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Formation of Taylor Cone Shaped Asperities on Cylindrical Surfaces by Applying Electric Discharges in Pulse

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Abstract. This paper presents the results of experimental research on Taylor cone shaped meniscuses formation on the surfaces of pieces by applying electric discharges in pulse. It examines the influence of energy stored in the capacitor and of pulse duration on their formation. The modification of piece surface micro-geometry aims to increase the capacity of absorption of radiation and of particle emission. It shows that the size of formed meniscuses depends on the energy regime of machining, on the gap size, on the duration of electric discharges in pulse and on thermal-physical properties of the material used to execute the piece.

Introduction

When processing the material by applying electric discharges in pulse (DEI) regardless of the applied technique, either dimensional processing or formation of deposit layers, the material melts and is drawn from the electrode surface (solid or liquid) and spherical craters are formed on their surfaces [1-5].

The authors of papers [6, 7, 8, 9] have registered three craters all having a spherical shape: the first is smooth, the second is rough and the third has a meniscus in the middle. Meniscuses were observed not only in the center of the craters but also at their peripheries.

In addition, a number of works are known [2, 8] which demonstrate that the appearance of meniscuses in the center of the craters is due to the perturbation of the surface liquid metal under the influence of high-voltage electric fields (generated by anode or cathode voltage drops) the force of surface pressure of the melted metal and that of the weight.

Proceeding from the above said, we may state that the processing by applying electric discharges in pulse can be widely used to modify the metal surface micro-geometry, the surfaces being flat or cylindrical [3, 4, 8, 9]. The process of modification of metal surface micro-geometry consists in the formation of conic meniscuses (Taylor cone) on them. Real surface area obtained after processing with electric discharges in pulse contributes to changing the nature of its interaction with the environment and other active surfaces of pieces with which the piece forms couples (for pieces used in machine construction). In cases of radiating surfaces (of heat, waves, electric and magnetic fields), or those that absorb radiation (heat radiation receivers, light waves, electromagnetic radiation, etc.) both the geometry and the area of active surfaces play an active decisive role on the features mentioned above [6, 7, 12].

A series of papers [3, 4, 8] study the geometry of craters formed on the surfaces of pieces made of different conductive materials after the application of DEI.

In what follows, we will present the results of experimental research on the micro-geometry modification of surfaces by applying DEI through the extraction of meniscuses from the processed surfaces of pieces made of tungsten.

Experimental research methodology

The experimental investigations have been performed under normal conditions in an air environment at room temperature. The determination of electric discharge parameters was performed with the help of the oscilloscoping method.

In order to form surfaces with specific geometric parameters by applying electric discharges in pulse an experimental installation that ensures the formation of conic meniscuses both on flat and on cylindrical surfaces was used.

The experimental installation consists of two modules: mechanical and electrical. The electrical module includes the generator of electric current impulses of the type RC which has a power block, an inducing block and a control block.

The pulse generator is the basic part of the tool-machine for processing by applying electrical discharges in pulse and ensures the formation of impulses of required characteristics. *The* coaxial shunt whose resistance was R = 0.003 Ω. was used to measure the size of the momentary and maximum currents in the discharge circuit.

To do the research we prepared cylindrical samples made of Wolfram with the diameter d equal to 0.25 mm. Pairs of electrodes made of the same material were used in the process of experimental research.

Figure 1 presents the scheme of electrode positioning in the process of machining.

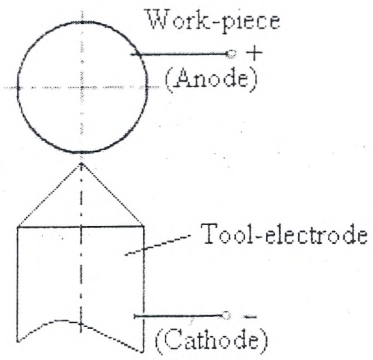

Fig. 1. The scheme of electrode positioning in the process of machining and their connection in the circuit of discharge of the current impulse generator

It was mentioned in some works [1-4, 8, 11] that the anode surface in the process of electric discharges in pulse melts more quickly compared to the cathode surface because the latter has a greater part of the energy released in the gap. Proceeding from these considerations, the work piece was permanently connected as anode in the process of machining by applying electric discharges in pulse.

It should be noted that the active part of the tool-electrode was sharpened in order to localize the electric discharges.

To determine the optimal conditions of extracting Taylor cone shaped asperities we did the microscopic analysis of the processed surface measuring the diameter of the extracted cone basis, the height and the geometry depending on the energy regime of the impulse generator (charging voltage of the capacitor).

The volume of the capacitor modifies step by step (at the step of 100μF) within the limits of 100-600 μF for certain values of the capacitor charging voltage. For special cases, these voltage values constituted 60V, 80V, 100V, 120V, 150V and 200V.

To determine the influence of pulse duration on the Taylor cone geometry in the process of DEI, the energy accumulated on the capacitor maintaining the gap size constant. Researches were made for more values of the discharge pulse duration, exactly 100μs, 125μs, 160μs, 180μs, 200μs and 220μs. The investigations were repeated several times in order to obtain accurate results.

Experimental results and their analysis

It was stated in the other works of the authors of this paper that to get Taylor cone shaped rough surfaces it is necessary for the liquid phase to appear on the machined surface, the asperity should be extracted and frozen (ultrafast solidification of the asperity shaped material). The experimental research shows that to realize the modification technology of surface micro-geometry by extracting Taylor cone shaped asperities it is necessary to satisfy the following conditions:

Providing the local melting of the piece determined by the relation (1) [1]:

$$Q = \frac{4W}{\pi d_c^2 S} \geq Q_{melt} \qquad (1)$$

where Q is the quantity of heat released in the plasma canal during DEI; W - energy released in the plasma canal; d_C is average diameter of the crater with a liquid phase on the cathode surface; S is the size of the gap between the electrodes; Q_{melt} is the volumetric density of the piece material melting determined by the relation $Q_{melt} = q_{top} \cdot \rho$; q_{top}, ρ are respectively the melting specific heat and density of the piece material.

An electric field with a voltage of about 10^8 V/m will be created in the gap:

$$E_{cr} = \sqrt[4]{64\pi^2 \rho g \gamma \cdot 3 \cdot 10^4} \qquad (2)$$

where is the critical voltage of the electric field; - metal density, - acceleration of free fall; - surface tension of the liquid material [2].

The direction of the electric field action coincides with the direction of weight force action.

When applying electric discharges in pulse, the amount of used energy and respectively its distribution in the plasma column of the electrical discharge in pulse and the electrode surfaces play an important role in erosive and thermal effects occurring on their surfaces [5].

Following the experimental research we found out that the process of modifying the micro geometry of metal piece surface is essentially influenced by such parameters as: electrode material, energy, size of the gap between electrodes and the discharge impulse duration. In this way, some energy conditions of extracting conic meniscuses were determined as a result of processing by applying electrical discharges in pulse. As a result of experimental research, it was stated that the extraction of conic meniscuses from cylindrical surfaces made of tungsten is possible when the charging voltage of the capacitor is Uc = 60V. At lower voltages no formation of Taylor cone asperities was noticed.

Figures 2 and 3 show conic meniscuses extracted from the cylindrical surface of the tungsten sample in different energetic regimes.

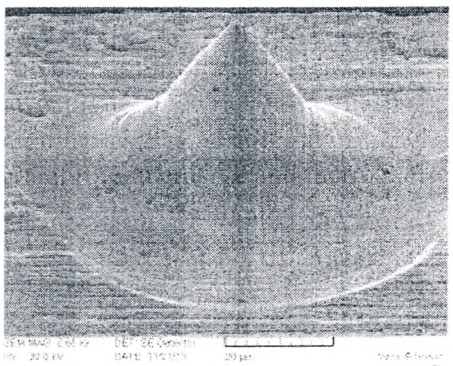

Fig. 2. Overview of asperities (Taylor cones) extracted from cylindrical surfaces of wires made of tungsten as a result of electric discharges in pulse (Uc=60V, C=200μF, S=0.3 mm, d=0.25 mm)

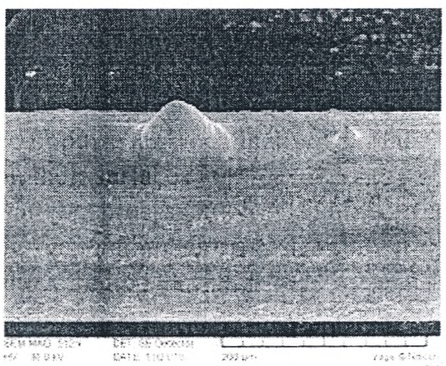

Fig. 3. Overview of asperities (Taylor cones) extracted from cylindrical surfaces of wires made of tungsten as a result of electric discharges in pulse (U_c=80V, C=200μF, S=0,3mm, d=0,25mm)

It has been noticed that if the charging voltage on the capacitor increases up to Uc = 80V, a picture of extracting multiple conic meniscuses appears. This phenomenon points to the existence of multiple canals of simultaneous discharge through which parallel currents of the same direction flow.

Based on previous research [2-4, 10] and the present one, the mechanism of electrical erosion was confirmed again as a result of the development of capillary waves on the surface of the liquid metal under the influence of strong electric fields generated by electrode spots.

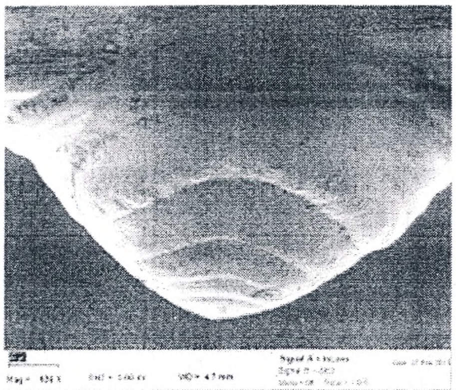

Fig. 4. The surface of an asperity: (a - with the presence of concentric waves on it; b - mosaic blocks on the lateral surface of a Taylor type cone)

The application of modern research apparatus (SEM) allowed us to establish that the lateral surface of the obtained asperities is a complicated one and presents micro-and nanometric undulations (see Figure 4). These undulations may be caused by current variation in the electrical discharge. It has previously been shown that DEI is multi canal. Some discharge canals die and others are born, so the current of solitary electrical discharge has a pulsating character.

This hypothesis is confirmed experimentally by the authors of [13]. From what is shown in Figure 5 it is seen that, within a solitary discharge, variations both of the pulse voltage and of the current take place. The variation of the current in a single pulse is multiple; this may be explained by the formation of multiple canals and of more conic asperities.

Further analysis of the lateral surface of Taylor type cones has demonstrated that during the process of solidification and constitution of solid material grains some asperities of nanometric dimensions are crystallized on their surface (Fig. 6). The phase structure and analysis of their material requires supplementary studies.

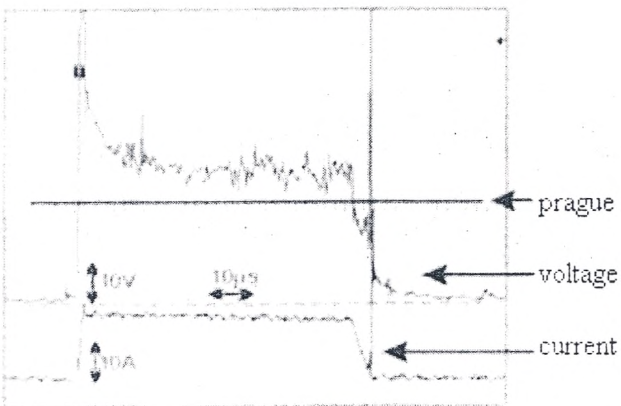

Fig. 5. Graphs of discharge as they are analyzed by a modern control system [13]

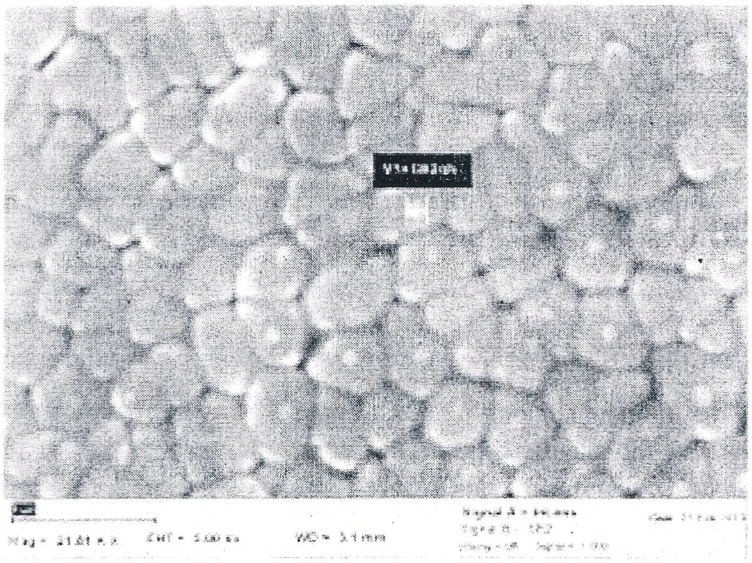

Fig. 6. Mosaic blocks on the lateral surface of a Taylor type cone

It should be noted that the extraction of asperities shaped as conic meniscuses (Taylor cones) occurred at a solitary discharge. The extraction of conic meniscuses through extensive oxidation of their surfaces was seen when the number of electric discharges increased.

In this case, on the surface of asperities, phases that contain oxygen, nitrogen, hydrogen and carbon can be synthesized which in their turn modify their functioning properties.

The appearance of meniscuses, their orientation and dimensions for one solitary discharge points directly to the fact that they cannot appear because of the depressions in the plasma canal, and are caused by the influence of the electric field along the vector radius from the electrode stain towards the machined surface of the work piece.

Proceeding from the results we have obtained, we can say that sufficient necessary conditions for the extraction and growth of conic meniscuses (Taylor cones) may be created due to electric discharges in pulse. The conic meniscuses located on the machined surface in a certain way may finalize the domain of its applicability in practice (either as surfaces with properties of electron emission, or as surfaces with properties of absorption of electromagnetic waves, etc.).

Conclusions

Based on the analysis of what has been mentioned above we may conclude:

- The modification of the surface micro geometry by applying electric discharges in pulse allows the increase of its active area by several times;
- The size of the gap between electrodes plays a decisive role in the process of extracting conic meniscuses from the machined surface;
- The geometry of meniscuses extracted from the conductive surfaces depends on the energy parameters, the gap and the positioning of the work piece;
- The formed meniscuses may serve as concentrators of thermal and electrical fields in the active areas of the cathodes;
- Under the conditions of applying electric discharges in pulse on metal surfaces sufficient conditions are created for the extraction and freezing of conic meniscuses;
- The formation of meniscuses (Taylor cones) can be observed both on the anode surface and on the surface of the cathode;
- We can observe capillary waves on the lateral surface of the Taylor cones and on the waves, there are mosaic blocks with nanometric asperities.

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