

IMPROVEMENT OF SURFACE LAYER QUALITY PARAMETERS OF STEEL PARTS AFTER NITROCARBURIZING BY ELECTROSPARK ALLOYING METHOD

Part 2. DEVELOPMENT OF A MATHEMATICAL MODEL FOR CONTROLLING THE STEEL PART SURFACE LAYER QUALITY PARAMETERS

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Due to the analyses of the results of the investigations disclosed in the paper, the mathematical models of the dependence of the surface quality parameters while nitrocarburizing by the electrospark alloying method (ESA) with the use of the special technological saturating media (STSM) (the equation of the increase in the thickness of the strengthened layer and the equation of the increase in the microhardness of the surface) on the energy and technological parameters of the ESA equipment, respectively, the discharge energy (W_p) and the labor intensity (τ), which allows determining the main technological parameters of the formed layer, namely, the thickness of the strengthened layer ($h_{sl.}$) and its microhardness ($H_{\mu sl.}$). Also established is the method for determining the constants of the equation of the increase in the thickness of the strengthened layer (the largest increase in the thickness of the strengthened layer depending on the discharge energy – $\Delta h_{sl.Wp_{max}}$, the activation energy – E , and the largest increase in the thickness of the strengthened layer depending on the labor intensity of the ESA processing – $\Delta h_{sl.\tau_{max}}$), as well as the equation of the increase in the microhardness of the surface (the largest increase in the microhardness of the strengthened layer depending on the discharge energy – $\Delta H_{\mu sl.Wp}$, the activation energy – E , and the largest increase in the microhardness of the strengthened layer depending on the labor intensity of the ESA processing – $\Delta H_{\mu sl.\tau}$).

INTRODUCTION

In Part 1 [1] of the paper, an analysis of modern methods for improving the quality parameters of surface layers of critical steel parts for power equipment of nuclear power plants (NPPs), the largest portion of which is occupied by pumps of various technological systems operating in harsh conditions and to which exceptionally high requirements are placed on their reliability.

It has been proved that to increase the reliability and durability of machine parts, it is not necessary to produce them from hard, wear-resistant and expensive materials [2–4], it is enough to provide only their surface layers with the necessary operational properties, leaving the “core” unchanged [5–7]. There has been proven the relevance of work on the creation of new composite materials that have protective surface layers and viscous, mechanically strong bases [8–11]. Also in Part 1 of the paper, an analysis of the modern and most widely used strengthening technologies is carried out, namely, applying of the metal-ceramic coatings to the surfaces of parts [12–14], performing the depositions of the coatings made of the composite materials [15, 16], coating the surfaces with the layers of aluminum oxide [17–19].

There have been separately considered the advantages and disadvantages of the chemical-thermal treatment (CTT) methods [20–22]. The important part of the technologies based on the use of the concentrated energy flows (CEFs) has been [23–25] highlighted, and the

advantages of the electrospark alloying (ESA) methods, which are also based on the use of the CEFs, have been proven over other alternative technologies [26–28]. The ESA method makes it possible to restore qualitatively the worn surfaces [29–31].

The disadvantages of the ESA method [32, 33] (increased surface roughness, the appearance of pores in some cases, reduced fatigue strength) can be eliminated by using the surface plastic deformation (SPD) technology after the ESA [34–36].

With the appearance of new technologies for improving the quality parameters of machine parts surfaces by the ESA method using special technological saturating media (STSM), it has become possible to create the surface structures with unique physico-mechanical and tribological properties: aluminizing [37–39], carburizing [40], nitriding [41], boron saturating [42], as well as covering with multi-component coatings [43–45].

There have been conducted the studies [1] allowing to establish correlations between the energy and technological parameters of the ESA equipment, respectively, W_p and labor intensity τ , and the main parameters of the surface layer quality, namely, the thickness of the strengthened layer $h_{sl.}$ and the microhardness of the surface (H_{μ}).

The availability of these dependencies would allow implementing a method for controlling the quality of the surfaces of parts and thus improving the technology for

manufacturing and repairing equipment, depending on the requirements that are put forward to them.

Thus, the purpose of the work is to improve the quality parameters of the surface layers of steel parts by developing a mathematical model for controlling the quality parameters of their surfaces while nitrocarburizing thereof by the ESA method.

INVESTIGATION RESULTS

In [1], it has been established that, for steels 20 and 40, with an increase in (W_p) and (τ), the thickness of the strengthened layer ($h_{sl.}$) increases. In this case, it consists of the thickness of the “white” layer, which is not detected

during etching with conventional reagents, and the diffusion zone, as well as (H_μ) of the surface (Table 1). The methodology for establishing correlation dependencies between W_p , τ and the thickness of the strengthened layer ($h_{sl.}$) and microhardness (H_μ) has been carried out using steel 20 as an example.

It has been considered the influence of W_p on the thickness of the strengthened layer, i.e. $h_{sl.Wp} = f(W_p)$ (Fig. 1).

Fig. 2 shows the dependences of the logarithm of the thickness of the strengthened layer ($\ln h_{sl.Wp}$) of steel 20 on the value of the reverse discharge energy (W_p^{-1}).

Table 1

Quality parameters of nitrocarburizing layers

Discharge energy W_p , J	Labor intensity τ , min/cm ²	Thickness of the strengthened layer ($h_{sl.}$), μm	Microhardness of the strengthened layer $H_{\mu sl.}$, MPa
Existing technology			
0.13	1.7	155.0	7150
0.52	0.8	170.0	9921
3.40	0.5	235.0	10050
Variant 1			
0.13	3.3	175.0	7310
0.52	1.7	190.0	10030
3.40	1.0	250.0	10250
Variant 2			
0.13	5.0	180.0	7360
0.52	3.3	200.0	10090
3.40	2.0	255.0	10290
Variant 3			
0.13	10.0	182.5	7365
0.52	5.0	202.5	10100
3.40	3.3	257.5	10300

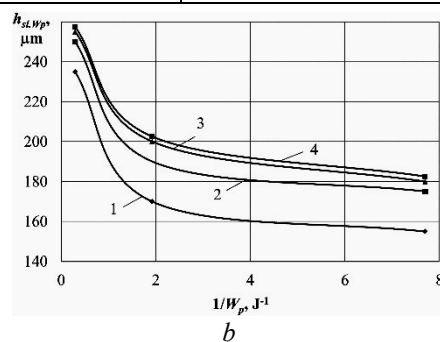
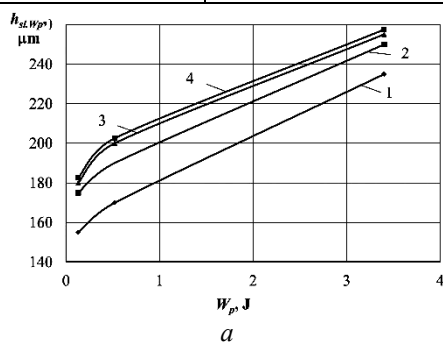


Fig. 1. The dependences of the thickness of the strengthened layer ($h_{sl.Wp}$) of steel 20 on W_p (a) and (W_p^{-1}) (b) in the existing technology and the first, second and third variants of the ESA process, respectively, graphs 1–4

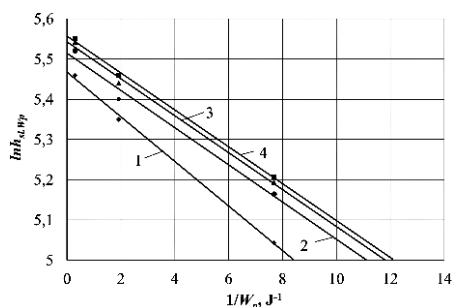


Fig. 2. The dependences of the ($\ln h_{sl.Wp}$) of steel 20 on the value of the reverse discharge energy (W_p^{-1}): 1 – the existing technology; 2 – the first; 3 – second; 4 – third variants of the ESA process

The analysis of Fig. 1 makes it possible to draw a conclusion that there is an exponential relationship between the increase in the thickness of the strengthened layer and the discharge energy (W_p). It has been noted that the increase in the thickness of the strengthened layer $\Delta h_{sl.Wp}$ increases with the increase in the activation energy of the nitro-carburizing process E .

From the correlation dependence of the increase in the thickness of the strengthened layer on the value of the reverse discharge energy (see Fig. 1,b), it follows that the logarithm of the thickness of the strengthened layer $\ln h_{sl.Wp} \sim (W_p)^{-1}$ and the activation energy E (see Fig. 2):

$$\ln h_{sl.Wp} \sim (W_p)^{-1}, E. \quad (1)$$

Having passed from the approximate equality to the exact equality, we have:

$$\Delta h_{sl.Wp} = C \cdot e^{\frac{-E}{Wp}}, \quad (2)$$

where $\Delta h_{sl.Wp_{max}}$ is the greatest thickness of the strengthened layer.

Then

$$\Delta h_{sl.Wp} = \Delta h_{sl.Wp_{max}} \cdot e^{\frac{-E}{Wp}}. \quad (3)$$

Dependence (3) can be considered as an equation of the thickness of the strengthened layer depending on the discharge energy.

When in (3)

$$E = Wp, \quad (4)$$

we will have:

$$\Delta h_{sl.Wp} / \Delta h_{sl.Wp_{max}} = e^{-1}. \quad (5)$$

Thus, the activation energy E is a physical quantity equal to the discharge energy Wp at which the thickness of the strengthened layer is e times less than its maximum value.

The value of E can be determined by the constant of equation (3). Its dimension J. $E = t g \alpha$, where α is the angle of inclination of the direct dependences of $\ln \Delta h_{sl.Wp}$ on Wp^{-1} . The second constant of equation (3) is $\Delta h_{sl.Wp_{max}}$. It is determined by the value of the segment cut off on the ordinate axis by the intersection

point of the extended straight line of the graph for the dependence of the logarithm of the thickness of the strengthened layer ($\ln \Delta h_{sl.Wp}$) on Wp^{-1} (see Fig. 2).

Here is a consideration of the labor intensity influence, τ , on the change in the thickness of the strengthened layer at the traditional labor intensity of the ESA and the one being studied, i.e. $\Delta h_{sl.} = f(t)$. Table 2 and Fig. 3 represent the dependences of the increase in the thickness of the strengthened layer $\Delta h_{sl.}$ of steel 20 on the labor intensity τ and the reverse value of τ^{-1} , at the existing technology and the first, second and third variants of the ESA.

Table 3 and Fig. 4 represent the dependences of the logarithm of the increase in the thickness of the strengthened layer ($\ln \Delta h_{sl.}$) on τ^{-1} .

Analysis of Fig. 3, a makes it possible to conclude that there is an exponential relationship between the increase in the thickness of the strengthened layer ($\Delta h_{sl.}$) and the labor intensity τ . It has been noted that the increase in the thickness of the strengthened layer $\Delta h_{sl.}$ increases with increasing labor intensity. From the correlation dependence of the increase in the thickness of the strengthened layer on the value of the inverse labor intensity (see Fig. 3, b), it follows that the logarithm of the increase in the thickness of the strengthened layer is proportional to τ^{-1} (see Fig. 4):

$$\ln \Delta h_{sl.} \sim (-\tau)^{-1}. \quad (6)$$

Table 2

Dependence of the increase in the thickness of the strengthened layer of steel 20 on τ and τ^{-1} , for all variants of the ESA for $Wp = 0.13; 0.52$, and 3.4 J

τ , min/cm ² and τ^{-1} , cm ² /min	$\Delta h_{sl.}, \mu\text{m}$	τ , min/cm ² and τ^{-1} , cm ² /min	$\Delta h_{sl.}, \mu\text{m}$	τ , min/cm ² And τ^{-1} , cm ² /min	$\Delta h_{sl.}, \mu\text{m}$
X	Y	X	Y	X	Y
$Wp = 0.13$ J		$Wp = 0.52$ J		$Wp = 3.4$ J	
τ		τ		τ	
1.7	0	0.8	0	0.5	0
3.3	20.0	1.7	20.0	1.0	15.0
5.0	25.0	3.3	30.0	2.0	20.0
10	27.5	5.0	32.5	3.3	22.5
τ^{-1}		τ^{-1}		τ^{-1}	
0.6	0	1.2	0	2.0	0
0.3	20.0	0.6	20.0	1.0	15.0
0.2	25.0	0.3	30.0	0.5	20.0
0.1	27.5	0.2	32.5	0.3	22.5

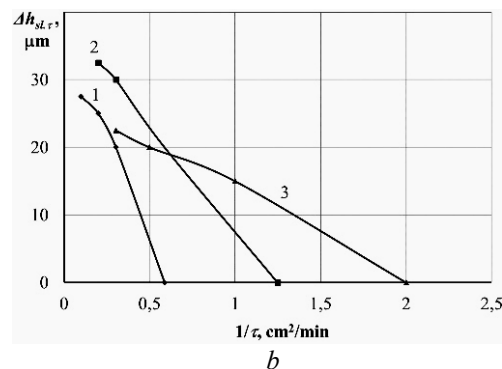
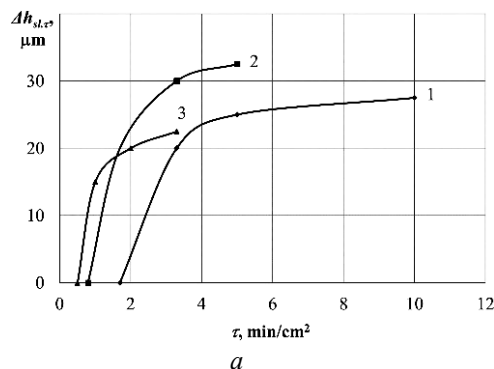
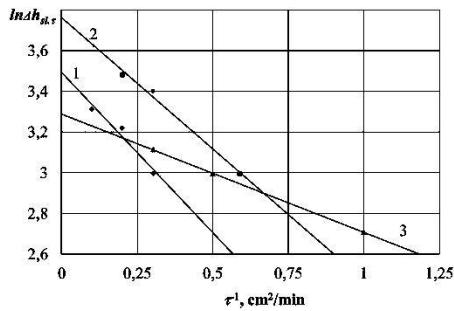


Fig. 3. Dependence of the increase in the thickness of the strengthened layer for steel 20 on τ and τ^{-1} for all variants of the ESA at $Wp = 0.13; 0.52$, and 3.4 J

Table 3

Dependence of $\ln \Delta h_{sl.\tau}$ on τ^{-1} at existing technology and all variants of the ESA for $W_p = 0.13; 0.52$, and 3.4 J

Value being reverse of labor intensity τ^{-1} , cm ² /min	$\ln \Delta h_{sl.\tau}$	Value being reverse of labor intensity τ^{-1} , cm ² /min	$\ln \Delta h_{sl.\tau}$	Value being reverse of labor intensity τ^{-1} , cm ² /min	$\ln \Delta h_{sl.\tau}$
X	Y	X	Y	X	Y
$W_p = 0.13$ J		$W_p = 0.52$ J		$W_p = 3.4$ J	
Steel 20					
0.3	2.99	0.6	2.99	2	2.70
0.2	3.22	0.3	3.40	1	2.99
0.1	3.31	0.2	3.48	0.5	3.11

Fig. 4. Dependence of $\ln \Delta h_{sl.\tau}$ of steel 20 on τ^{-1} at existing technology and all variants of the ESA for $W_p = 0.13; 0.52$, and 3.4 J

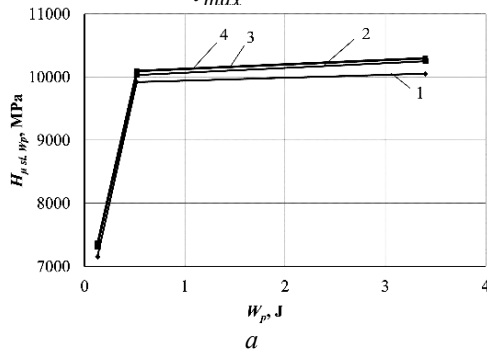
Having passed from the approximate equality to the exact one, we will have:

$$\ln \Delta h_{sl.\tau} = C \cdot e^{-\frac{1}{\tau}}, \quad (7)$$

where $C = \Delta h_{sl.\tau_{max}}$ ($\Delta h_{sl.\tau_{max}}$ is the greatest increase in the thickness of the strengthened layer).

$$\Delta h_{sl.\tau} = \Delta h_{sl.\tau_{max}} \cdot e^{-\frac{1}{\tau}}. \quad (8)$$

The dependence (8) can be considered as an equation of the increase in the thickness of the strengthened layer depending on the labor intensity, and its constant $\Delta h_{sl.\tau_{max}}$ can be determined by the



value of the segment cut off on the ordinate axis by the point of the intersection of the extended straight line of the graph for the dependence of the logarithm of the increase in the thickness of the strengthened layer ($\ln \Delta h_{sl.\tau}$) of steel 20 on (τ^{-1}) (see Fig. 4).

Taking into account that the total increase in the thickness of the strengthened layer depends on W_p and τ , that is, $\sum \Delta h_{sl.\tau} = f(W_p, \tau)$ it could be concluded that

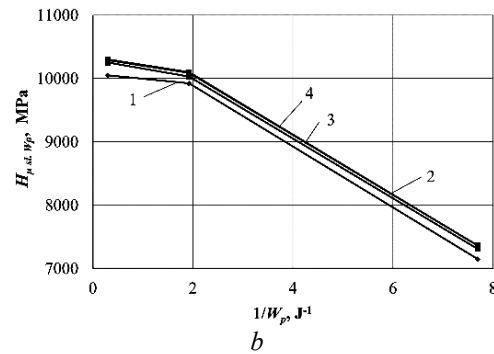
$$\Delta h_{sl.} = \Delta h_{sl.W_p_{max}} \cdot e^{-\frac{E}{W_p}} + \Delta h_{sl.\tau_{max}} \cdot e^{-\frac{1}{\tau}}. \quad (9)$$

The dependence (9) can be taken into account by the equation of the total thickness increase of the strengthened layer.

Here is considered the influence of W_p on the microhardness of the strengthened layer, i.e. $H_{\mu sl.W_p} = f(W_p)$.

Fig. 5, a shows the dependence of the microhardness of the strengthened layer ($H_{\mu sl.W_p}$) of steel 20, respectively, on $W_p = 0.13; 0.52$, and 3.4 J (a) and the values of $W_p^{-1} = 7.7; 1.9$, and 0.3 J⁻¹ (see Fig. 5, b) at the existing technology and all variants of the ESA.

Fig. 6 shows the dependence of the logarithm of the microhardness of the strengthened layer ($\ln \Delta H_{\mu sl.W_p}$) of steel 20 on the value of (W_p^{-1}).

Fig. 5. The dependence of the microhardness of the strengthened layer ($\Delta H_{\mu sl.W_p}$) of steel 20 on W_p (a) and on (W_p^{-1}). (b) at the existing technology and all variants of the ESA

The analysis of Fig. 5 makes it is possible to conclude that there is an exponential relationship between the increase in the microhardness of the strengthened layer and the discharge energy (W_p). With an increase in the microhardness of the strengthened layer, $\Delta H_{\mu sl.W_p}$ increases with an increase in the activation energy E .

From the correlation dependence of the increase in the microhardness of the strengthened layer on the value of (W_p^{-1}) (see Fig. 5, b), it follows that the logarithm of the microhardness of the strengthened layer $\ln \Delta H_{\mu sl.W_p} \sim (W_p)^{-1}$ and activation energy E (Fig. 6)

$$\ln \Delta H_{\mu sl.W_p} \sim (W_p)^{-1}, E. \quad (10)$$

Having passed from the approximate equality to the exact one, we will have:

$$\Delta H_{\mu \text{ sl. } W_p} = C \cdot e^{\frac{-E}{W_p}}, \quad (11)$$

where $C = \Delta H_{\mu \text{ sl. } W_{p \max}}$ ($\Delta H_{\mu \text{ sl. } W_{p \max}}$ is the greatest increase in the thickness of the strengthened layer).

Then

$$\Delta H_{\mu \text{ sl. } W_p} = \Delta H_{\mu \text{ sl. } W_{p \max}} \cdot e^{\frac{-E}{W_p}}. \quad (12)$$

The dependence (12) can be considered as an equation of the microhardness of the strengthened layer depending on the discharge energy.

When in (12)

$$E = W_p. \quad (13)$$

We will have:

$$\Delta H_{\mu \text{ sl. } W_p} / \Delta H_{\mu \text{ sl. } W_{p \max}} = e^{-1}. \quad (14)$$

Thus, the activation energy E is a physical quantity equal to the discharge energy W_p , at which the microhardness of the strengthened layer is e times less than its maximum value.

The value of E can be determined by the constant of equation (12). Its dimension is [J]. $E = tga$, where α is the angle of inclination of direct dependences $\ln \Delta H_{\mu \text{ sl. } W_p}$ on W_p^{-1} . The second constant of equation (12) is $\Delta H_{\mu \text{ sl. } W_{p \max}}$. It is determined by the value of the segment that is cut off on the ordinate axis by the intersection point of the extended straight line of the

graph of the dependence of $\ln \Delta H_{\mu \text{ sl. } W_p}$ on W_p^{-1} (see Fig. 6). Here is considered the effect of the labor intensity, τ on the increase in microhardness of the strengthened layer, i.e. $\Delta H_{\mu \text{ sl.}} = f(\tau)$.

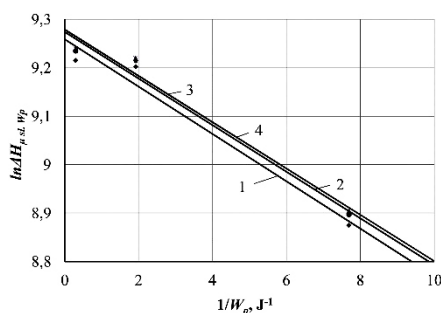


Fig. 6. The dependence of the microhardness logarithm of the strengthened layer of steel 20 on W_p^{-1} (b) at the existing technology and all variants of the ESA

Table 4 and Fig. 7 represent the dependences of the increase in microhardness of the strengthened layer ($\Delta H_{\mu \text{ sl. } \tau}$) of steel 20 on τ and τ^{-1} at the existing technology and all variants of the ESA for $W_p = 0.13$; 0.52, and 3.4 J. The analysis of Fig. 7 gives an opportunity to conclude that there is an exponential relationship between the increase in the microhardness of the strengthened layer ($\Delta H_{\mu \text{ sl. } \tau}$) and τ . It has been noted that the increase in takes place with increasing τ .

Table 5 and Fig. 8 represent the dependences of the logarithm of the increase in the microhardness of the strengthened layer ($\ln \Delta H_{\mu \text{ sl. } \tau}$) of steel 20 on (τ^{-1}).

Table 4

Dependences of increase in microhardness of steel 20 on τ and τ^{-1} at existing technology and all variants of the ESA process for $W_p = 0.13$; 0.52, and 3.4 J

τ , min/cm ² and τ^{-1} , cm ² /min	$\Delta H_{\mu \text{ sl. } \tau}$, MPa	τ , min/cm ² and τ^{-1} , cm ² /min	$\Delta H_{\mu \text{ sl. } \tau}$, MPa	τ , min/cm ² and τ^{-1} , cm ² /min	$\Delta H_{\mu \text{ sl. } \tau}$, MPa
X	Y	X	Y	X	Y
$W_p = 0.13$ J		$W_p = 0.52$ J		$W_p = 3.4$ J	
τ		τ		τ	
1.7	0	0.8	0	0.5	0
3.3	160	1.7	109	1.0	200
5.0	210	3.3	169	2.0	240
10	215	5.0	179	3.3	250
τ^{-1}		τ^{-1}		τ^{-1}	
0.6	0	1.2	0	2.0	0
0.3	160	0.6	109	1.0	200
0.2	210	0.3	169	0.5	240
0.1	215	0.2	179	0.3	250

From the correlation dependence of the increase in the microhardness of the strengthened layer on the value being reverse of labor intensity (see Fig. 7,b), it follows that the logarithm of the microhardness of the strengthened layer $\ln \Delta H_{\mu \text{ sl. } \tau} \sim (\tau)^{-1}$ (see Fig. 8):

$$\ln \Delta H_{\mu \text{ sl. } \tau} \sim (\tau)^{-1}. \quad (15)$$

Having passed from the approximate equality to the exact equality, we have:

$$\Delta H_{\mu \text{ sl. } \tau} = C \cdot e^{\frac{-1}{\tau}}, \quad (16)$$

where $C = \Delta H_{\mu \text{ sl. } \tau_{\max}}$ ($\Delta H_{\mu \text{ sl. } \tau_{\max}}$ is the greatest increase in the microhardness of the strengthened layer).

Then

$$\Delta H_{\mu \text{ sl. } \tau} = \Delta H_{\mu \text{ sl. } \tau_{\max}} \cdot \frac{-1}{\tau}, \quad (17)$$

the dependence (17) can be considered as an equation of the increase in the microhardness of the strengthened layer depending on the labor intensity, and its constant $\Delta H_{\mu \text{ sl. } \tau_{\max}}$ is determined by the segment cut off on the ordinate axis by the point of the intersection of the straight line of the dependence graph ($\ln \Delta H_{\mu \text{ sl. } \tau}$) of steel 20 on τ^{-1} (see Fig. 8).

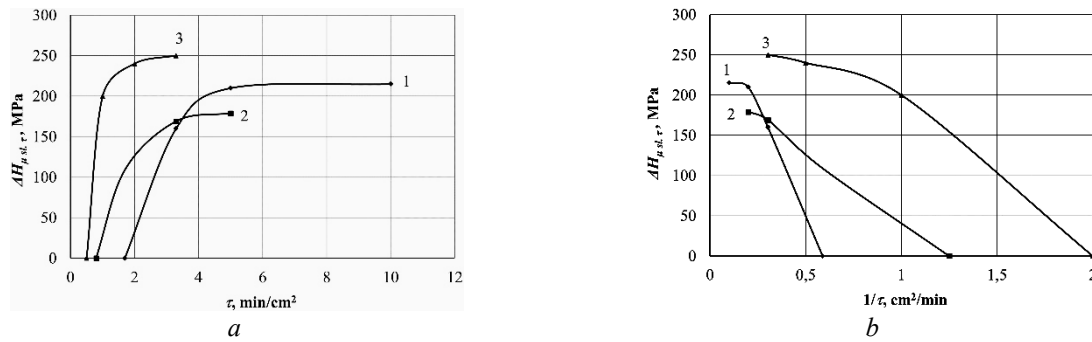


Fig. 7. Dependence of increase in microhardness of steel 20 on τ and τ^{-1} at existing technology and all variants of the ESA process for $W_p = 0.13; 0.52$, and 3.4 J

Table 5

Dependence of $\ln \Delta H_{\mu sl \tau}$ of steel 20 on (τ^{-1}) at existing technology and all variants of the ESA process for $W_p = 0.13; 0.52$, and 3.4 J .

Value being reverse of labor intensity τ^{-1} , cm^2/min	$\ln \Delta H_{\mu sl \tau}$	Value being reverse of labor intensity τ^{-1} , cm^2/min	$\ln \Delta H_{\mu sl \tau}$	Value being reverse of labor intensity τ^{-1} , cm^2/min	$\ln \Delta H_{\mu sl \tau}$
X	Y	X	Y	X	Y
$W_p = 0.13 \text{ J}$		$W_p = 0.52 \text{ J}$		$W_p = 3.4 \text{ J}$	
0.3	5.08	0.6	4.69	1	5.30
0.2	5.35	0.3	5.13	0.5	5.48
0.1	5.37	0.2	5.19	0.3	5.52

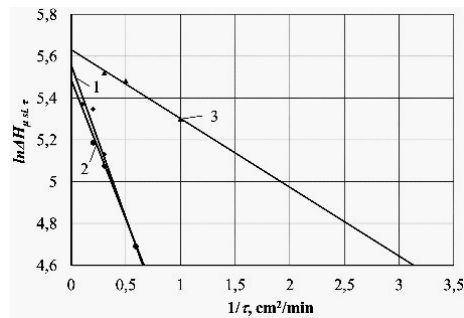


Fig. 8. Dependence of $\ln \Delta H_{\mu sl \tau}$ strengthened layer τ steel 20 on (τ^{-1}) at existing technology and all variants of the ESA process for $W_p = 0.13; 0.52$, and 3.4 J

Taking into account that the total increase in the microhardness of the strengthened layer depends on W_p and τ that is, $\sum \Delta H_{\mu sl} = f(W_p, \tau)$, it can be concluded that

$$\sum \Delta H_{\mu sl} = H_{\mu sl, W_p \max} \cdot e^{\frac{-E}{W_p}} \cdot \Delta H_{\mu sl, \tau \max} \cdot \frac{-1}{\tau}. \quad (18)$$

The dependence (18) can be taken into account by the equation of the increase in microhardness of the strengthened layer depending on the ESA parameters.

CONCLUSIONS

1. There have been developed the mathematical models of the dependences of the surface quality values during nitro-carburizing by the ESA method using STSM (the equation of the increase in the thickness of the strengthened layer and the equation of the increase in the microhardness of the surface) on the energy and technological parameters of the ESA equipment, respectively, the discharge energy (W_p) and the labor intensity (τ). The above allow determining the main technological parameters of the formed layers, namely,

the thickness of the strengthened layers (h_{sl}) and its microhardness ($H_{\mu sl}$).

2. A method for determining the constants of the equation for the increase in the thickness of the strengthened layer (the greatest increase in the thickness of the strengthened layer depending on the discharge energy, namely, $\Delta h_{sl, W_p \max}$, the activation energy – E , and the greatest increase in the thickness of the strengthened layer depending on the labor intensity of the process, namely, $\Delta H_{\mu sl, W_p \max}$, as well as the constants of the equation for the increase in the microhardness of the surface (the greatest increase in the microhardness of the strengthened layer depending on the discharge energy, namely, $\Delta H_{\mu sl, W_p \max}$, the activation energy E and the greatest increase in the microhardness of the strengthened layer depending on the labor intensity of the ESA process, namely, $\Delta H_{\mu sl, \tau}$).

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**УДОСКОНАЛЕННЯ ПАРАМЕТРІВ ЯКОСТІ ПОВЕРХНЕВИХ ШАРІВ ДЕТАЛІВ
ЗІ СТАЛІ ПІСЛЯ НІТРОЦЕМЕНТАЦІЇ МЕТОДОМ
ЕЛЕКТРОІСКРОВОГО ЛЕГУВАННЯ**
**Частина 2. РОЗРОБКА МАТЕМАТИЧНОЇ МОДЕЛІ УПРАВЛІННЯ ПАРАМЕТРАМИ
ЯКОСТІ ПОВЕРХНЕВИХ ШАРІВ СТАЛЬНИХ ДЕТАЛЕЙ**

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В результаті проведених у статті досліджень розроблено математичні моделі залежності параметрів якості поверхонь при нітроцементації методом ЕІЛ із використанням спеціальних технологічних насичуючих середовищ (СТНС) (рівняння приросту товщини зміцненого шару та рівняння приросту мікротвердості поверхні) від енергетичних і технологічних параметрів обладнання ЕІЛ, відповідно, енергії розряду (W_p) і трудомісткості (τ), що дозволяє визначати основні технологічні параметри сформованого шару: товщину зміцненого шару ($h_{з.ш.}$) і його мікротвердість ($H_{\mu з.ш.}$). Також встановлена методика визначення констант рівняння приросту товщини зміцненого шару (найбільший приріст товщини зміцненого шару залежно від енергії розряду – $\Delta h_{з.ш. Wp_{max}}$, енергія активації – E та найбільший приріст товщини зміцненого шару залежно від трудомісткості обробки ЕІЛ – $\Delta h_{з.ш. \tau_{max}}$) а також рівняння приросту мікротвердості поверхні (найбільший приріст мікротвердості зміцненого шару залежно від енергії розряду – $\Delta H_{\mu з.ш. Wp}$, енергія активації – E та найбільший приріст мікротвердості зміцненого шару залежно від трудомісткості обробки ЕІЛ – $\Delta H_{\mu з.ш. \tau}$).