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Features of ion nitriding technology multicriteria optimization

E.K. Solovykh, I.V. Shepelenko*, A.E. Solovuch, S.E. Katerynych

Central Ukrainian National Technical University, Kropyvnytsky, Ukraine
**E-mail: kntucpfzk@gmail.com*

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Abstract

In this work, the technology of 30HGSA steel ion nitriding was optimized in terms of tribotechnical characteristics – wear intensity and friction coefficient. When choosing controlled factors, the influence of all existing groups of factors that can affect the process of ion nitriding is taken into account: structural, technological and operational. Friction and wear tests were carried out under conditions that are as close as possible to the actual operating conditions of aircraft parts made of 30HGSA steel. As a result of experiments on friction and wear, tribotechnical characteristics of coatings were obtained depending on structural, technological and operational factors, respectively, to the matrix. The conducted studies showed the presence of three clearly defined zones in the dependences of wear intensity and friction coefficient on specific load at different sliding speeds and technological parameters of ion nitriding: run-in zones, uniform and catastrophic wear. The nature of samples dependences hardened by ion nitriding and heat-treated samples is similar and coincides with modern views on the laws of friction and wear processes. Analysis of tribotechnical characteristics showed the effectiveness of ion nitriding technology in comparison with traditional heat treatment. The optimal processing modes for the studied steel and triboconjugation have been established.

Key words: ion nitriding, optimization, wear intensity, friction coefficient, processing modes, operational factors.

Introduction

In the world mechanical engineering, a priority direction has developed – the technology of surface hardening and the application of multifunctional coatings. The possibility of creating products with a unique combination of the base material properties and the surface layer causes the growing interest of engineering enterprises and other industries in the wider use of this potential. The use of multifunctional hardening coatings makes it possible to repeatedly increase the durability of machines, operating temperatures and speeds, while reducing fuel consumption and providing the possibility of intensifying many production processes [1, 2].

In the theory and practice of the use of hardening coatings, the need to optimize the technology for such an important characteristic as the reproducibility of properties is noted [3]. The development of any technological process (TP) is inevitably associated with the solution of optimization problems, and in the field of creating functional coatings, optimization issues occupy a key place. This is because a large number of application methods, combined with an extensive nomenclature of materials from which the coating is formed, as well as many influencing factors, provide technologists with a wide range of alternative options.

Today in world practice there are more than 200 surface hardening technologies. Most of them are alternatives. The acceptance of optimal decisions on the choice of alternative technologies at the stage of designing new equipment, manufacturing, operation and repair should be carried out according to the criteria of the maximum strength and durability of the hardened part achieved with minimal energy and other material costs, as well as with minimal environmental damage [1-3].

Glow discharge chemical-thermal treatment is the most progressive and energy-saving in a wide range of alternative technologies. Ion nitriding (IN), which is traditionally used to improve wear resistance, corrosion resistance, and endurance limit, has received the widest industrial application and rapid development [3]. The great technological possibilities of IN technology pose the need to solve optimization problems, taking into account structural, technological and operational factors.

Literature review

Compared to traditional gas saturation, glow discharge treatment provides reduction in energy consumption by an order of magnitude, and also reduces the duration of the technological cycle by an order of magnitude. The advantages are also controllability, stability and predictability of processing results. When hardening steels and cast irons, there are no changes in the size and shape of parts, as well as changes in surface roughness. Nitriding in a glow discharge is the finishing operation. This eliminates the need for final mechanical processing. All these characteristics confidently place IN technology as an alternative to classical carburizing followed by hardening [4].

In world practice, IN uses ammonia as a working gas. This creates environmental problems as well as explosive problems. However, the main disadvantage regarding the use of hydrogen-containing media is hydrogen embrittlement of applied coatings and substrates. V.G. Kaplun and his collaborators developed the technology and equipment for IN in hydrogen-free media [5]. This technology preserves the bulk initial strength of the products, the process becomes absolutely environmentally friendly, the consumption of working gas is reduced, and the design of the equipment is simplified by eliminating dissociators that are very difficult to operate. At the same time, the surface layer has greater plasticity, which is especially important for gear parts and parts operating under shock loads.

During the period of reconstruction and renewal of equipment technological park for applying protective coatings, it is the IN technology that is in especially high demand. In the practice of aircraft engine building, traditional carburizing and nitrocarburizing have been switched to IN of gear wheels. This process reduces the complexity of manufacturing by 1.5-2 times, because parts are processed at a low hardness of the material and are sent for hardening in the finished form. IN technology is mainly used to improve wear resistance. This also increases the corrosion resistance and endurance limit [6].

In this regard, it is extremely important to search for optimal conditions for the implementation of IN technology for individual indicators that can affect the process: structural, technological and operational.

Purpose

The aim of the work is to search for optimal solutions and establishing a connection between the technological regimes of IN and the tribotechnical characteristics of the studied material.

Research Methodology

When choosing material for research, we proceeded from the following considerations. An analysis of statistical data shows that of all parts of the airframe and power plant rejected during the overhaul of the aircraft, approximately 45% are products made of steels of various grades. Of this amount, the largest percentage of rejection falls on parts made of 30HGSA steel – 30%, and about 50% of them cannot be restored [3]. That is why the optimization of the IN technology was carried out on steel 30HGSA, the chemical composition of which is presented in Table 1.

Table 1

The chemical composition of steel 30HGSA, % [7]

C	Si	Mn	Ni	Cr	S	P	Cu
0.28 – 0.34	0.9 – 0.12	0.8 – 1.1	≤ 0.3	0.8 – 1.1	≤ 0.025	≤ 0.025	≤ 0.3

Using peer review methods and a series of screening experiments, we obtained an average a priori ranked number of factors that affect the IN technology (Fig. 1).

Thus, a planning matrix was compiled, which included the first six technological factors (Fig. 1), as well as operational factors: sliding speed and specific load in triboconjugations. As optimization criteria, the main tribotechnical characteristics are taken – the wear intensity I_n and the friction coefficient μ.

Friction and wear tests were carried out under conditions that are as close as possible to the actual operating conditions of aircraft parts made of 30HGSA steel: lubricant – CIATIM-201, specific load – 2.5...25 MPa; sliding speed – 0.4...1.3 m/s. The samples were subjected to heat treatment (quenching from 1143 K in oil, tempering at 823 K), as well as IN (reactive gas composition: 95% N_2+5% C_3H_8; saturation temperature t = 873 K; reactive gas pressure P = 100 Pa; diffusion saturation time τ = 2.5 hours).

Standard tests were carried out according to the scheme: disc – block. The disc-counterbody is made of the same steel, hardened at 1143...1163 K in oil, tempered at 783...543 K, hardness – 37...38 HRC. The surface roughness of the block, depending on the processing modes, corresponded to R_a = 0.29...0.41 μm, and the disc-counterbody – R_a = 0.53 μm.

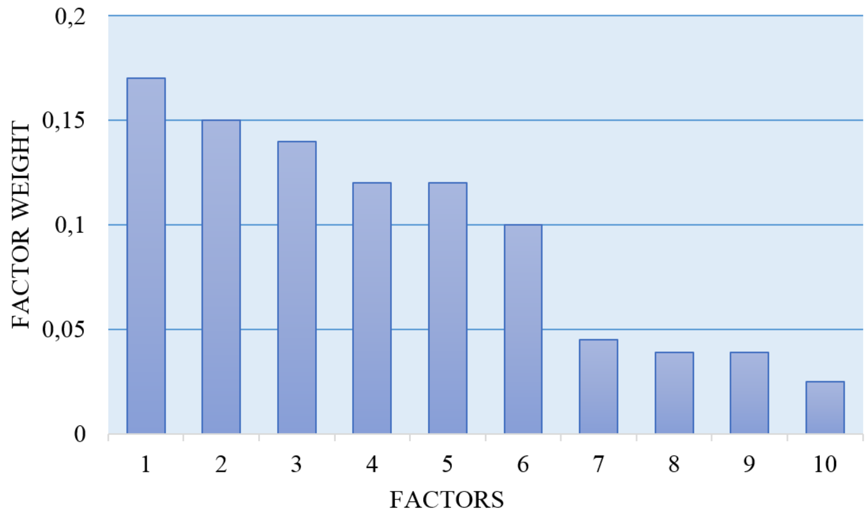
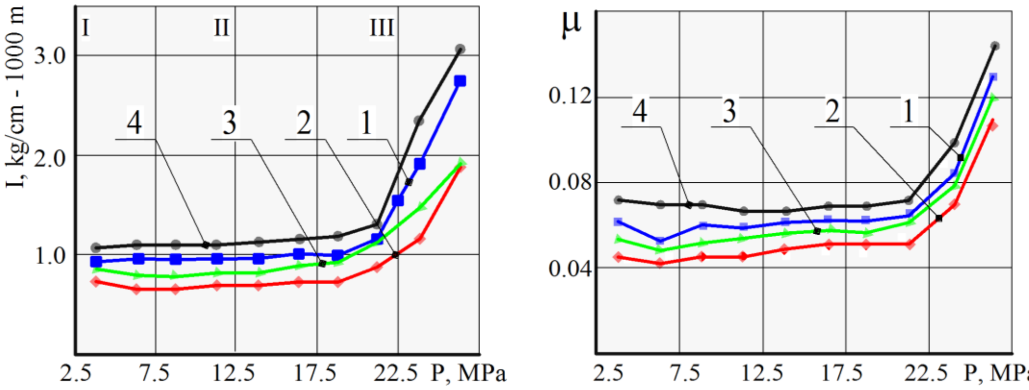


Fig. 1. A ranked row of structural, technological and operational factors: 1 – saturation temperature; 2 – reactive gas pressure; 3 – composition of reactive gas; 4 – ion treatment time; 5 – operational load; 6 – sliding speed; 7 – coating thickness; 8 – part material; 9 – operating current of the saturation process; 10 – operating voltage of the saturation process

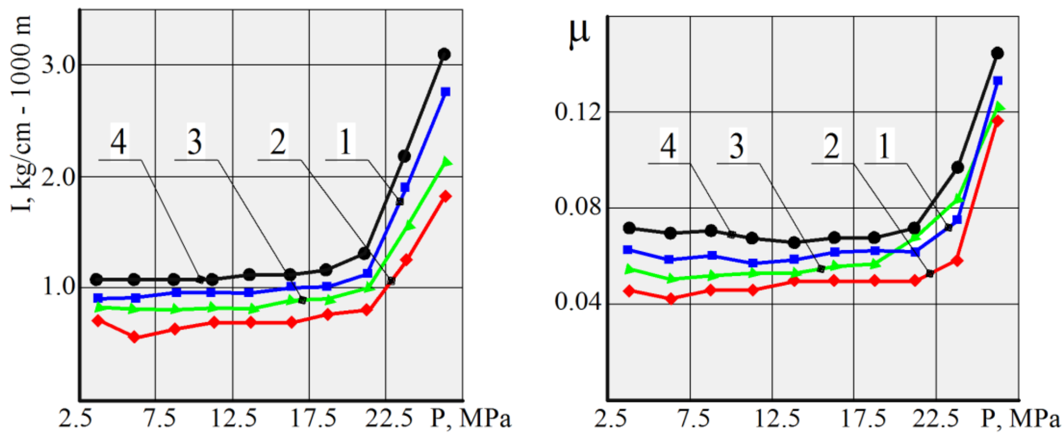
Results

As a result of carrying out experiments on friction and wear, the tribotechnical characteristics of coatings were obtained depending on structural, technological and operational factors (Fig. 2, a-f).



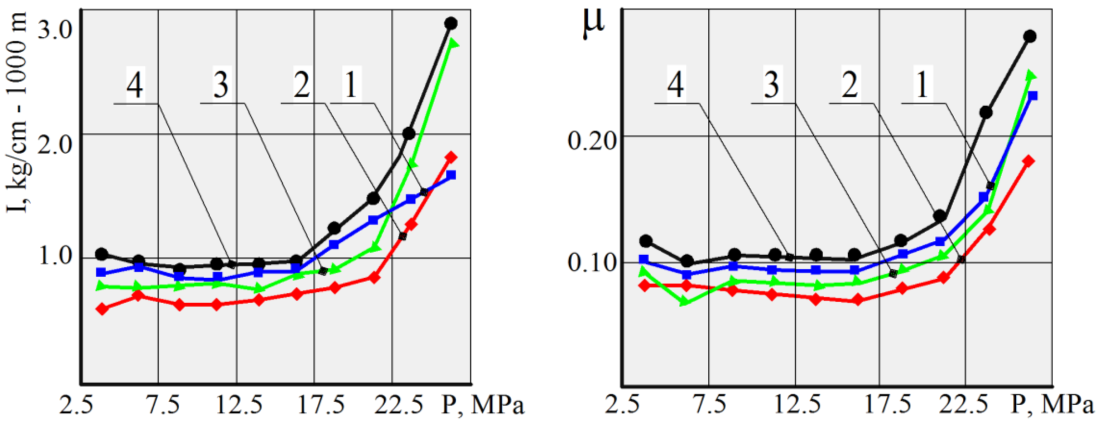
a) b)

Fig. 2. Dependence of wear intensity *I* (a) and friction coefficient *μ* (b) of HT+IN treatment on specific load *P* at sliding speed *V*: *1 – V* = 0.4 m/s; *2 – V* = 0.7 m/s; *3 – V* = 1.0 m/s; *4 – V* = 1.3 m/s
I – running-in zone; II – zone of uniform wear; III – zone of accelerated wear



a) b)

Fig. 3. Dependence of wear intensity *I* (a) and friction coefficient *μ* (b) of IN treatment on specific load *P* at sliding speed *V*:
***1 – V* = 0,4 m/s; *2 – V* = 0,7 m/s; *3 – V* = 1,0 m/s; *4 – V* = 1,3 m/s**



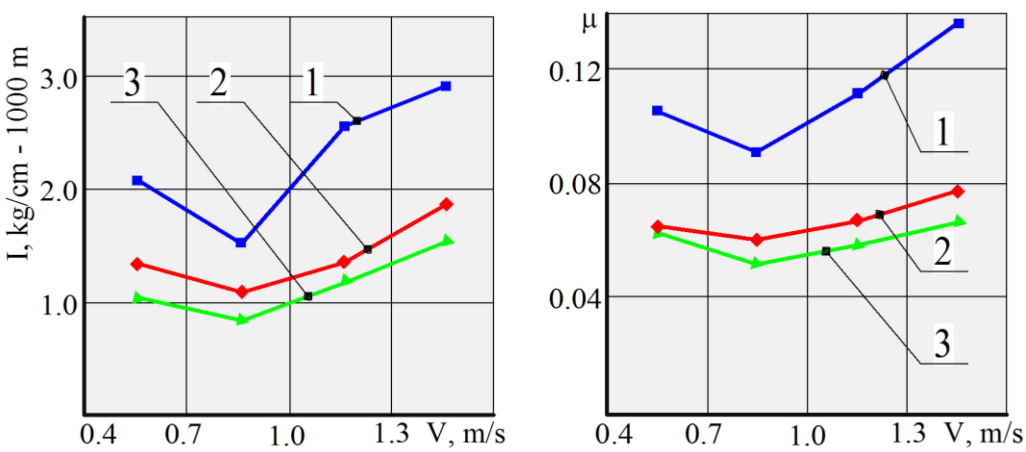
a) b)

Fig. 4. Dependence of wear intensity *I* (a) and friction coefficient *μ* (b) of HT treatment on specific load *P* at sliding speed *V*: *1* – *V* = 0,4 m/s; *2* – *V* = 0,7 m/s; *3* – *V* = 1,0 m/s; *4* – *V* = 1,3 m/s

The study of the obtained dependences (Fig. 2-4) showed the leading role of preliminary heat treatment (HT) of samples according to the mode – quenching from 1143...1163 K in oil – tempering at 783...843 K.

The analysis of the obtained results (Fig. 2-4) revealed the presence of three clearly defined zones, in the dependences of I and μ on the specific load at different sliding speeds and technological parameters of the IN: running-in zones, uniform and catastrophic wear. The nature of the dependences of hardened by IN samples (with and without preliminary HT) and heat-treated samples (without IN hardening) is similar. This type of dependencies coincides with the modern, generally accepted views on the laws of friction and wear processes.

However, the dependences of I and μ on the specific load P for heat-treated and hardened by IN samples have significant differences (Fig. 5). Increased wear is observed in heat-treated samples starting at P values of 13...14 MPa order, while hardened by IN begin to wear out intensively – at 18...19 MPa.



a) b)

Fig. 5. Dependence of wear intensity *I* (a) and friction coefficient *μ* (b) on sliding speed *V* at specific load *P* = 20 MPa and following treatment: 1 – HT; 2 – IN; 3 – HT+IN

Thus, there is an increase in the zone of uniform wear, which, of course, provides an extension of parts normal operation range at increased specific loads. With the same values of specific loads P and sliding speeds, the wear intensity I of hardened by IN samples is 1.7...2.1 in absolute values, and the friction coefficient μ is 1.9 times less than heat-treated samples. This implies the effectiveness of IN in comparison with traditional heat treatment.

Studies of the dependences of I and μ on the sliding speed V established (Fig. 3) that with an increase in V from 0.4 m/s, they gradually decrease, reaching a minimum at 0.7 m/s. With a further increase in V, these characteristics increase. Thus, the optimal sliding speed for the studied steel in this triboconjugation is V = 0.7 m/s.

Conclusions

The conducted studies allowed us to draw the following conclusions:

1. The proposed approach to optimizing the IN technology made it possible to improve the tribotechnical characteristics of the material, namely:

- reduce wear by 1.7...2.1 times, reduce friction coefficient by 1.9 times at a load increased by 1.4...1.5 times and the recommended sliding speed of 0.7 m/s for steel substrates hardened by ion nitriding, compared to surfaces that are heat treated in a classical way;

- expand the range of parts normal operation by increasing the zone of uniform wear.

2. The following optimized parameters of coating formation are recommended for use: process duration t = 140…190 min; reactive gas pressure p = 100…115 MPa; composition of the reaction mixture N_2 = 80…90% + Ar = 5…15%; saturation temperature T = 843…873 K.

3. The effectiveness of IN application in comparison with traditional heat treatment has been proven.

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Солових Е.К., Шепеленко І.В., Солових А.Е., Катеринич С.Е. Особливості багатокритеріальної оптимізації технології іонного азотування

В роботі виконано оптимізацію технології іонного азотування сталі 30ХГСА за триботехнічними характеристиками – інтенсивністю зношування та коефіцієнтом тертя. При виборі керованих факторів враховано вплив усіх існуючих груп, які можуть впливати на процес іонного азотування. Випробування на тертя та знос проведені в умовах, які максимально наближені до реальних експлуатаційних режимів деталей авіаційної техніки. В результаті проведення експериментів на тертя та знос отримані триботехнічні характеристики покриттів залежно від конструкційних, технологічних та експлуатаційних факторів відповідно до матриці. Проведені дослідження показало наявність трьох, чітко виражених зон у залежностях інтенсивності зношування та коефіцієнта тертя від питомого навантаження при різних швидкостях ковзання та технологічних параметрах іонного азотування: зони припрацювання, рівномірного та катастрофічного зношування. Характер залежностей зразків зміцнених іонним азотуванням та термооброблених зразків подібний та збігається із сучасними поглядами на закономірності процесів тертя та зношування. Аналіз триботехнічних характеристик показало ефективність технології іонного азотування порівняно із традиційною термообробкою. Встановлено оптимальні режими обробки для досліджуваних сталі та трибосполучення.

Ключові слова: іонне азотування, оптимізація, інтенсивність зношування, коефіцієнт тертя, режими обробки, експлуатаційні фактори.