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Specifics of Surface Micro-Geometry Modification under the Action of Temperature and Electric Field of Electrode Spots

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Abstract. The paper presents the results of experimental research on the possibilities of micro-machining conductive and semi-conductive materials that gives them new functional properties. It emphasizes that surface micro-geometry modification occurs in practically all cases of the action by concentrated sources of energy, but a prescribed geometry can be reached only under strict conditions. The process of this geometry formation is a function of the physical and mechanical properties and the chemical composition of the processed material, the gradient of applied energy, the intensity of electric field applied in the discharge gap between the workpiece and the tool-electrode, polarity (positive or reverse/negative) in the discharge circuit of the current impulse generator, etc. It is known that on the processed surface can be formed spherical shaped craters, round asperities or Taylor cone shaped asperities. Depending on the shape and the size of asperities, the active surface area, and, respectfully, the emission and absorption properties of elementary particles and light radiation are modified.

Introduction

Pulse electrical discharge machining (PEDM) as a process of rapid transformations of electrical field energy in other types of energy is of interest as the object of investigations not only in physics and energetics, but, from the point of view of practical implementation, in material machining too [1,2,3,4,5,6].

At the modern stage of production the need to improve of material machining techniques becomes more actual. Therefore, to obtain prescribed, complex shape surfaces, during conducting and semiconducting material machining, it is very important to choose the appropriate machining method to reduce from the start the occurring problems during the execution process. This can be done rather qualitative by applying the electrical discharge machining.

In the case of the action with concentrated sources of energy under the workpiece surfaces it is possible to obtain their micro-geometry modification. Modification of surface micro-geometry in particular cases allows increasing the active surface area of thermo-cathodes. It is known that in electronics often there is a need to increase the active surface area of workpieces of equipment, such as electronic tube cathodes, in order to increase the intensity of the emission current in the process of their functioning [7,8,9,10,11,12].

Experimental Setup

With the purpose of developing reverse polarity PEDM a special generator designed for semi-conductive materials and metal surface processing was used. The use of this generator allows obtaining on the metal and semi-conductive materials surfaces thin films with enhanced physical and mechanical properties. In addition, the experimental setup equipped with fastening/adjusting devices of input parameters allows micro-geometry modification of the conductive surfaces with prescribed precision [1, 13,14,15].

It should be noted that in case of formation thin films, it isn't beneficial the presence of the liquid phase on the processed surfaces, and in the case of micro-geometry modification this phenomenon is counter favorable. With this in mind, the developed generator is equipped with a special device that allows the selection of energy regimes within wide limits [7, 13, 14, 16, 17].

The scheme of positioning of wire shaped electrodes and their connection in the discharge circuit is shown in Fig. 1.

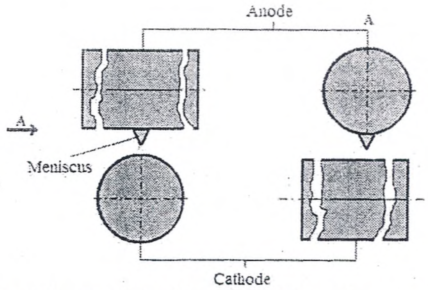


Fig. 1. The scheme of positioning of wire shaped electrodes and their connection in the discharge circuit of the current impulse generator

It is known so far that in the process of dimensional processing and layer deposition formation by electro-erosion method material removal from the anode electrode surfaces takes place with or without its deposition on the cathode electrode surface. It is known that the effects of the interaction of EDI plasma canal are increased on the surface of the anode compared with the surface of the cathode [1, 8, 16, 18, 19]. Therefore, for surface micro-geometry modification, the workpiece is connected in the discharge circuit of the condenser battery as anode (Fig. 1). And respectively, when it is desired to obtain thin films, the workpiece connects in the discharge circuit as cathode.

Results of Experimental Investigations

The investigations carried out with the interaction of the electrical discharge plasma canal with the electrode surfaces have shown that the electro-erosion phenomenon has actually two types of characteristic effects: type I - appearance on the electrode surfaces of the "cold" electrode spots arising on roughness and oxides on them, and causes both surfaces clean of impurities, as well as thermal interact with them, causing structural changes in the surface layers of small thickness (of the order of micrometers); type II - on the electrode surfaces after the "cold" the "hot" spots are formed which causes their melting, accompanied by the phenomenon of vaporization and removal of electrode material in the form of drops [1]. Effects occurring on the electrode surfaces depend on the way of including them in the discharge circuit (as anode or as cathode). These goals have been studied and it was established that those spots which are of short impulse duration are "cathodic" spots, and those of long duration – are "anodic"; so in the case of micro-geometry modification the workpiece must be included in the discharge circuit as anode.

Interaction of the plasma canal with workpiece electrode surface doesn't always have a pure thermal character [1, 7], but often the workpiece surface is enriched with the elements contained in the environment and with those of anode-tool material content.

The authors of the paper studied the influence of the impulse duration (τ) on the quality of the machined surface. It has been established that if the impulse duration $\tau < 10$ µs, then about 90% of metal is removed from the workpiece surface as a vapor and the rest in the form of molten metal. In the case when the impulse duration constitutes $\tau > 1000$ µs, only about 10% of metal is removed in the form of vapor. Considering this fact, for high values of τ and the average current I_m, the liquid droplets of great dimension can be obtained on the workpiece surface during processing. In addition, the roughness of the processed surface depends not only on the average current and the impulse duration, but on the connection polarity of the electrodes too. Surfaces processed by the PEDM method at direct and indirect polarity differ essentially, that can be explained by the fact that the processes occurring on the surfaces of the anode and the cathode pass in different ways. At the direct polarity surface elemental fragments are larger than those obtained at the indirect polarity.

The authors assumed that the crater that forms on the surface of the workpiece in the discharge process has the form of a spherical calotte (ideal).

Through the research it has been found that in the center of the crater, as noted in [1, 7, 8, 13, 16], a conical meniscus forms. It is necessary to emphasize that the meniscus can appear not only on the cathode surface, but on the anode surface too [13]. In this case both their size and shape considerably differ. As a result of experimental investigations it was established that the extraction of the conical meniscuses from the cylindrical surfaces is possible in the case when the voltage on the condenser battery is $U_c \geq 50V$ for wires with diameters 0.2-0.25 mm of made of W+Re10% alloy. For lower values of the voltage the formation of Taylor cone shaped asperities doesn't attest on these types of wires.

The conical meniscuses extracted from the cylindrical surface of the workpiece made of tungsten alloys are presented in Fig. 2 at different energetic regimes: at the voltage on the condenser battery of U=60V (Fig. 2 a,b,c,d), of U=70V (Fig. 2 e,f,g,h) and of U=80V (Fig. 2 i,j,k,l), the rest parameters being constant.

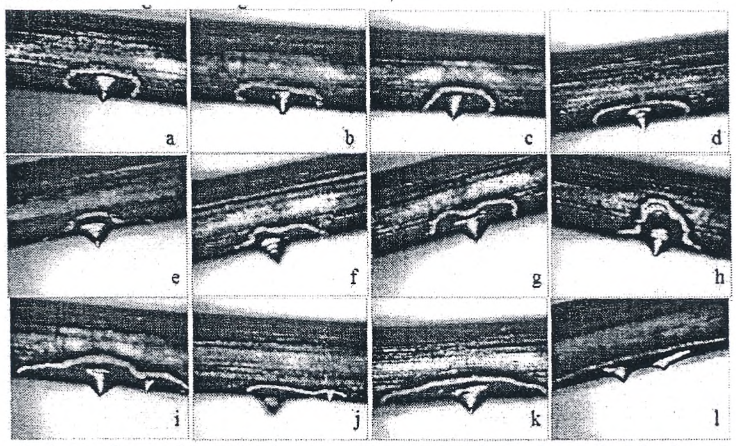


Fig. 2. General view of asperities (Taylor cones) extracted from the cylindrical surfaces of wires made of W+Re10% alloy after a solitary electrical impulse:
$C=200\mu F$, $S=0.3$ mm, $d_{wire}=0.25$mm, $n=1$

If we compare the obtained meniscuses, it is clearly observed that the zone of interaction of EDI plasma canal under processed wire has increased concomitant with the increase of the voltage on the condenser battery. It has been shown that the size of Taylor cone asperities depends on the energy parameters.

At further increase of the voltage on the condenser battery up to U_c = 80V, we can observe another effect when the multiple extraction of the conical meniscus takes place (Fig. 2 i,j,l) . This phenomenon indicates us about the simultaneous existence of multiple canals through which parallel discharge currents flow in the same direction. Following experimental research it was found that on the process of surfaces micro-geometry modification of metal pieces essential influence have the next parameters, such as: the electrode material, the energy, the size of the discharge gap between the electrodes and the discharge impulse duration. Thus, some energetic conditions were determined for extracting conical meniscuses as a result of processing by applying electrical discharges in impulse.

The energetic parameters create possibilities for conical asperities extraction. It was established practically [17] that at the voltages lower than 50V, wire diameters of 0.25 mm and the capacity of the condenser battery of $C=200\mu F$ conical asperities can't be formed on the piece surface indifferent of the used material. The influence of the condenser capacity in this case isn't so significant; the cones are formed for $C=200\ \mu F$, as well as for $C=600\ \mu F$.

Both the geometric dimensions of conical asperities, as well as peak angle size influence the active areas of the electrodes. At the processing of cylindrical sample-anode (diameter of 2 times higher) with 0.4 mm diameter cathode cones don't form on the processed surface, there are only undulations. In this case the impulse energy is distributed over a larger area. Because the volume of the molten metal in this case is about 4 times greater than the forces of gravity and the force of surface tension beyond the electro-dynamic forces, it prevents cone formation [17].

The increase of the electric field intensity could provide solution of the problem, but its application leads to overheating and excessive evaporation of sample material.

To increase the current intensity the condenser battery with higher capacities should be used, which leads to decrease of the discharge frequency in accordance with the relation:

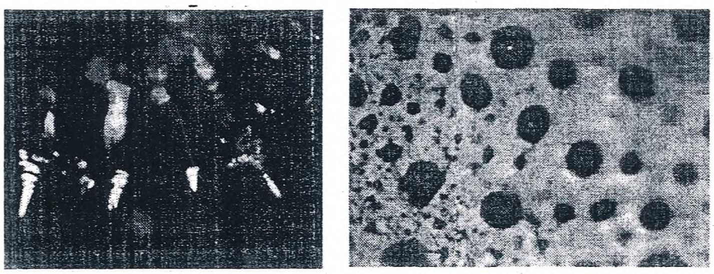
$$i = I\sin\omega t,\ \omega = \frac{2\pi}{T},\ T = 2\pi\sqrt{LC} \Rightarrow i = I\sin(\frac{1}{\sqrt{LC}}t) \quad (3)$$

If we talk about the current amplitude value, then this can obtain the maximum values for small capacities due to significant decrease of the impulse duration, i.e. current will be greater when C will be lower. Practically it was observed that at decrease of diameter (of active area) of the cathode, the other parameters being unchanged, we obtained conical asperities. This proves the importance of maintaining the current density at certain values to achieve cones [1]:

$$j = \frac{i}{S} \quad (4)$$

It turned out that the most important is that at least one of the electrodes must be of less active surface area. But better still is the case, when the active cathode surface area is less due to increasing the electric field intensity and the temperature at the anode surface. At the conditions of the performed experiments, the cathode with diameter of 0.2 mm was applied, so in this case the area of the active surface is $3.14 \cdot 10^{-8}\,m^2$.

The number and the size of the conical asperities on the sample depend on the irregularities presented on the surfaces of both electrodes and on their areas, and don't depend on the thickness and the volume of the electrodes. This is shown by the following experience. In both cases we used the same electrode-tool as sample (the first with a flat end and the second - sharped. The surfaces were processed as anodes in the same energy regime. As a result, on the sharped end a variety of relatively high asperities has been formed (Fig. 3.a), the same time, on the flat end the semi-spherical craters with small cone in the center appear (Fig. 3.b).



a b

Fig. 3. The morphology of processed samples-anodes:
W+Re 10%; U=240V, C=600μF, S=0.3mm, $\varnothing_{tool}=\varnothing_{workpiece}$=4mm, n=10 [17]

After processing the polished flat surface of the same samples we obtained the cones which were several times lower than those obtained on the sharped surface. In the first case (Fig. 3a) cones are much bigger compared with craters' dimensions. In the second case (Fig. 3b) the tip of the cone is flush with the ends of the semi-spherical crater, which confirms the spherical shape of the electrode spots.

The only difference between these two cases is in the fact that one of the active surfaces is bounded by a curvature with radius, while the first presents the flat surface. Due to the conical shape of the sample in the second case processed surface area A is higher under the same conditions.

Based on previous [7, 8, 13, 14] and present research it was confirmed once again the mechanism of electrical erosion as a result of the development of capillary waves on the surface of the liquid metal under the action of strong electric fields generated by electrode spots. Applying contemporary research apparatus (SEM) allowed determining that the lateral surface of formed asperities is complicated and has corrugations of micro- and nanometer order [15, 17]. These waves are possible caused by current variation in the electric discharge. Earlier it was already shown that EDI is one multi-canal. Some canals die and others are born, so the current of a solitary electric discharge is of the pulsating nature [7].

Analysis on the lateral surface of the Taylor type cone has shown that in the process of solidification and constituting of solid material grains some additional nanometer-scale asperities are crystallized on their surface. The structure and phase analysis of their material requires further studies. It should be noted that the extraction asperities with conical meniscus shape (Taylor cones) is performed in solitary discharge. Increasing the number of electrical discharges leads to initial conical meniscus extraction, followed by the intensive oxidation of their surfaces below. The appearance of meniscuses, their orientation and dimensions in the case of a solitary discharge indicate directly the fact that they can't arise by reason of the plasma canal depressions, and are caused by the action of electric field along the radius vector from the electrode spot to the processed surface of the workpiece. This hypothesis is experimentally confirmed by the authors of the paper [20]. The current variation in a singular discharge impulse is manifold, which explain the increase of number of canals and conical asperities formation. The extracted conical meniscuses on the surfaces obtained by the authors were applied to enhance the thermo-electronic emission, and in accordance with [5, 9, 11] it can be used as ion emitters.

Conclusions

The results obtain lead to the following:

- the geometry of extracted meniscuses from the conductive surfaces is a function of energetic parameters, discharge gap and positioning of the workpiece;
- the formed meniscuses can serve as thermal and electric fields concentrators in active areas of cathodes;
- in terms of applying electrical discharges in impulse on metal and semi-conductive materials surfaces the necessary and sufficient conditions for the extraction and freezing conical meniscuses are created;
- the additional capillary waves and the mosaic blocks on them with asperities of nano-metric order are observed on the lateral surface of the Taylor cone;
- it was experimentally demonstrated the possibility of simultaneously extraction of several cones at a singular discharge depending on the process parameters.

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