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EXPERIMENTAL RESEARCH ON THE BEHAVIOR OF TOOL-ELECTRODES MADE OF CONDUCTIVE MATERIALS BY APPLYING DEI

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ABSTRACT: This paper presents the results of experimental research on the behavior of tool- electrodes made of copper, brass, aluminum and graphite by applying pulsed electrical discharges. The electrodes applied to the formation of the surface layers are made of conductive materials subjected to different energetic modes during the experimental investigations. The authors studied the effects that appear between the base electrodes (anode and cathode) varying the polarity and charging voltage of the capacitor while the other regimes remain constant (gap, DEI frequency, capacity and time).

KEYWORDS: tool-electrode, conductive materials, erosion, spot electrode.

1. INTRODUCTION (HEADING 1)

Electric discharges generally represent a concentrated source of energy that has currently asserted itself in a wide applicative domain in technologies of material processing. Since B. R. Lazarenko and N.I. Lazarenko invented the method of processing materials through electro erosion, a new term was introduced in use "spark electric discharge" or "electrical sparking". This type of electric discharges was first applied in dimensional processing [1, 8, 9, 13, 14] and later, in the formation of superficial deposition layers made of compact materials [13] and dust [4]. Further development of this method of processing made it possible to correct the surfaces to a higher class of roughness [14]. However in the literature related to this domain of electric discharges various terms, such as electrical discharge in pulse, "micro spark" etc. are being used.

Thus "electric sparks" [1, 2, 10, 11], "micro-electro discharge" [3, 5, 6, 7] and "electric discharge in pulse" [4] are characterized by the presence of two electrodes between which there is a gap, of $2\cdot10^{-6}...10^{-3}$ m, a pulse current in the gap of $10^{-8}...10^{-4}$ s, the total falling of electrode voltage being about 20 V; meanwhile between the electrodes there is a cloud of plasma and all this takes place in dielectric media.

It follows from the above said that, in fact, these concepts reflect the same essence and they may be considered synonyms. In [2] eloquent arguments are brought according to which these are early stages of electrical arch discharge.

During dimensional processing by applying DEI, there is no direct contact between the tool and the work piece as, during the process of deposition layer formation they are permanently separated by a film of dielectric liquid or gas. As a result of the voltage produced by the generator, the dielectric medium (gas or liquid) is pierced by an electrical discharge in pulse of short duration ($10^{-8}...10^{-4}$ s) which due to the temperature that develops (over 10000°C) melts the local work piece and the tool- electrode. After a pause, necessary for the deionization of the dielectric environment, the tool- electrode and the work piece are again subjected to the action voltage and there is a new electric discharge that causes local melting and material removal from another point of the piece (during dimensional processing) or of the tool-electrode (during the formation of deposition layers). The frequency of discharges can reach 400 kHz.

Pulsed electrical discharge that occurs between the tool- electrode and the piece is actually a plasma discharge [2, 9, 10] and has all its features which differentiates it fundamentally from an electrical arch discharge. It primarily points to the current densities of 10^6-10^8 A/cm^2 and the electric field values of about 10^4 V/cm that cannot be reached through electric arch discharge.

Another important feature of the pulsed electric discharge is that during them, the gap voltage always drops to 15-25 V for generators of controlled impulses and to 40-70 V for generators of relaxation. Due to these features, the processing through electro erosion by applying DEI has an intense erosion character, well targeted and well dosed unlike the arch discharge that has a destructive effect, unmanaged, leading to low productivity, but producing serious tool-electrode wear. As for the way in which DEI between the tool-electrode and the piece is produced, there are several theories among which the best known are [10]:

a) the theory of spark discharge channel for pure dielectric fluids. Although in practice there is no absolutely pure dielectric, a clean, well filtered dielectric may be assimilated to such a dielectric. In this case, before the electric discharge in pulse, an electronic current is established between the nearest points on the surface of the tool-electrode and of the work piece. Since the electrons of this current have a low energy, they cannot produce the ionization of the dielectric environment, but they produce a local heating that leads to the formation of a gas bubble. This gas bubble causes the pulsed discharge which then leads to removing the material;

b) the theory of forming the discharge channel for real industrial dielectric fluids. According to this theory, real dielectric fluids contain impurities typical of erosion products or of pyrolysis products that form an ionized discharge channel via bridges formed by particles. One discharge is followed by another one in the direction of two nearest points;

c) the theory of forming the discharge channel in a gaseous medium includes two mechanisms: the first, while the two electrodes contract, Joule-Lentz heat is emitted on the active resistance between them which favors electron emission, and, respectively, the formation of the conductivity channel; the second involves the application onto the gap of high intensity ($10^7...10^8$ V/m) electric fields that facilitate electron emission accelerating them and forming the conductive channel in the avalanche.

From this point of view, of particular interest are the layers formed by applying pulsed electrical discharges that can be created from compact materials as well as from the powder of these alloys or of their mixtures. It is worth mentioning that this method is also beneficial due to the fact that an intermediate layer which ensures perfect adhesion of the deposit on the piece, as in the case of welding, is formed.

The surface layer may serve as a constructive element of pieces and can also alter the emission and absorption properties of various types of radiation via the modification of the surface micro-geometry.

2. METHODOLOGY OF EXPERIMENTAL RESEARCH

The qualitative properties and parameters of the deposition depend to a great extent on the composition, structure and geometry of the used electrode.

The electrodes are executed in the form of cylindrical rods, often using electrodes with a diameter of 0.8…1 mm, however electrodes whose diameter is 0.5...2 mm may be used as well. The electrode diameter is chosen depending on the diameter of the craters that appear during the electric discharge between the electrode and the work piece. When applying electrodes with diameters larger than 1.5 mm, the density of coverage is worse. The most used material for electrodes are graphite, brass and copper.

The realization of a qualitatively corresponding deposition must take into account the operating parameters which directly intervene in the process of hardening [5, 6]:

a) electric parameters:

- the ability of the capacitor C (F);
- the intensity of the working current I (A);

b) temporal parameters:

- pulse duration τ (s);

c) technological parameters:

- electrode rotation n (revolutions/min);
- displacement speed v (mm/rev);
- dimensioning of the tool-electrode.

Where necessary, we may adopt more moderate regimes to complete the tools in order to obtain a little roughness and more intense regimes for roughing tools when roughness is not very important.

When selecting the working regime, the following points should be taken into account:

- when the electrode rotation increases the amount of deposited material increases too;
- the increase of current and voltage leads to increased thickness;
- the increase of the frequency of pulses determines the increase of the amount of material transferred to the cathode.

The principle of the method of hardening via electric discharges in pulse (DEI) is particularly accessible, basically relying on the effect of electrical erosion which is followed by a controlled transfer of material from the tool-electrode toward the piece electrode (fig.1).

Thus under the influence of an electric field, due to a controlled pulse generator, there is a possibility for the appearance of discharge plasma micro channels. The transfer of the harsh material towards the piece surface to be hardened will take place in the working gap between the tool-electrode and piece-electrode.

The displacement of the tool-electrode onto the surface of the work piece will follow the path of the hardened contour, ensuring the conditions of a working gap necessary for the optimal process of forming plasma channels caused by the energy of impulses produced by electrical discharges between the tool-electrode and the piece-electrode. The quality of the deposit depends heavily on maintaining a constant and permanently controlled distance between the tool-electrode and the piece-electrode.

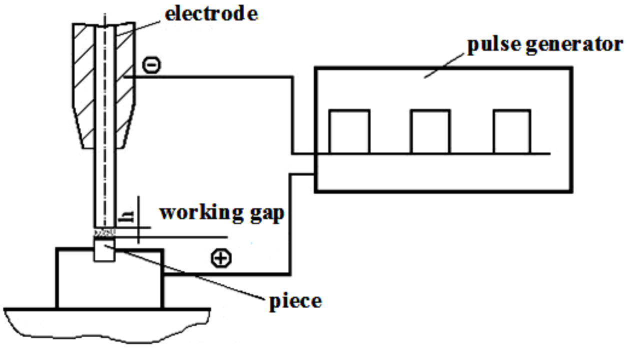


Figure 1. Working scheme of hardening by the application of electric discharges in pulse [4]

3. THE RESULTS OF EXPERIMENTAL RESEARCH

In [7] they applied pulsed electrical discharges in pulse with a graphite tool-electrode, applying bipolar pulses in the regime of maintaining "cold" electrode spots. It was noticed during the experiment that graphite deposits occur on the work piece surface when the tool-electrode is used both as anode and as cathode as a result of the effect of electric discharges in pulse on graphite, copper and brass with a graphite tool -electrode. The study of the piece surface morphology after the interaction with plasma electric discharges in impulse attests the fact that when using an electrode made of graphite as cathode, the deposited layer is thicker.

Typical of this method is the fact that during the formation of coatings there are no linear or volume changes in the material subjected to hardening. In order to realize hardening via electrical discharges in pulse the following conditions should be observed:

- high conductivity of the processed work piece; the greater the conductivity the lower the losses of electricity;

- before hardening the tool is subjected to standard thermal processing;

- the tool (plate or stamp) should be uniform and not have any defects;

- areas subjected to hardening must be degreased with pure petrol or pure technical spirits. If the surfaces have protective coatings or are covered with rust, they should first be cleaned with abrasive paper.

Superficial application via pulsed electrical discharges is currently divided into the following main areas:

- dimensional processing aimed mainly at removing a part of the material from the surface of the semi-finished article in order to modify its shape and dimensions to obtain the product under imposed technical conditions;

- the formation of the deposited layer whose main aim is the transfer of the removed material from the surface of one of the electrodes to the surface of the other one to modify the properties and composition of the work piece surface layer;

- the formation of surface layers by enriching the machined surface of the piece with elements from the working environment.

Having analyzed what has been said above, when the tool- electrode is connected as cathode, we may conclude that in this case we have graphite deposits on the surface of the work piece processed by electrical discharges in pulse which are thin graphite films (fig. 2). These deposits may be explained by the fact that the tool-electrode material is not a metal and the processes at electrical discharges in pulse do not occur as in conventional alloying.

Analysis of micro-sections has shown that, when the graphite electrode is the cathode, there are parts on the piece surface similar to the case when the piece is the anode; thus we have the zone of thermal influence.

Similar confirmations that the graphite tool-electrode as cathode erodes more than when it is anode, were reported in [6].

The metallographic analysis of superficial layers of machined pieces has shown that besides deposits of graphite there is a white layer separated from the basic material with the help of the passage layer. The investigation of these layers hardness (fig. 3) shows that regardless of the tool-electrode polarity besides graphite deposits on the work piece surface there is also a white layer of high micro-hardness. Experimental research shows that the surface micro hardness may be increased by about 2-10 times compared to the basic material and its thickness varies within the limits 5-10 µm.

The first area of application of this machining process was very diverse in machine and apparatus building allowing to process those materials that are not subjected to processing by conventional methods (metal carbide with high melting temperature of the type WC, TiC, TaC, semiconductors, etc.), ensuring the treatment of complex surfaces (holes, orifices, cavities, prominences, etc.) and last but not least providing a total automation of processing [6, 9].

The second direction of applying this method related to the modification of the composition and structure of the surface layer of the piece used in machine and apparatus building has branched off as follows:

- formation of depositing layers from compact materials in which the material removed from the tool-electrode surface plays the main role in the modification of the superficial surface of the processed piece.

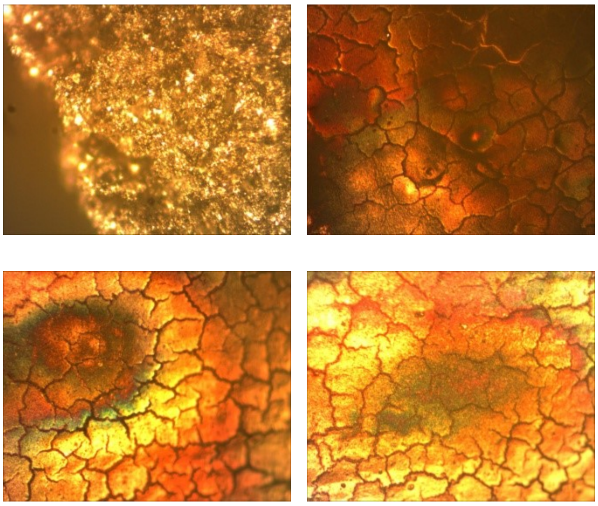


Figure 2. Piece microstructure after the application of electric discharges in pulse for: graphite anode; graphite cathode: 1) C=600 μF; f=5 Hz; S=0.55mm; U=60 V; 2) C=600 μF; f=5 Hz; S=0.55 mm; U=100 V; 3) C=600 μF; f=5 Hz; S=0.55 mm; U=160 V;4) C=600 μF; f=5 Hz; S=0.55 mm; U=220 V; 5) C=600 μF; f=5 Hz; S=0.55 mm; U=260 V

- formation of depositing layers from powders and powder mixtures in which the powder material first and second, the tool-electrode, play the main role or in special cases the tool material practically does not influence the deposit composition and properties.

The third direction ensures the modification of the piece surface layer composition and properties in conditions of lack of piece dimension modification or it is accompanied by a decrease of roughness on the machined surface which is actually a relatively new trend and in special literature it is considered rather as a scientific statement than as a well-defined technique applied in practice.

It is assumed in all cases applicable to this method of processing that the processed surface roughness is directly related to the size of craters with a liquid phase that appear on the machined surface; however when depositing layers are formed one can notice a growth of some separate areas of deposits that violate the condition of forming continuous layers [7, 8, 10, 11]. This is due to the emergence of some initial or induced asperities that serve as hubs for the electric field of electrical discharges in pulse and directing the removal and transfer of the material either from the liquid phase of the tool-electrode or from the powder material introduced into the gap for the formation of a deposit with special properties.

The superficial processing by applying electric discharges in pulse is characterized by the following advantages [7, 11, 12]:

- the deposited material is ensured good adhesion to the material of the piece;

- deposits may be formed not only from pure metals but also from their alloys and hard alloys (powder metallurgy);

- the heating of the piece metal is practically missing during the processing;

- micro metallurgic processes occur during alloying to the cathode surface. This allows the formation of alloys which confer the surface new properties related to the cathode material, as well as that of the deposition material;

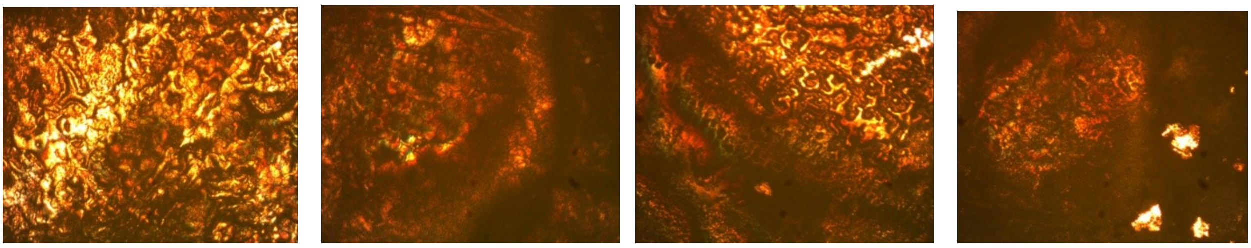
- diffusional enrichment of the cathode surface with elements of the anode without changing the cathode;

- localized alloying is possible;

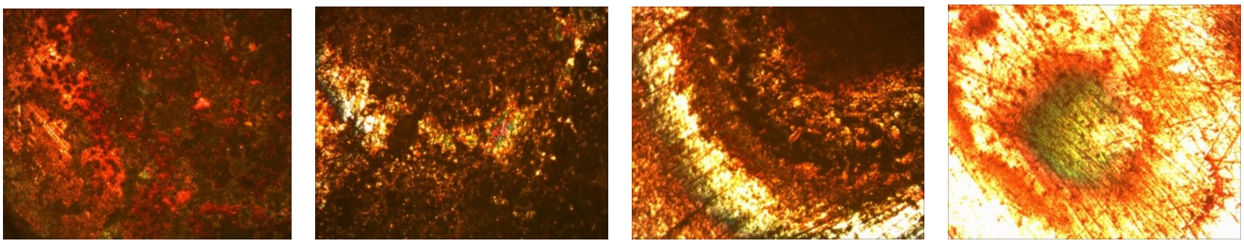
- before alloying the surface does not require good cleaning of impurities unlike other methods. The technology of deposit formation is very simple and the necessary equipment is of small size and easily transportable.

When deposits of compact materials are formed [4, 7], bar shaped anode electrodes are applied and they are made of materials with prescribed properties depending on the properties necessary to be conferred to the piece (antifriction materials, anticorrosive materials, Pd and Rt, hardening materials, such as carbides of different materials and graphite or their combinations, etc.).

Usually the research of the intensity of deposits formation was done depending on the energetic regime of processing and the frequency of pulse discharges indicating the material for the execution of the electrode and its diameter (for bars of cylindrical section) or the thickness of the cross-sectional width (for bars of rectangular section).

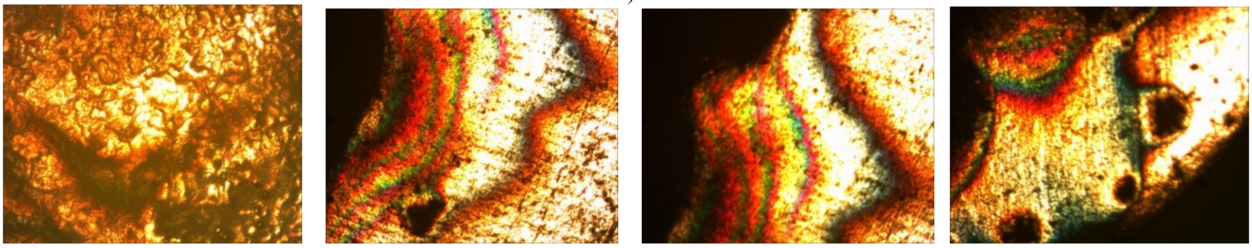


graphite cathode; copper anode

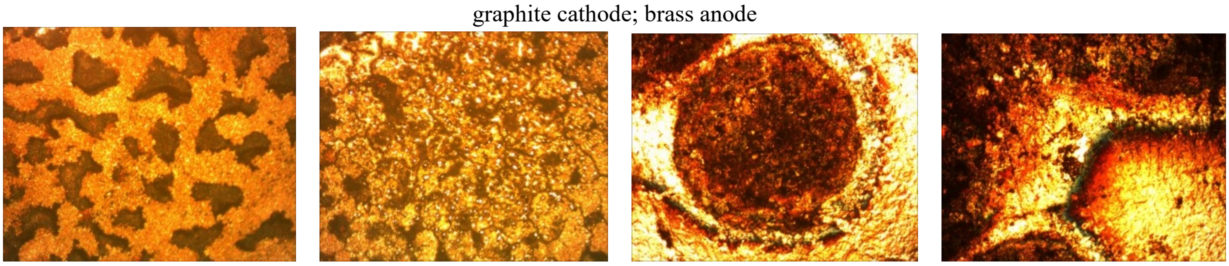


graphite anode; copper cathode

a)

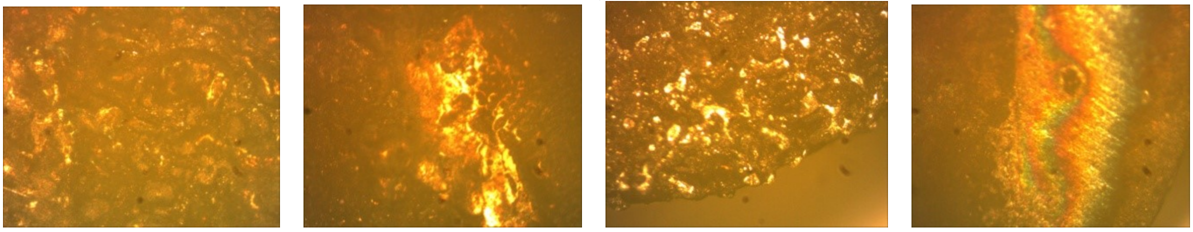


graphite cathode; brass anode

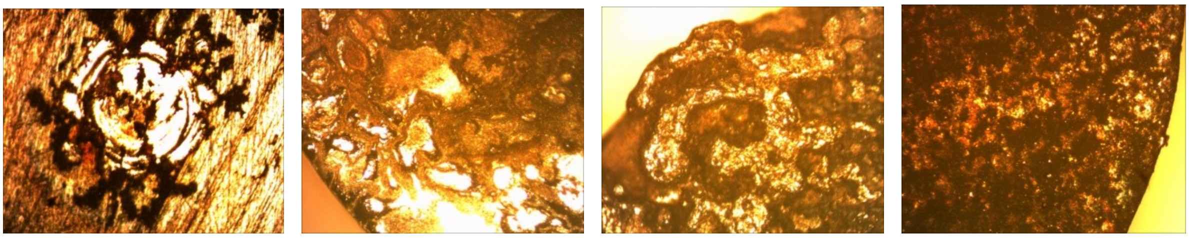


graphite anode; brass cathode

b)



graphite cathode; aluminum anode



graphite cathode; aluminum anode

c)

Figure 3. Piece micro structure after the application of electric discharges in pulse for: a) graphite-copper; b) graphite-aluminum; c) graphite-brass: 1) C=600 µF; f=5Hz; S=0.55 mm; t = 30 s; U=60 V; 2) C=600 µF; f=5 Hz; S=0.55 mm; t = 30 s; U=100 V; 3) C=600 µF; f=5 Hz; S=0.55 mm; t = 30 s; U=160 V; 4) C=600 µF; f=5 Hz; S=0.55 mm; t = 30 s; U=220 V; 5) C=600 µF; f=5 Hz; S=0,55 mm; t = 30 s; U=260 V

It is necessary to determine the role of the cross-sectional area of the tool- electrode in the formation of the deposit. Experimental research results presented in [11] show that the energy emitted in the gap is divided into several components:

Wp is the energy emitted in the plasma channel, Wa is the energy emitted at the anode surface and Wc is the energy emitted at the cathode surface.

The indicated dimensions are different and their redistribution occurs depending on the material of the cathode piece, anode electrode and on the properties of the working environment in the gap. Usually a technology is more efficient if no special conditions are imposed that is why the research of electric discharges in pulse of electrodes was done in an ordinary atmospheric environment for electrodes made of copper, graphite, brass.

4. CONCLUSIONS

We may conclude from the above said that:

- when designing the tool-electrodes one should take into account the operational conditions;

- the form of the tool-electrode will allow it to operate so that its surface could relax for several machining cycles;

- the materials available for the development of the tool-electrode are: technical copper, technical graphite as well as aluminum and brass;

- the dimensions of the tool-electrode depend on the dimensions of the surface to be processed and the energetic regime of processing;

- the tool-electrodes used in all cases serve to introduce the energy of effect from the generator into the gap made by the piece and the tool;

- The tool-electrodes may have a cylindrical form and may be made of the same or of different materials.

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