the phenomena in the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge and to determine the interrelationship of the factors that determine the course of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge.

Presenting main material

The process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge is implemented in two stages: cleaning the surface of the ped by nitriding and nitriding itself. The technological process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge is reduced to the following operations [1-4]:

- degreasing of parts;
- installation of parts on the device, which at the same time should serve for local protection against nitriding (cover the protective surface with a metal and dielectric screen). The gap between the part and the screen is allowed no more than 0.3-0.5 mm;
- installation of parts, thermocouples and a witness to monitor nitriding results in the furnace chamber;
- cleaning the surface of the part by cathodic spraying for 15…40 minutes under a voltage of 800…1000 V at a pressure of about 133 Pa. Cathodic sputtering of the treated surface ensures heating of parts up to 300…400°C;
- reaching the specified nitriding temperature and exposure to obtain the desired thickness of the nitriding layer (tables 1, 2). The pressure during nitrogen saturation is maintained in the range of 400…650 Pa, and the operating voltage is 350…550 V;
- cooling of parts in the furnace chamber to 150…200°C at a pressure of 13.0…65 Pa. lasts 1.0…2.0 hours.

Table 1

The main parameters of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge of parts made of different steels

Steel brand	Temperature, °C,	Gas mode	Duration in hours to obtain a layer thickness, mm					Hardness on the surface, HV
			0,15-0,2	0,2-0,25	0,25-0,3	0,3-0,35	0,35-0,4	
40Kh	520	1,2	4-5	7-9	9-12	12-15	15-18	500-550
40KhFA	520	1	4-5	6-8	9-12	15-18	-	-
	520	2	4-5	6-8	8-10	12-15	15-18	510-560
18KhGT	530	1,2	4-5	6-8	9-12	15-18	-	620-680
	550	1,2	3-4	4-5	6-8	9-12	15-18	530-600
30Kh3MF	530	1	4-5	6-8	9-12	15-18	-	700-760
	530	2	4-5	5-7	6-8	9-12	15-18	-
38Kh2MYuA	550	1,2	4-5	5-7	7-9	9-12	15-18	900-950

Samples made of 40Kh13 steel with a size of 30x30 mm and a thickness of 10 mm were used in the experimental studies. The gas mode of nitriding (Table 2) provides uniform hardening of the surfaces of the samples (uniform thickness of the diffusion layer). Technological parameters of the formation of reinforced layers: temperature of thermocycling - 550 ± 30˚C; pressure – 25 … 150 Pa; processing time - 10 hours; the ratio of reaction gases is 80% Ar + 20% N_2.. With the help of the proposed technology, it is possible to process various parts. For example, crankshafts, sleeves of internal combustion engines, gears of various modules, screws of extruders, shafts, stamps, molds, long parts with holes, etc. Ion nitriding is used for processing cast iron and various steels and alloys: structural and tool, martensitic aging, corrosion-resistant, chromium and chromium-nickel steels of the ferritic and austenitic class, etc. A promising new technology for strengthening titanium, refractory metals - niobium, molybdenum.

Analysis of literary sources and recent research, as well as patent information search [1-4] shows that the wide use of vacuum thermocyclic nitriding technology in the plasma of a pulsating glow discharge is limited by the lack of research on the relationship of factors that determine the course of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge discharge and generalizing conclusions and recommendations on the selection of technological parameters of this technology. These circumstances confirm the relevance and necessity of studying the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge.

A significant number of technological parameters of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge in combination with a wide range of materials from which the strengthened surface layer is formed give technologists a wide range of alternative options. In such a situation, the effectiveness of the decisions taken will depend on the availability of the necessary criteria for assessing the performance of the structural material under the specified operating conditions. For the successful development of a technological process, the strengthened surface layer must have a physical meaning and sufficiently characterize the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge [1-5].

Table 2

The main technological parameters of the nitriding process of parts made of various steels

Mode No processing	Diffusion saturation time, min.	Reaction gas pressure, Pa	The composition of the reaction gas	Gas temperature, °K	Operating temperature, °K	Surface microhardness layer, MPa	Diffusion thickness layer, μm
1	180	125	90%N_2 + 5%C_3H_8 + 5%Ar	773	788	3700	288
2	150	200	95%N_2+ 5%C_3H_8	873	725,5	10062	125
3	210	75	80%N_2 + 5%C_3H_8 + 15%Ar	673	850,5	9955	286
4	150	175	80%N_2 + 5%C_3H_8 + 15%Ar	873	819,2	8175	215
5	210	50	90%N, + 5%C,H_8 + 5%Ar	773	694,3	10590	142
6	180	100	90%N_2 + 5%C_3H_8 + 5%Ar	673	881,8	8270	253
7	240	225	95%N_2- 5%C_3H_8	773	756,8	8985	208
8	90	250	80%N_2 + 5%C_3H_8 + 15%Ar	673	709,9	9100	267
9	180	125	95%N_2+ 5%C,H_8	873	834,9	8945	181
10	150	50	80%N_2 + 5%C_3H_8 + 15% Ar	773	772,4	10235	179
11	210	175	90%N_2 + 5%C_3H_8 + 5% Ar	673	897,3	8144	312
12	150	100	95%N_2+ 5%C_3H_8	873	803,6	8335	228
13	210	225	80%N_2 + 5%C_3H_8 + 15% Ar	673	678,6	10835	267
14	180	150	95%N_2+ 5%C_3H_8	773	866	8841	215
15	240	25	90%N_2 + 5%C_3H_8 + 5% Ar	873	741	9150	191
16	90	150	90% N_2 + 5%C_3H_8 + 5% Ar	673	780	8659	212

When strengthening the surfaces of structural elements, the term structural or structural strength of metals is widely used [6-8]. The concept of structural strength includes a number of parameters or indicators that characterize not only the strength of structural elements, but also their durability (resource), bearing capacity, and most importantly, reliability. The indicators of structural strength of elements include strength under various types of load at low and high temperatures, under the influence of the surrounding environment (corrosive-erosive, etc.) [6-8]. By using the technological process of the reinforced surface layer, which affects the quality of the surface layer, it is possible to control the values of the parameters of the structural strength of the materials. Evaluating the operating conditions of the most heavily loaded structural elements, the simultaneous influence of dynamic loads, elevated temperatures, and a corrosive environment was established. Among dynamic loads, cyclic loads are of particular interest. With systematic repetition of loading and unloading, defects in the material structure accumulate, which leads to the appearance of microscopic cracks, the combination of which causes fatigue failure. It is possible to establish the maximum cyclic load at which the material does not collapse with the help of thermomechanical high-frequency fatigue tests, namely, if it is necessary to determine the value of the endurance limit of the strengthened structural material. Corrosion damage significantly reduces the mechanical properties of the structural material. Thus, it is advisable to study the endurance limit and corrosion resistance, which is characterized by a specific increase in mass, as a surface with a strengthened surface layer.

To study the hardening process, the parameters that most affect the endurance limit and corrosion resistance of hardened surface layers were determined: time of diffusion saturation, pressure and composition of the reaction gas, temperature of the diffusion saturation process, and operating temperature (Table 3). It should be noted that the values of such parameters as the pressure and temperature of the reaction gas given in the table during the process of the strengthened surface layer are not constant: the pressure of the reaction gas changes periodically (with a period of 15...30 min.), and the temperature fluctuates in within 25...35°C.

Table 3

Nitriding process parameters affecting the quality of parts surfaces

№	Parameters	Value
1	Diffusion saturation time, min.	90...240 (крок 30)
2	Reaction gas pressure, Pa	25...250 (крок 25)
3	Gas temperature, °K	673...873 (крок 100)
4	The composition of the reaction gas	1) 90%N_2 + 5%C_3H_8 + 5% Ar; 2) 95%N_2+ 5%C_3H_8; 3) 80%N_2 + 5%C_3H_8 + 15% Ar
5	Operating temperature, °K	663...913

Studies of the microhardness of the surface layers after the strengthened surface layer revealed an increase in its values to 11250 MPa (Table 4.) and a gradual decrease to 4200 MPa at a depth of up to 310 microns.

Table 4

Microhardness of the surface layers of the sample after nitriding

Mode No processing	Microhardness of the surface layer, MPa	
	without pulsating glow discharge	with a pulsating glow discharge
0	3100	3700
1	9032	10062
2	8164	9955
3	7414	8175
4	8614	10590
5	8047	8270
6	8089	8985
7	8154	9100
8	7534	8945
9	9111	10235
10	9904	8144
11	7040	8335
12	9898	10835
13	7950	8841
14	8061	9150
15	7769	8659
16	7179	8663

Processing modes are presented in Tables 2 and 3. From the analysis of the results given in Table 4, it is clear that nitriding in a pulsating glow discharge contributes to an increase in the microhardness and depth of hardening of the treated surface layers. In any case, such values of the microhardness of the samples are 2.5...3.0 times higher than those without the influence of a pulsating glow discharge and 1.5 times higher than those of the samples after gas nitriding (90%N2+10%Ar; T=600°C; 1=4.0 h).

The analysis of the data in Table 4 allows us to conclude that there are some ranges of nitriding temperature and reaction gas pressure, at which the microhardness of the surface layers reaches its maximum values: for nitriding temperature, this range is within 550...600 °C, for gas pressure - in between 200...230 Pa. As the time of diffusion saturation increases, the microhardness of the surface layer decreases, and more intensively - after 2 hours of treatment. With regard to the effect on the microhardness of the composition of the reaction gas, it was established that it acquires maximum values when using a mixture of 90%N_2+ 5%C_3H_8 + 5%Ar, and minimum values - when using a mixture of 80%N_2 + 5%C_3H_8 + 15%Ar.

As a result of conducting research on the anti-corrosion ability of ion-nitrogenized steel samples, an increase in corrosion resistance by 1.7...3.1 times was found (Table 5). This is of particular interest when the benefits of nitriding are also aimed at increasing fatigue strength. Processing modes of the reinforced surface layer for the data of Table 5 are presented in Table 2.

To determine the fatigue resistance, at least 10-15 samples strengthened by vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge were studied. Each sample was brought to failure, while the amplitude of oscillation of the sample and the frequency of loading were kept constant during the entire time of the study almost until its failure. Fatigue test base N=107 load cycles. During the fatigue test at elevated temperatures, the sample was heated to the specified temperature before loading and kept in the heating chamber for an additional 30 min. The moment of the beginning of the destruction of the sample was determined by the drop in the resonance frequency of its oscillations by 10...15 Hz. The quantitative characteristics of fatigue are influenced by the temperature of the surrounding environment. As the test temperature increases, starting from 500 °C, the endurance limit decreases.

Table 5

Results of corrosion resistance research of nitrided samples

Mode No processing	Specific mass increase of sample A, after 10 hours of testing	
	without pulsating glow discharge	with a pulsating glow discharge
0	0,58	0,40
1	0,17	0,12
2	0,22	0,18
3	0,19	0,17
4	0,17	0,15
5	0,20	0,18
6	0,20	0,19
7	0,21	0,18
8	0,19	0,16
9	0,16	0,14
10	0,18	0,18
11	0,21	0,20
12	0,16	0,14
13	0,19	0,16
14	0,18	0,15
15	0,20	0,20
16	0,21	0,18

Diffusion processes on the surface of the sample are activated under the non-additive influence of temperature and the external environment, which leads to the appearance of microscopic surface cracks, which are the beginning of fatigue failure. Fatigue resistance is influenced by both the number of load cycles and the time the sample is exposed to high temperatures under conditions of cyclic loading. Vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge limits the speed of diffusion processes, which has a significant effect on increasing the endurance limit. Thanks to the technological process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge, it was possible to increase the endurance limit of samples by 15...20% with an increase in the number of cycles to destruction in the languages of simultaneous action of cyclic loads and temperature.

On the basis of the conducted experimental studies, it was established that the main mechanisms of increasing the endurance limit of materials due to the application of the technological process of diffusion saturation of the surface with nitrogen in a pulsating glow discharge in the thermocyclic mode are: strengthening of surface layers; creation of a favorable scheme of residual stresses; change in patterns of deformation of surface layers; change in chemical and adhesive properties of the surface. The relatively small depth of penetration of nitrogen ions cannot be considered as a factor limiting the possibilities of this type of treatment to increase the endurance limit, because the implementation of treatment modes is related to the modification of submicron-thick surface layers. In addition, it was experimentally established that layers whose thickness is several times greater than the ion-nitrogenized region can have an increased endurance limit.

The strengthening of the surface layers occurs according to the following mechanisms, the contribution of which depends on various factors (temperature and grade of the material being processed, parameters of the technological process, etc.): the formation of structures with strengthening phases (nitrides, carbonitrides, etc.), which cause dispersion hardening; deformation hardening during plastic change of the shape of the ion-nitrogen layer; strengthening due to the formation of solid solutions, which create an energy barrier and make it difficult to move dislocations; decrease in grain size, which leads to an increase in the area of grain boundaries and hinders the movement of dislocations.

As you know, the greatest danger from the point of view of ensuring a high level of the endurance limit of materials is represented by residual tensile stresses. They contribute to the development of near-surface cracks, the penetration of molecules of the external environment into the origins of microcracks and accelerate the diffusion of impurity atoms. In the conditions of multi-cycle fatigue, the residual compressive stresses that occur during the diffusion of nitrogen into the surface layers acquire great importance. In the case of diffuse saturation of the surface with nitrogen in a glow discharge, a nitrogen atom embedded in the matrix pushes neighboring atoms apart, creating residual compressive stresses. These stresses effectively protect the surface from destruction.

Ionic nitriding treatment significantly affects the chemical and adhesive properties of the surface of hardened materials. The formation of chemical compounds in steels and alloys due to the introduction of nitrogen or an increase in its concentration limit changes the speed of chemical reactions and the kinetics of the growth of oxide films, increases their adhesion to the base. This leads to a decrease in the intensity of the formation of adhesion knots and contributes to the improvement of the mechanical properties of materials.

Conclusions

The analysis of literary sources and recent studies showed that the wide use of the technology of vacuum thermocyclic nitriding in plasma of a pulsating glow discharge is limited by the lack of research on the relationship of factors that determine the course of the process of vacuum thermocyclic nitriding in a plasma of a pulsating glow discharge and general conclusions and recommendations for the selection of technological parameters of this technologies.

Based on studies of the influence of the stress state and mechanical properties on the strength characteristics, a mechanism for increasing the endurance limit of ion-nitrogenized surface layers has been established. On the basis of the analysis of the stress-strain state, it is possible to predict the characteristics of cyclic strength, which allows controlling the regimes of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge within wide limits.

As a result of the conducted research, the regularities of the influence of the parameters of the technological process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge on microhardness, the depth of diffusion saturation, the magnitude and distribution of residual stresses in the strengthened layers of steel surfaces have been established. It is shown that:

- to obtain the maximum microhardness of the surface layer, which reaches 7600 MPa, the reaction gas pressure must be within 200...250 Pa, the diffusion saturation time - 90...150 min.; process temperature -- 500...600°C;
- to obtain the maximum thickness of the diffusion layer of 150...305 μm, the pressure of the reaction gas must be within 200...250 Pa, the diffusion saturation time - 180...240 min.; process temperature - 550.. .600°C;
- residual compressive stresses of the order of 445...950 MPa occur in the ion-nitrogenized layers, the level and distribution of which depend on the technological parameters of the process of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge and on the preliminary heat treatment.

As a result of conducting research on the properties of the surface layers of samples strengthened by nitriding, it was established that, thanks to the use of vacuum thermocyclic nitriding in the plasma of a pulsating glow discharge, the corrosion resistance increases by 3.1 times, and the endurance limit of steel structures at temperatures up to 640°C increases by 15...20%.

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Рутковський А.В., Радько О.В., Солових Є.К., Катеринич С.Є., Солових А.Є. Дослідження процесу вакуумного термоциклічного азотування у плазмі пульсуючоготліючого розряду.

Одним із важливих та перспективних напрямків у вирішенні задач щодо підвищення опору термомеханічній втомі елементів конструкцій є використання вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду. Широке використання технології вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду обмежено відсутністю визначення взаємозв'язку факторів, що визначають хід процесу вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду та відсутністю рекомендацій по вибору оптимальних технологічних параметрів процесу, Ці обставини підтверджують необхідність подальшого вивчення процесу вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду.

У результаті проведених досліджень встановлено закономірності впливу параметрів вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду на мікротвердість, глибину дифузійного насичення, величину та розподіл залишкових напружень у зміцнених шарах сталевих поверхонь. На підставі використання результатів експериментів визначено межу витривалості і корозійну стійкість зміцнених іонно азотованих поверхневих шарів. У результаті проведення досліджень властивостей поверхневих шарів зразків, зміцнених азотуванням, встановлено: що завдяки використанню вакуумного термоциклічного азотування у плазмі пульсуючого тліючого розряду, товщина дифузійного шару складає 40…300 мкм; мікротвердість поверхневого шару досягає 7600 МПа; виникають залишкові напруження стиску порядку 445…950 МПа, корозійна стійкість підвищується у 3,1 рази, а. межа витривалості сталевих конструкцій при температурах до 640 °С підвищується на 15...20%.

Ключові слова: вакуумне термоциклічне азотування, математична модель, технологічний процес, плазма, пульсуючий тліючий розряд