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Influence of electrospark alloying parameters on steel surface quality during nitrocarburizing

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In the article, due to the conducted research, there have been established the dependences of the quality parameters of the steel part surfaces while nitrocarburizing thereof by the ESA method on the energy parameters of the equipment (discharge energy, Wp) and the technological parameters of the process (labor intensity, τ). The experimental studies have shown that with an increase in the discharge energy there increases the thickness of the strengthened layer, and its microhardness, as well as the surface roughness and its continuity. With an increase in the labor intensity, the thickness of the strengthened layer, its microhardness, and the surface continuity also increase, and the surface roughness almost does not change.
Keywords: electrospark alloying, special technological saturating media, nitrocarburizing, surface layer, quality parameters.

Вплив параметрів електроіскрового легування на якість поверхні сталі під час нітроцементації. *Н. В. Тарельник, Д. Б. Глушкова, О. П. Гапонова, Є. В. Коноплянченко, В.О.Скрипніков*

В статті в результаті проведених досліджень встановлено, що залежності параметрів якості поверхонь стальних деталей при нітроцементації методом ЕІЛ від енергетичних параметрів обладнання (енергії розряду, W_p) і технологічних параметрів процесу (трудомісткості, τ). Експериментальними дослідженнями встановлено, що зі збільшенням енергії розряду збільшуються: товщина зміцненого шару, його мікротвердість, шорсткість і суцільність поверхні. При збільшені трудомісткості зростає товщина зміцненого шару, його мікротвердість і суцільність поверхні, а шорсткість майже не змінюється.

1. Introduction

Today, due to the increase in the standard parameters of dynamic equipment of the machines operating in agricultural, automotive, petrochemical, aerospace and other industries, and often under the negative influence of the environment (temperature, radiation, chemicals, abrasives, etc.), there is much tension around the issue of increasing the reliability and durability of the parts, especially critical ones that guarantee trouble-free operation of the equipment.

Considering that destruction of machine parts usually begins with the surfaces, it is very important to improve the existing methods and develop new ones in order to increase the surface quality parameters. A great majority of scientists, both in Ukraine and in other countries, have been engaged in solving the problems concerning the formation of the part surface layers having the special properties that can withstand the processes of destruction of the parts, which begin with the appearance of the damages in the surface layers that are incompatible with further operation thereof. Conducting research in the direction of creating modern composite materials is relevant and timely. The crucial task is the creation of new composite materials and the implementation thereof to form, the surfaces which are made of those and characterized by the increased wear resistance parameters and the availability of a hard and viscous base having a sufficiently high values of the fatigue strength [1-4].

2. Objective and problem statement

Modern scientific and technical preparation for performing a production process, in its arsenal, has a large number of technologies for improving the quality of the part surfaces, both by strengthening their surface layers (chemical-thermal treatment (CTT) [5-7], high-frequency current hardening [8-10], laser treatment [11-13] and others), and by applying special protective coatings (condensed ion bombardment [14-16], various methods of spraying [17-19], galvanizing [20-22], electric spark alloying [23-25], etc.).

The most common technologies for improving the surface layer quality of the parts include surfacing the coatings made of composite materials [26, 27], performing vapor depositions [28 - 30], laser surfacing [31], processing with the use of laser melt injection [32], applying chemical depositions [33].

Among the above technologies, a large percentage is occupied by the CTT methods, the most common of which are carburization, nitrocarburization, nitridizing, etc. [5-7]. Although the CTT method is widely used, it also has significant disadvantages. Those are a long period of processing time, distortion of the shape of the part because of slotting and warping, needing in complex, bulky and energy-intensive equipment, etc.

The modern ESA technologies, with the advent of special technological saturating media (STSM) in their arsenal, have an ability to create the unique structures with characteristic physical, mechanical and tribological properties at the nanoscale in the surface layers of the parts [34, 35].

While moving the anode (tool electrode (TE) to the cathode (areas being alloyed), high shock wave pressures and temperatures arise on their local surfaces [36, 37]. In this case, the anode is instantly being heated. A drop or a solid part is being separated from the instantly heated anode surface and moving to the cathode. The temperature of the short-term (50–400 microseconds) local microvolumes of the surfaces can reach (5-7) 10^3 ^{0}K. As soon as the elements of the anode, cathode and the environment begin interacting, the diffusion processes start increasing, the new phases are being formed and the structure of the surface is changing.

The greatest advantages of the ESA process are: the environmental safety, the possibility of local processing, strong adhesion of the applied coating to the base, the absence of deformations, etc. [38, 39], the creation of transition layers to improve adhesion when applying coatings by other methods, for example, spraying [40]. In addition, the ESA method is proposed to be used in repair technologies for parts operating both under normal conditions [41] and for the restoration of parts of equipment operating under radiation exposure conditions [42].

The disadvantage of the ESA method is considered an increase in surface roughness [43], but it is eliminated by subsequent treatment of the coating by performing the surface plastic bombardment, for example, with the use of the AFUF method (abrasive-free ultrasonic finishing) [44, 45].

With the appearance of new technologies for improving the quality parameters of the machine part surfaces by the ESA method using the special technological saturating media (STSM), it became possible to create the surface structures with unique physical and mechanical, and tribological properties, alternative to those formed by the CTT methods: aluminizing [46], carburizing [47], etc.

As a result of the literary and patent analysis of the works devoted to nitridizing, nitrocarburizing and carburizing, which had been performed by the ESA method, both by compact TE and with the use of STSM, it has been established that the authors studied the influence of the discharge energy (Wp) on the quality parameters of the formed surface layers. In this case, the processing productivity value (Q) and the value that is reciprocal of productivity, i.e. the labor intensity of the process (τ), were taken according to the technological recommendations for the ESA units.

Thus, the aim of the work is to increase the durability of steel parts for dynamic equipment by improving the nitrocarburizing technology due to studying the influence of the processing time, i.e. the labor intensity of the RSA process, (τ) on the quality parameters of the formed surfaces.

3. Material and methods

According to the previous paper [48], the authors conducted studies of the aluminum influence on the quality parameters of surface layers of carbon and low-alloy steels such as 20, 40, 45, 50, 40X steels, etc. with the purpose of their further use as a basis for further nitridizing and nitrocarburizing by the ESA method. Considering that in the course of processing with the use of the ESA method by the aluminum TE at Wp = 3.40 J, the specified treatment mode was used in further studies.

Aluminum was applied by the TE made of aluminum wire Ø 3.0 mm of the AT mark, according to ISO 209-2:2002. The STSM was produced in the form of a pasty mixture prepared by mixing urea (45%), yellow blood salt (45%), and Vaseline (10%).

To assess the impact of the labor intensity on the quality of the formed coating, the authors increased it approximately two, three and four times, (Table 1).

The process of nitrocarburizing by the ESA method was carried out in the following sequence:

On the surface of samples made of steel 20 and creel 40, measuring 15x15x8mm, an aluminum coating was applied using the ESA unit of the "Elitron-52A" model at Wp = 3.40 J.

On the aluminum-alloyed surface, the STSM was applied. Without waiting for the STSM to dry, the alloying process was carried out by the TE in the form of a graphite rod of the EG-4 mark measuring 3×3×25 mm at Wp = 0.13; 0.52, and 3.40 J and at labor intensity, according to Table 1.

To conduct the metallographic studies of the prepared samples, an optical microscope of the "MIM-7" type was used to assess the quality of the layer, its continuity, the thickness and structure values of the sublayer zones, namely, the diffusion zone, and the heat-affected one. The microhardness measurements were performed on the microhardness tester of the PMT-3 type by providing the indentation of a diamond pyramid under a load of 0.05 N, according to GOST 9450-76. The roughness of the coating was assessed using the profilograph-profilometer of 201 model of the «Kalibr» plant production.

Table 1. Dependence of labor intensity of ESA process on discharge energy.

Discharge energy (Wp), J		0.13	0.52	3.4
Labor intensity (τ), min/cm^2	Variant 1	~ 3.3	~ 1.7	~ 1.0
	Variant 2	~ 5.0	~ 3.3	~ 2.0
	Variant 3	~ 10.0	~ 5.0	~ 3.3

4. Results and discussion

Fig. 1 shows the microstructures of the coatings of the steel 20 samples after aluminizing (the ESA process by the aluminum TE) at Wp = 3.40 J and nitrocarburizing by the ESA method at labor intensity, according to the 1st, 2nd and 3rd variants, respectively, Table 1, at Wp = 0.13; 0.52 and 3.40 J. The quality parameters of their surface layers are represented in Table 2.

The analysis of Fig. 1 and Table 2 has shown that the coating structure, regardless of the treatment variant (Table 1), consists of three zones. Those are the "white" layer, the diffusion zone and the base material. In all the variants, with increasing Wp, the thickness of the "white" layer, the diffusion (transition) zone, their microhardness, roughness and continuity increase. The same parameters, except for the surface roughness, which does not change, also increase with increasing treatment time, i.e. the labor intensity of the ESA process.

Fig. 2 shows the microstructures of the coatings of steel 40 samples after aluminizing (the ESA process by aluminum TE) at Wp = 3.40 J and nitrocarburizing by the ESA process at the labor intensity, according to variant 1, variant 2, and variant 3, respectively, Table 1, at Wp = 0.13; 0.52 and 3.40 J. Table 2 here represents the quality parameters of their surface layers.

4. Results and discussion

The analysis of Fig. 2 and Table 2 has shown that the structure of the coating of steel 40, as well as of steel 20, regardless of the treat-

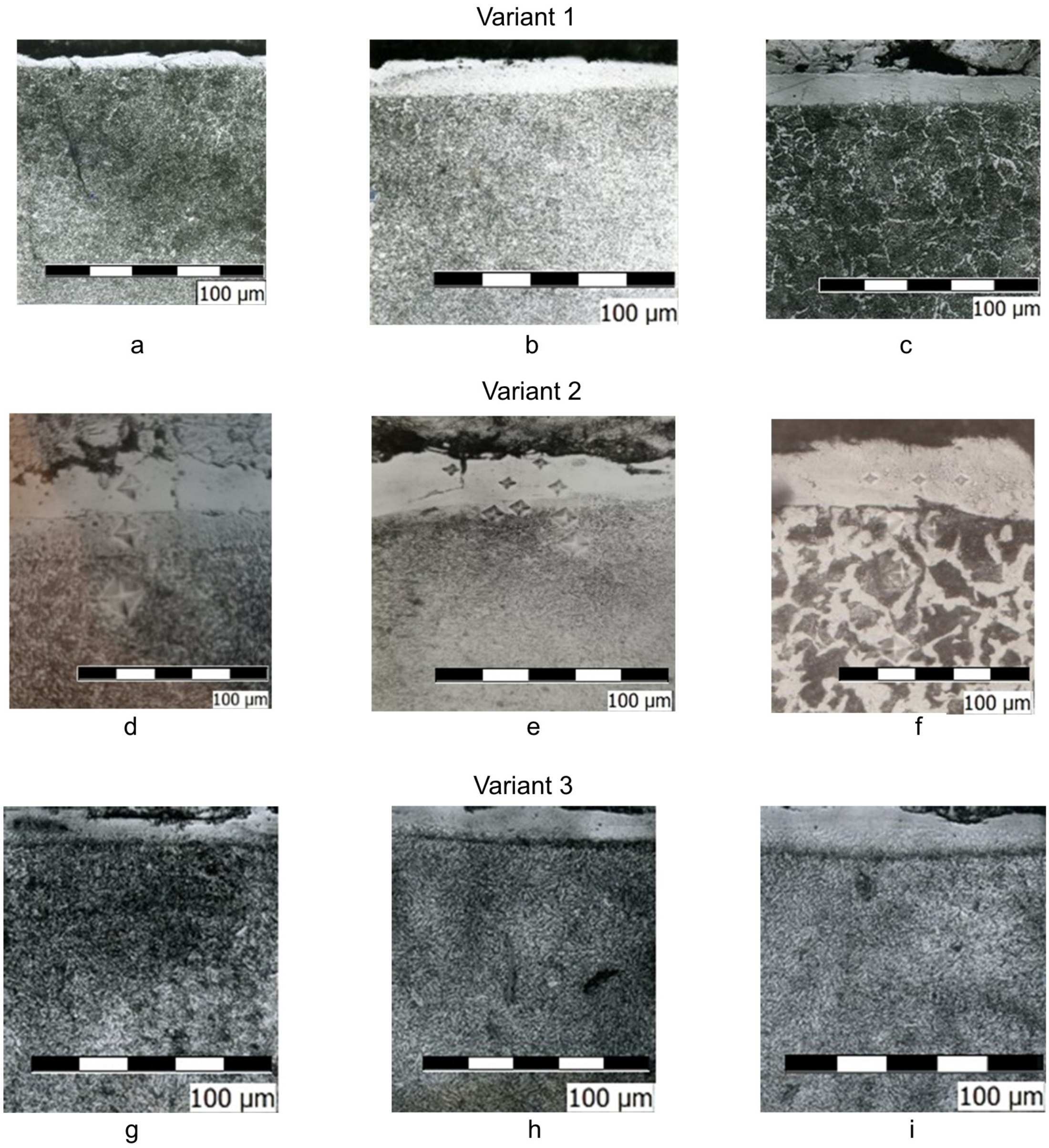

Fig. 1. Microstructure evolution of nitrocarburized coatings on steel 20 samples obtained by the electrospark alloying (ESA) method at various discharge energies (Wp): a, d, g – (Wp = 0.13 J); b, e; h – (Wp = 0.52 J); and c, f; i – (Wp = 3.40 J). Treatment durations (τ) for each mode (Variants) are listed in Table 1.

ment variant (Table 1), consists of three zones - the "white" layer, the diffusion zone, and the base material. In addition, in all the variants, with an increase in Wp, the thickness of the "white" layer, the diffusion (transition) zone, their microhardness, roughness and continuity increase. The same parameters, except for the surface roughness, which does not change, also increase with an increase in the treatment time, i.e. the labor intensity of the ESA. The difference is that when nitrocarburizing steel 40, the thickness of the strengthened layer and its microhardness increase slightly.

Figs 3-5 show the dependences of the thickness of the strengthened layer (a) and the microhardness of the "white" layer on Wp and τ during nitrocarburizing by the ESA method of steel 20 for, respectively, variant 1, variant 2, and variant 3 of the process.

It should be noted that for steel 40, the nature of the dependences of the thickness of the strengthened layer and the microhardness of the "white" layer on the discharge energy and processing time (labor intensity of the ESA) during nitrocarburizing for all the processing variants (Table 1) does not differ from the dependences indicated in Figs. 3 to 5, for steel 20.

Table 2. Quality parameters of surface layers of steel 20 and steel 40 samples after nitrocarburizing by the ESA method using the STSM.

Discharge energy, J	Labor intensity (τ), min/cm2	Thickness of strengthened layer, μm	Distribution of microhardness (Hμ) in the surface layer as it deepens at a measurement step of 30 μm.								Roughness, Ra, μm	Continuity of the "white" layer, %
			30	60	90	120	150	180	210	240		
Steel 20												
Variant 1												
0.13	3.3	145-165	7310	5800	4850	4550	2700	1700			1.0	95
0.52	1.7	155-190	10030	6800	5210	4750	3750	2300	1700		1.5	100
3.40	1.0	210-260	10250	8250	5750	5130	4170	3460	2500	1700	6.5	100
Variant 2												
0.13	5.0	170-185	7360	5870	4920	4850	2920	1750			1.0	100
0.52	3.3	180-215	10090	6890	5310	4780	3770	2350	1700		1.6	100
3.40	2.0	230-280	10290	8280	5850	5190	4220	3450	2420	1850	6.4	100
Variant 3												
0.13	10.0	170-185	7360	5090	4810	4530	2710	1700			1.1	100
0.52	5.0	180-215	10100	6280	5050	4580	3750	2320	1700		1.5	100
3.40	3.3	230-280	10300	6370	5090	4910	4170	3440	2240	1700	6.3	100
Steel 40												
Variant 1												
0.13	3.3	170-185	7510	5850	4820	4500	2790	1700			1.0	95
0.52	1.7	180-215	10520	6830	5120	4570	3740	2310	1700		1.5	100
3.40	1.0	230-280	10550	8260	5130	4970	4160	3430	2450	1700	6.5	100
Variant 2												
0.13	5.0	175-190	7550	5160	4890	4540	2820	170			1.0	100
0.52	3.3	185-220	10560	6340	5180	4630	3810	2410	1700		1.6	100
3.40	2.0	235-285	10580	6470	5240	4980	4310	3490	2480	1700	6.4	100
Variant 3												
0.13	10.0	175-190	7560	5140	4820	4540	2750	1700			1.1	100
0.52	5.0	185-220	10560	6290	5070	4590	3760	2320	1700		1.5	100
3.40	3.3	235-285	10550	6380	5080	4920	4270	3470	2220	1700	6.3	100

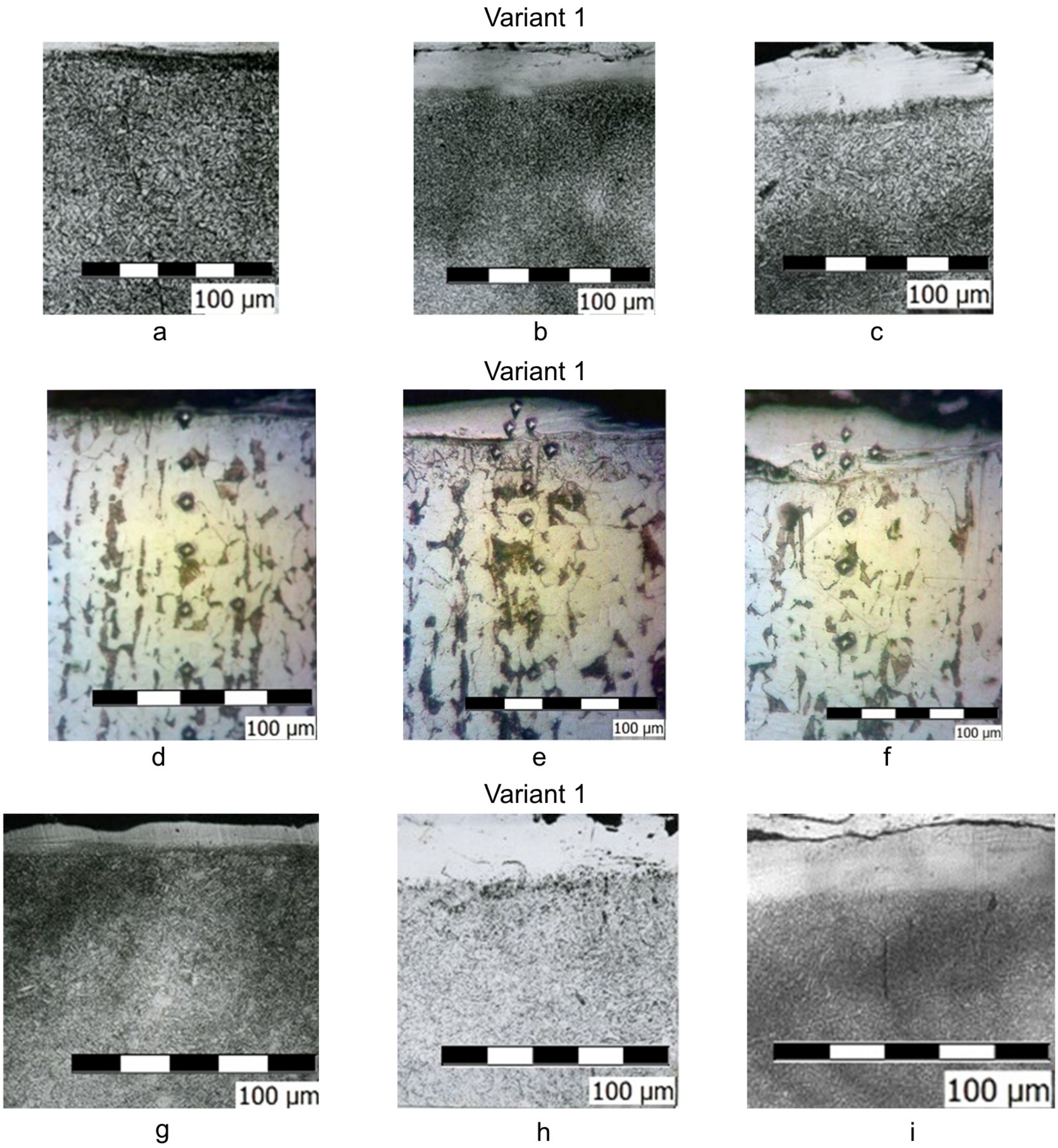

Fig. 2. Microstructure evolution of nitrocarburized coatings on steel 40 samples obtained by the electrospark alloying (ESA) method at various discharge energies (Wp): a, d, g – (Wp = 0.13 J); b, e; h – (Wp = 0.52 J); and c, f; i – (Wp = 3.40 J). Treatment durations (τ) for each mode (Variants) are listed in Table 1.

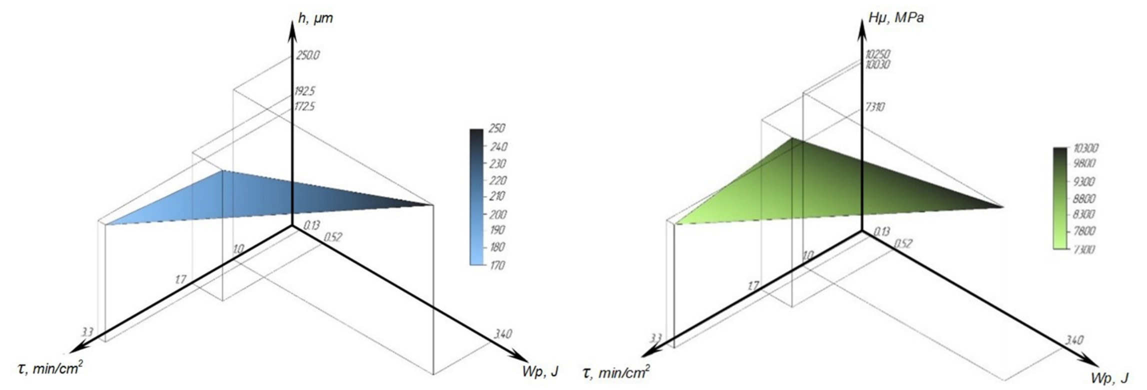

Fig. 3. Dependences of the thickness of the strengthened layer (a) and the microhardness (b) of the "white" layer on Wp and τ during nitrocarburizing of steel 20 for variant 1.

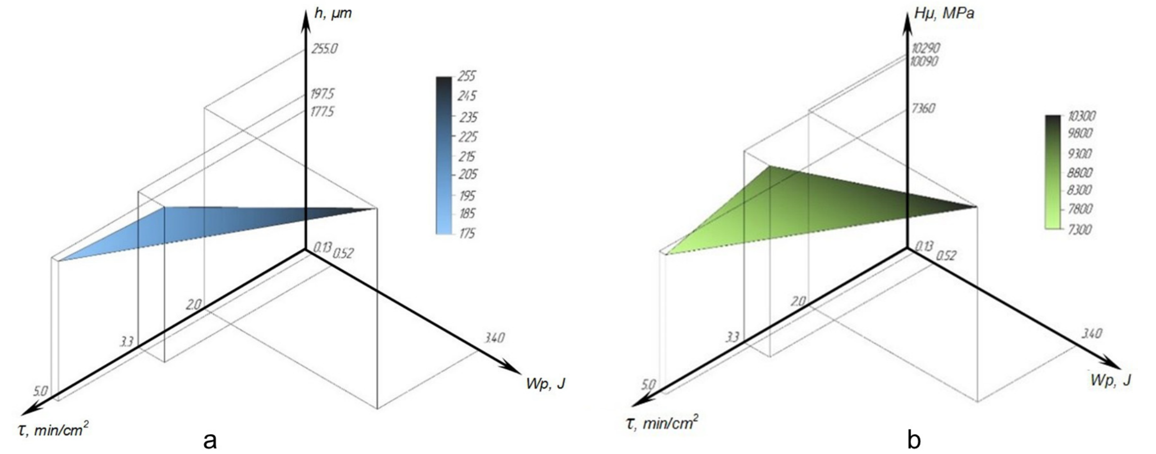

Fig. 4 - Dependences of the thickness of the strengthened layer (a) and the microhardness (b) of the “white” layer on Wp and τ during nitrocarburizing of steel 20 for variant 2.

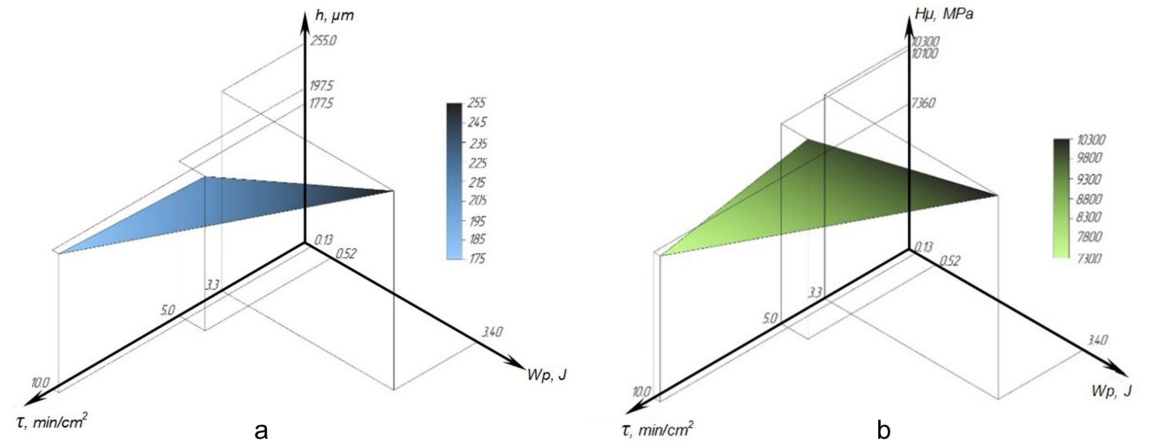

Fig. 5 - Dependences of the thickness of the strengthened layer (a) and the microhardness (b) of the “white” layer on Wp and τ during nitrocarburizing of steel 20 for variant 3.

A slight difference is noted only in the increase in the thickness of the “white” layer and the microhardness (see Table 2).

5. Conclusion

During the work, the following results were obtained:

1. Due to the metallographic, durometric and topographic studies of the surface layers of steel 20 and steel 40 after aluminizing and nitrocarburizing by the ESA method, a correlation dependence of the quality parameters of the surfaces of the steel parts during nitrocarburizing by the ESA method on the energy parameters of the equipment (discharge energy) and the technological parameters of the process (labor intensity) has been established:

- with an increase in the discharge energy, the thickness of the sthengthened layer and the diffusion (transition) zone, its microhardness, roughness and surface continuity increase;
- with increasing the labor intensity of the ESA, the thickness of the sthengthened layer, the diffusion zone, its microhardness and surface continuity increase, while the roughness almost does not change.

2. As a result of replacing steel 20 with steel 40, the thickness of the sthengthened layer and its microhardness slightly increase, while the roughness and continuity almost do not change.

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