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# Structure and Properties of Surface Layers of Pieces Cemented when Interacting with the Plasma Channel of Electric Discharges in Pulse

PhD. Eng. BEȘLIU Vitalie
State University „Alecu Russo", Moldavia Republic

## ABSTRACT

*In this paper it is presented a cementing method of the superficial layer of the parts surface by applying electric discharge in pulse with electrode tools made of graphite. By metallographic analyses and studying the micro hardness of superficial layers of plastic mold steel parts it has been determined the fact that the electric discharge in pulse under a regime of overexcitement induce thermal and thermo chemical processes, that considerable influence micro hardness of the white layer by increasing its value of 18 times.*
***Keywords**: cementing method, superficial layer, electric discharge.*

## 1. Introduction

For hardening and depositing protection layers, an important role have the electro physical methods of materials processing based on the usage of energy concentrated fluxes, like bunch of electrons [16], laser rays [17], low temperature plasma [1, 16], electric discharge in pulse etc. [1].

One of these methods is the superficial processing by applying electro discharge in pulse on metallic surfaces that with great success is being applied to harden the pieces, mechanisms in machine building [2, 3]. It is known the fact that the superficial processing with electric discharge pulse applying is characterized by a long string of advantages presented in papers [4, 5, 6], but has disadvantages also like: small thickness of the processed surface layers, relatively small productivity, high roughness surface. Not searching for the disadvantages, this process has been developing lately and widely it is being used in different applicability domains.

The hardness process by applying electric discharge in pulse of metallic surface is based on the electric erosion effect and on the polar transfer of the anode material to cathode by applying between this two the electric discharge in pulse. This assures the possibility of forming processed surface part of a superficial layer with special physical-chemical properties [1]. For processing the surface like in this method, for tool anode electrode are used different conductor materials like : copper, metal carbons, graphite, nickel), influencing the chemical and mechanical properties of the researched part (by changing its hardness, resistance to usage, roughness) [1, 6].

It has been demonstrated the fact that the usage of tool electrode made of graphite can influence the decrease of the superficial layer roughness under processing [7, 13] and increasing the micro hardness [9, 10, 11].

There is a row of pieces that due to building motives cannot be processed by classical methods in the purpose of decreasing surface roughness. By the practical application of electric discharge in pulse at hardness it has been noticed that using the tool electrode made of graphite can decrease the surface roughness [7]. In paper [7] have been made experimental researches using steel 45 for piece material in normal state, and the tool electrode made of Ti, Ni, Cu and Ag. The experiences have been made on the „Elitron-22" installation within energies 0,2-0,4 J.

The experimental results obtained after the electric discharge have proved that the minimal roughness (fig. 1) is obtained for the copper electrode. For the cases followed by the processing with tool electrode made of graphite it has been noticed a small decrease of the roughness for all the 4 cases. These results are being proved by the fact that on the graphite electrode processing on the coated surfaces with Ti and Ni, carbons that are hardly melted take place, they submit melting that leads to surface leveling. Decreasing roughness with graphite electrode can be explained by the material processing.

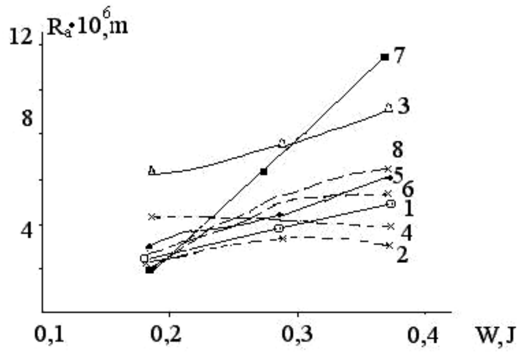



**Fig. 1** *Dependence of surface roughness on the energy of electric discharges in pulse*
*Anode material: 1-Cu; 2-Cu+graphite; 3-Ag; 4-Ag+graphite; 5- Ti; 6-Ti+ graphite; 7-Ni; 8-Ni+graphite. Cathode material: steel 45 [7].*

Having this high enough electric resistance compared to most of the metals, graphite is fast warming up in the electric discharge process till temperatures of 800-1000°C. Interacting with the surface leads to the decrease of the abnormality surface, and by mechanical shocks influence to a fine relief.

Authors of paper [9] have made experimental researches with tool electrode made of graphite and copper in deionizer water and kerosene, pieces being made of plastic mold steel. The trying have been made on a electric pulse generator that assures a medium value of the discharge current I=1; 2; 4; 8 şi 16 A and a discharge duration of $\tau$= 6; 12; 25; 50; 100; 200; 400; 800 and 1600 μs.

Research of these probes micro section demonstrated that, on the part surface forms the white layer with highest hardness followed by the zone of thermal influences and the basic material. Measuring piece micro hardness after Vickers was done with a 10 g heaviness during 15 s and a increase of white layer hardness of almost 3 times than the basic material was determined.

Analysis of the obtained data, demonstrate the fact that, in case of tool electrode usage made of graphite, the white layer hardness is higher than using copper indifferent of the dielectric used. The X-ray study of this cross section has shown that using kerosene as working medium, on the part surface appears cemented than using deionizer water.

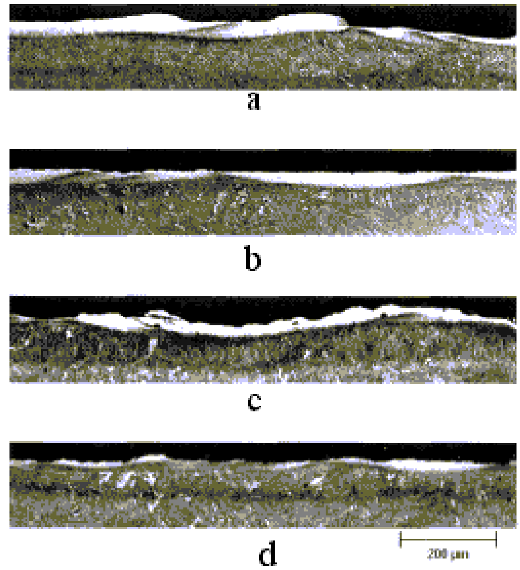



**Fig. 2** *General view of piece cross section: in deionizer a) I=16 A graphite electrode; b) I=16 A copper electrode; c) I=8 A graphite electrode; d) I=8 A copper electrode [9].*

In case of applying tool electrode made of graphite in air medium being connected as anode [11] and as a cathode on piece surface, also a change could be seen of micro hardness with formation of some graphite deposition on part surface [10].

The analyze of this papers had lead to the idea of increasing more and more the micro hardness of processed part surface it would be very suitable to use the tool electrode made of graphite. Next we will present the experimental research results of surface hardening by applying tool electrodes made of graphite and bipolar impulses in a regime of under excitation.

## 2. Experimental research method

In papers [8, 12] it is mentioned that the thermal and thermal chemical treatments with electric discharge in pulse applying, can take place without melting and vaporizing of processed part material. So for obtaining thermal treatment without melting the material it is necessary that the discharge duration to be smaller than $10^{-7}$ s. Regarding this things it has been elaborated a current pulse generator of RCL type which scheme is presented in figure 3 [12]. This feeding source has: power pulse generator 1, block of high voltage2 and the co mandate block 3, a more detailed description is presented in paper [12]. Studying the oscillating graph of the similar discharges presented in figure 4 we can say that the discharging pulse duration can vary from 9 to 94 μs, duration between pulses being of 6-15 μs. From the general view of the oscillating graph we can see that the polarity during a solitary discharge reverse changes due to inductance from electrical circuit scheme. That means that one of the electrodes in the positive period is a cathode, and in the negative one becomes an anode and reverse. Also we can see that the value of the current amplitude in the discharge circuit for the positive semi period is twice bigger than the negative period.

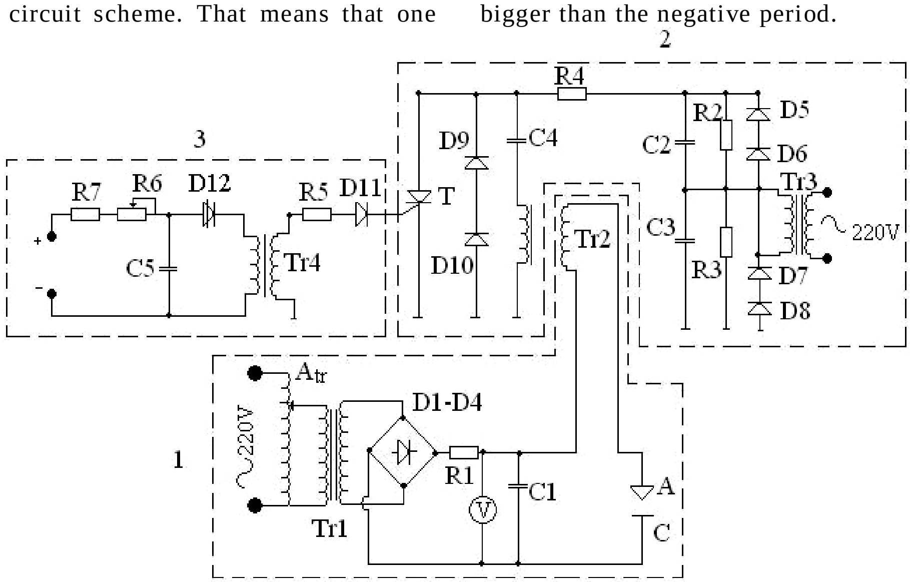



**Fig. 3.** *The main electric scheme of the feeding source for thermal and thermal chemical treatment of piece surfaces by electric discharge in pulse*

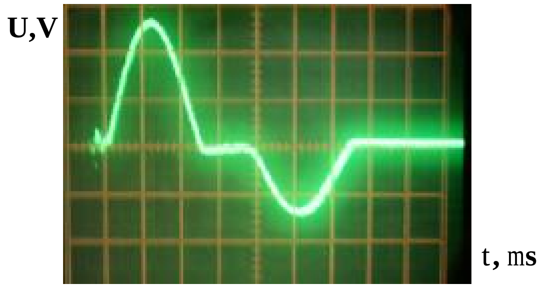



**Fig. 4.** *General view of the oscillating graph obtained by means of the source described above in the discharge circuit: $U_c$=400 V, S=1,5 mm, C=8 μF, f=8 Hz.*

Experimental researches have been made in air conditions at atmosphere pressure, in over excitation regime in which the piece or the electrode had the possibility to polarity change the positive semi period. Under the influence of high voltage impulse a conductivity channel takes place through what by applying the power pulse the force discharging takes place forming the plasma channel.

The tool electrode is made off graphite bar with 2 mm diameter, rounded at the end under semispherical form, and the piece made of steel 45 in plastic mold as a square of 20×20×5, which moves from the electrode with a speed of V=1 mm/s (fig.5).

The voltage of charging the capacitor battery varies from 400 V to 600 V, interstice energy varies between 0,26 - 0,58 J, discharge frequency f=8 Hz, interstice size S=0,5 mm, pulse duration τ=60 μs, capacity C=8 μF.

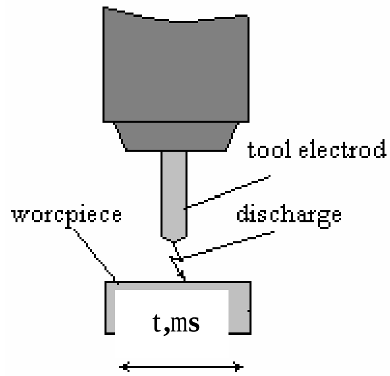



**Fig. 5.** *Cinematic scheme of surface processing using the method of electric discharge in pulse applying graphite electrodes.*

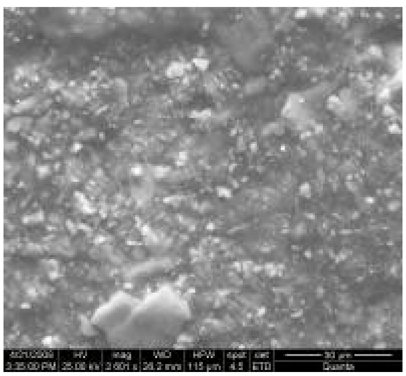
Micro hardness of superficial layer is measured with ПМТ-3М with weight on penetrator of 5g during 7s. Piece surface morphology after processing has been studied with scanning electronic microscope QUANTA-200 (FEI Filips).

## 3. Experimental results and their interpretation

In result of electric discharge in pulse action on steel 45 plastic mold, with the tool electrode made of graphite, on the part surface take place graphite depositions on the usage of the tool electrode as anode as well as the cathode. Morphology study of the part surface after interacting with plasma electric discharges in pulse show us that in case of electrode made of graphite usage as a cathode the depositions are bigger. For the same number of passes the higher the energy emitted in the interstice is, the lower the graphite depositions are (fig. 6)

The metal graphic analysis of processed parts has shown the fact that, on the part surface besides the graphite depositions also forms the white layer, separate from the basic material through an intermediate layer. Research of these layers micro hardness shows that highest micro hardness is on the white layer (fig. 7). Value of micro hardness is a function of processing energetic regime, of the number of passes and of the tool electrode polarity. High micro hardness of the white layer can be explained by the fast heating of a small volume of material followed by the sudden cool of this or due to diffusion phenomena in the part surface. White layer thickness is almost 5 - 14 µm and is a function of the processing energetic regime.

From the graphics presented in fig. 8-15 we can see that the micros hardness curves can have exponential shapes, micro hardness slowly decreasing, as well as their deviations to, followed by a decreasing of micro hardness in the intermediate zone. This micro hardness decreasing can be explained by the appearance of the recurrence phenomenon or by the carbon diffusion from the intermediate layer to the surface one fig. 8 (1, 3), fig. 9 (3), fig. 12 (1, 3), fig. 15 (1, 3). These phenomena cannot be observed when the white layer micro hardness is maximum indifferent of the tool electrode polarity fig. 9 (2), fig. 14 (3) etc.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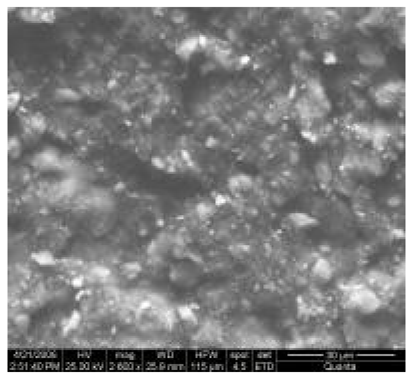
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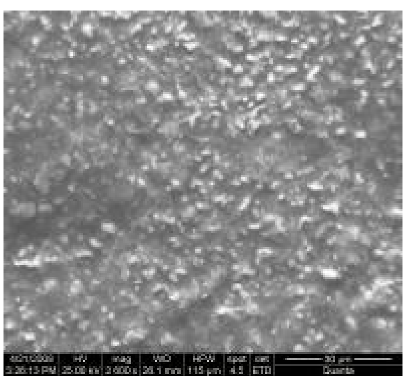
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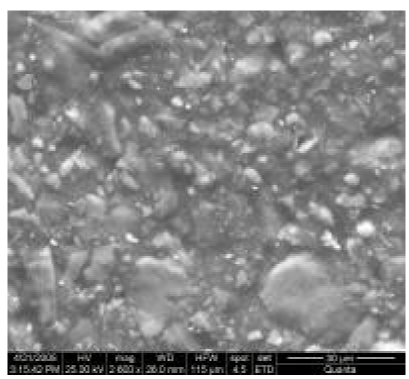
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**Fig. 6.** *The surface morphology after applying electric discharges in pulse for the regimes: C=8 µF; f=8 Hz; V=1 mm/s; S=0,5 mm; n=2 treceri; a-W=0,42 J, b-W=0,58 J, the tool cathode electrode, c-W=0,42 J, d-W=0,58 J, the tool anode electrode.*

We can see that the maximum micro hardness for the case when the tool electrode is an anode is obtained at two passes, for the emitted energy in the interstice of W=0,42 J and makes up 101, $8\times10^8$ Pa which is 10 times higher than the basic material micro hardness material fig. 16 (3) afterwards the maximum micro hardness of the white layer decreases. For the interstice energy of W=0,58 J fig. 16(2) maximum value of micro hardness is also obtained for two passes being almost 4 times bigger than the basic material, following a decrease of the maximum micro hardness with the increase of passes number. For emitted energies in the interstice of almost W=0,26 J maximum micro hardness value curve is obtained at one single pass. In case of using as an anode the tool electrode for all the three energies we can see an increase of the maximum micro hardness followed by a decrease with the number of passes.

For emitted energies in the interstice between W=0,26 J and de W=0,42 J at two passes, white layer micro hardness has almost $50,3\times10^8$ Pa and $77,2\times10^8$ Pa which means an increase of the micro hardness of almost 4-7 times than the material in the initial state fig. 17 (1,2). At the interstice energy of W=0,58 J fig. 17(3) the maximum micro hardness is obtained at 3 passes is higher than the initial micro hardness of almost 18 times.

From analyzing the experimental results we can underline that, the maximum micro hardness on the usage of tool electrode as anode can be obtained at 1-2 passes, and on the usage of tool electrode as cathode at 2-3 passes in the same processing regimes. Decreasing micro hardness as a function of passes number can be explained by the recurrence of the superficial layer or by destroying it under the remaining tension actions which appear in it.

So, from the analyses results that in case of using tool electrode with polarity changing we have both thermal and chemical thermal phenomena due to diffusion phenomena from the superficial layer

So we can suppose that using tool electrode as a cathode in the first semi period on the part surface we can obtain higher graphite deposition (graphite erosion as a cathode is higher than the case of anode graphite [10, 12, 14]), and after a certain pause during the second semi period are developing the diffusion processes [4, 9, 11] that assure conditions for the deposited carbon on the part surface to diffuse in its height by changing its physical-chemical properties of the surface layer. For tool electrode anode the processes are reversed, in the end taking place a smaller increase of the micro hardness as in the cathode electrode.

On parts processing with electric discharge in impulse it is very important the determination of diffusion coefficient and the thickness of the superficial layer. According to paper [12] we can mention that like in the experiment described above each processing cycle takes a few steps: high temperature when the plasma channel of the electric discharge in impulse interacts with the part surface and the low temperature due to the pause between semi periods as well as the pause between two electric discharge.

The facts presented in papers [4, 12, 15] allow the determination of the effective diffusion coefficient of $D_{ef}$ elements, with the relation:

$$D_{ef} = N(D_1t_1 + D_2t_2 + D_3t_3 + D_4t_4) \quad (1)$$

in which: N- is the number of processing cycles; $D_1$ - the diffusion coefficient in the first semi period; $D_2$ - the diffusion coefficient in the pause between the first and the second semi period; $D_3$ - diffusion coefficient in the second semi period; $D_4$ - diffusion coefficient between two discharges; $t_1$ and $t_3$ are the duration of electric discharges in both semi periods; $t_2$ and $t_4$ are the duration of pauses between the two semi periods and of the pause between two discharges.

Quantitative the number of processed cycles belongs to the one of electric discharges in impulse with which interacts with the processed surface of the part. If we think that, each electric discharge in impulse leaves on the processed surface a sign that looks like a circle with the $d_0$ diameter than for a $A_0$ surface for which we determine the elements concentration, we can write: $(A_0 = pd_0^2/4)$, and if the processed surface is a square, its surface will be $A_d = a^2$.

On the surface processing with electric discharge in impulse application $A_d \geq A_0$, the quantity of processing cycles will be determined with the relation [4, 12, 15]:

$$N = (A_d / A_0)ft \quad (2)$$

in which f - is the electric discharge in impulse frequency, and $t$ - processing time of the probe surface.

In the time distance that is the pause between two electric discharges redistribution of the elements in the deposition layer doesn't take place because the temperature is low, and as a result the diffusion speed in this period is much smaller [4, 12].

The researches made by the authors of paper [15], have proven that, the formed layers with the electric discharge in impulse application are made of two zones: the first zone is the zone of uniform distribution of alloyed elements- called mixing zone and the second one- the diffusion zone. In the first zone take place the complex metallurgical processes caused by the vaporization, melting and mixing of the liquid phases of the alloyed materials and of the part material matrix, and on the second zone take place the diffusion processes caused by the thermal processes in solid state at considerable depths of the piece material [4, 12].

For describing the proposed mechanism it could be applied according to [4, 15] the one-dimensional equation of the diffusion elements from a layer with h thickness in a semi infinite body:

$$\frac{\partial C_j}{\partial t} = D\frac{\partial^2 C_j}{\partial x^2}, (j = 1,\ldots,N) \qquad (3)$$

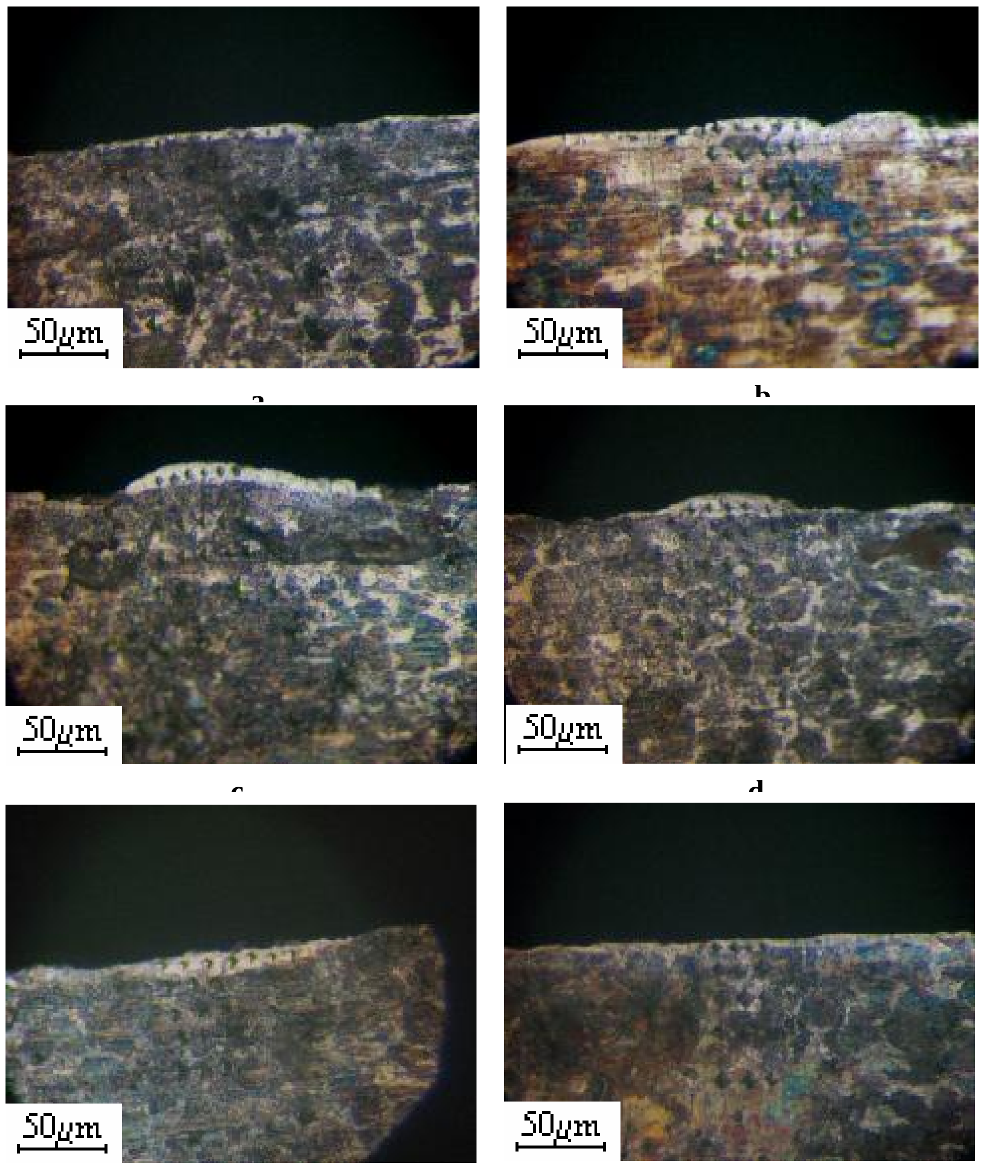


**Fig. 7.** *Micro structure of the steel 45 piece after applying the electric discharges in pulse with the tool electrode catode in the rgimes : C=8 µF; f=8 Hz; V=1 mm/s; S=0,5 mm; a- W=0,42 J, n=2 treceri, b-W=0,42 J, n=3 treceri, c- W=0,26 J, n=3 passes; d- W=0,26 J, n=4 passes; e- W=0,58 J, n=4 passes; f-W=0,58 J, n=4 passes (tool electrode anode).*

The initial conditions for the first processing cycle have been established as it goes:

$$C_1(x,0)=\begin{cases} C_0, & \text{if } 0\le x\le h;\\ 0, & x>h.\end{cases} \quad (4)$$

in which $C_0$ is the initial concentration of the part material from the surface layer deposited on probe surface. For the next cycles the initial conditions are determined from the element concentration distribution in the previous cycle regarding the deposited thickness layer:

$$C_j(x,0)=\begin{cases} C_0, & \text{if } 0\le x\le h;\\ C_{j-1}(x-h), & x>h.\end{cases} \quad j\ge 2. \quad (5)$$

According to [15] the thickness layer h is considered to be constant for each processing cycle and is determined separately for each case having the equilibrium equation of the quantity substance with the relation:

$$h=\frac{\int_0^{\infty} C(x)dx}{C_0 N} \quad (6)$$

From the things analyzed above we can say that the effective diffusion coefficient can be experimental determined after the method in paper [15], and applying the mathematical model presented above we can determine the thickness of the formed layer.

## 4. Conclusions

In the result of electric discharge in impulse action on steel 45 plastic mold with tool electrode made of graphite used as an anode as well as a cathode, when applying bipolar discharging have been observed that: indifferent of the tool electrode polarity on the part surface we can only see graphite depositions of a higher or smaller quantity s well as the appearance of the white layer with an important micro hardness; from the researches made we can say that surface micro hardness can be 2-18 times amplified depending on the chosen processing regime; generally the maximum value of micro hardness is reached at 2-3 passes for steel 45 and means a 10 times amplifying when using the tool electrode as anode, and almost 18 times on applying the tool electrode as cathode; Knowing the carbon concentration distribution in the part surface layer can be determined the effective diffusion coefficient and the thickness of the formed layer.

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## Structure et propriétés des couches extérieures de morceaux cimentés en agissant l'un sur l'autre avec la Manche de plasma des décharges électriques dans l'impulsion

**Résumé**

En ce document il est présenté une méthode de cimentage de couche superficielle de la surface de pièces en appliquant la décharge électrique dans l'impulsion avec des outils d'électrode faits de graphite. Des analyses métallographiques et en étudiant la dureté micro des couches superficielles de pièces en acier de moule en plastique on l'a déterminé le fait que la décharge électrique dans l'impulsion sous un régime d'overexcitement induisent des processus chimiques thermiques et thermo, cette dureté micro d'influence considérable de la couche blanche en augmentant sa valeur de 18 fois.

## Struktur und Eigenschaften der Deckschichten Stücke beim Einwirken zementiert auf den Plasma-Kanal der elektrischen Entladungen im Impuls

**Zusammenfassung**

In diesem Papier wird er eine zementierenmethode der oberflächlichen Schicht der Teiloberfläche dargestellt, indem man elektrische Entladung im Impuls mit den Elektrodenwerkzeugen anwendet, die vom Graphit hergestellt werden. Indem metallografische Analysen und das Studieren der Mikrohärte der oberflächlichen Schichten Plastikform-Stahlteile, ist es der Tatsache, dass die elektrische Entladung im Impuls unter einem Regime von Overexcitement die thermischen und Thermo chemischen Prozesse verursachen, dieser Mikrohärte des beträchtlichen Einflusses der weißen Schicht festgestellt worden, indem man seinen Wert von 18-mal erhöhte.