OBTAINING SURFACES WITH TAYLOR CONE SHAPED ASPERITIES OF MICRO- AND NANO-SCALE DIMENSIONS USING THE EDI METHOD

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Abstract: Nowadays the stage of technical progress is characterized by a transit from macro to micro and nano scale dimensions. The present paper is devoted to experimental investigations concerning the treatment of conductive surfaces by applying electric discharges in impulse (EDI). We have particularly focused on the modifications of metal surface micro-geometry leading to the formation of Taylor cone shaped asperities. We have established and presented the best energetic regimes of extracting the latter from cylindrical and flat pieces made of W+10%Re using EDI.

Key words: electrode spots, meniscus, impulse, micro-geometry, metal surface, electric discharges, electrode, Taylor cones.

1. INTRODUCTION

The modern stage of scientific and technical progress is characterized by a transit from macro- to micro- and nano- organization of matter.

It was stated that during the treatment of metal surfaces using EDI the material is drawn on the electrodes and this is accompanied by the formation of spherical calotte shaped craters. Such a surface geometry is caused by the form of electrode spots [1, 5].

The already formed craters facilitate the creation of new craters in the electric field strongly concentrated at the edge of the existing ones [8].

Three types of craters are registered, all of them having the form of a spherical calotte: the first is even, the second is rough and the third has a Taylor cone shaped asperity in the middle. Asperities of this type have been observed not only in the centre of craters as some authors stated [2], but also at their periphery.

Based on the phenomena described above (obtaining craters and forming conic asperities on the electrode surface, which we observe during the process of metal surface treatment by applying EDI), we confirm the fact that this process may be largely used aiming at modifying the micro-geometry and chemical composition of metal surfaces of different geometry [3, 4]. The process of modifying the micro-geometry of metal surfaces consist in the formation on them of some conic asperities (Taylor cones) and this leads to the increase of the treated surface by 8 times and, as a result, to the increase of the piece active surface by about 4 times.

The formation of conic asperities on the piece surface treated using EDI leads to the increase of its active area. At present, this phenomenon may be successfully used in the production of cathodes applied in the construction of installations of processing materials with fascicles of electrons or anodes used for the emission of narrow ion fascicles [7] performing the function of concentrating electric and thermal fields in the active zones of cathodes during the process of electronic emission. The treated piece has a surface with a special micro-geometry that would facilitate an electronic, thermal emission and that of electromagnetic fields that are more increased in comparison with the same piece that is not treated using this method.

2. METHODOLOGY OF EXPERIMENTAL INVESTIGATIONS

The formation of conic asperities in the centre of craters is due to the perturbation of the liquid metal surface influenced by the electric fields of high strength, the force of superficial voltage of the melted metal and less by the component of weight force.

A special installation containing the following main parts - the RC impulse generator, the inducing block and the control block - has been used to do the research. The control block allows a fine regulation of the discharge frequency within the limits $(1...10^5)$Hz.

The electric scheme of the installation is presented in figure 1. If we refer to this scheme we can notice that the control block is destined not only for the variation of the discharge frequency; it also permits to carry out the synchronization of inducing and power impulses. The functioning principle of the generator presented in figure 1 is based on the accumulation of electric energy and its discharge in the electric field.

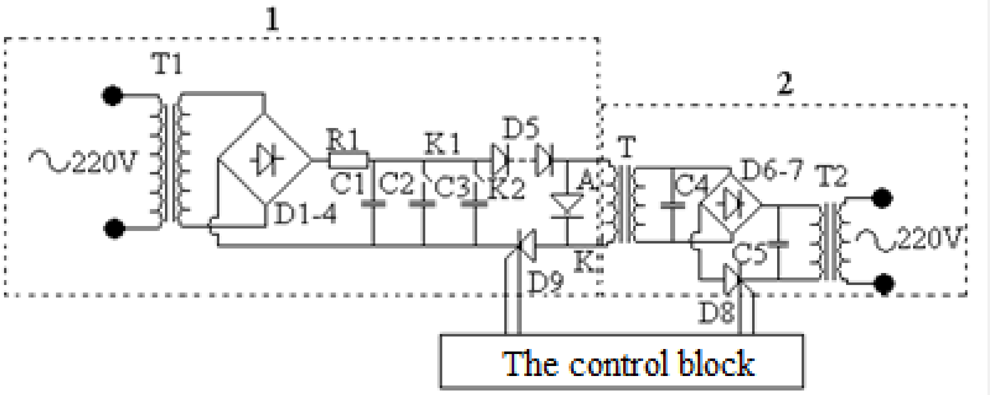


Fig. 1. The main electric scheme of the installation, [8]:
1 - generator of power impulses; 2 - inducing block.

Cylindrical or flat samples of different dimensions made of wolfram and rhenium alloy with properties presented in Table 1 were prepared to do the research.

Table 1. Properties of materials used in the process of experimental research, [8].

Material	Melting temperature (ºC)	Hardness (HB)	Density (kg/m^3·10^{-3})	Specific thermal capacity (cal/(g grad)
W+10%Re	3180	200	21.02	0.0326

Figure 2 presents the position of electrodes used in the process of experimental investigations and their connection in the circuit of discharge of the impulse generator. The previously treated electrodes plucked as elements of the fixing device positioning. Then the electrodes approached each other manually until their contact after which the interstice size was selected.

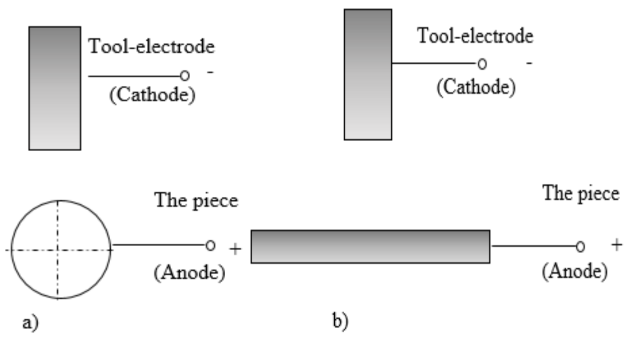


Fig. 2. Schemes of electrode positioning used in the experimental investigations and their connection in the circuit of power impulse generator discharge: a) the case of cylindrical piece; b) the case of flat piece.

To do the experimental investigations on the extraction of Taylor cones on cylindrical surfaces (Fig. 2a) by applying EDI, we used pairs of electrodes – the wire-piece made of the material resented in Table 1 and the tool-electrode of the same material shaped as a cylindrical bar.

The pair of electrodes-piece-plate made of W+10%Re with flat treating surface and a tool-electrode made of the same material but cylindrically shaped- was used to do the experimental research on extracting Taylor-cone shaped asperities on flat surfaces (Fig. 2b).

Throughout the research we obtained Taylor cones when the generator battery is charged with voltage values between (40...240)V and the capacity of the condenser battery is modified gradually (with the pace 100μF) within the limits (100...600)μF, the interstice S selected between electrodes (0.1...0.4)mm, the thickness of electrodes within the limits (0.2...4)mm, made of the material presented in Table 1.

3. THE RESULTS OF EXPERIMENTAL INVESTIGATIONS

Having studied the samples of the surfaces treated via the method of EDI using the method of optic microscopy with the optical microscope XIM600 and the SEM with electronic microscopes Vega TESCAN 5130 and QUANTA 200 (FEI Fillips), we can observe that Taylor cones are formed not only in the centre of the crater but also at its peripheries due to the development of electro-hydrodynamic instability on the melted tungsten surface as a reaction of the plasma channels and the substance interaction (Figures 3, 5).

Varying the interstice size, it is possible to obtain almost any degree of intensification of the working surfaces with the emission of energy on the surfaces subjected to treatment or in the interstice. Increasing the interstice size, we may obtain such states when the heating of the volume of the treated material is not essential and the geometry of the sample surfaces does not change. This possibility may be applied in the development of new surface treating technologies by applying electric discharges in impulse.

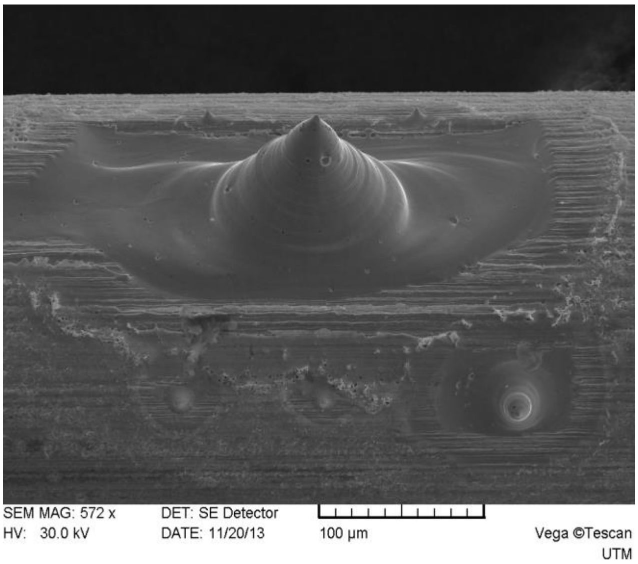


Fig. 3. Scanning electron microscope (SEM) image of a conic asperity surrounded by smaller ones, extracted on the surface of the piece material at a solitary discharge (the piece and the tool-electrode being made of W+Re10% as cylindrical wire with a diameter of 0.2mm, the condenser battery charged at the voltage U=70V; the capacity of the condenser battery is C=200μF, the interstice having the value S=0.2mm)

It was practically stated that the efficiency of forming cones on metal surfaces is significantly greater when the piece is connected as anode [5, 6]. This phenomenon is due to the fact that at short electric discharges the emission of energy is stronger at the anode (Fig. 4a) for the same value of electric current that passes the interstice under conditions of a solitary electric discharge, the decrease of cathodic voltage is lower (as an absolute value) than the anodic one and, as a result, it gets cool sooner without cone extraction (Fig. 4b).

To modify the micro geometry of metal surfaces the tool electrode should be connected in the circuit of discharge as cathode because for a longer period of time it will not essentially change the form and dimensions initially established. This will permit to homogenize the treating process using the EDI method.

A plasma channel is noticed at one cm distance and at 0.5cm distance there are approximately three channels. Thus if the distance is shorter than 0.2mm, the number of channels is higher and their enumeration practically becomes impossible. The

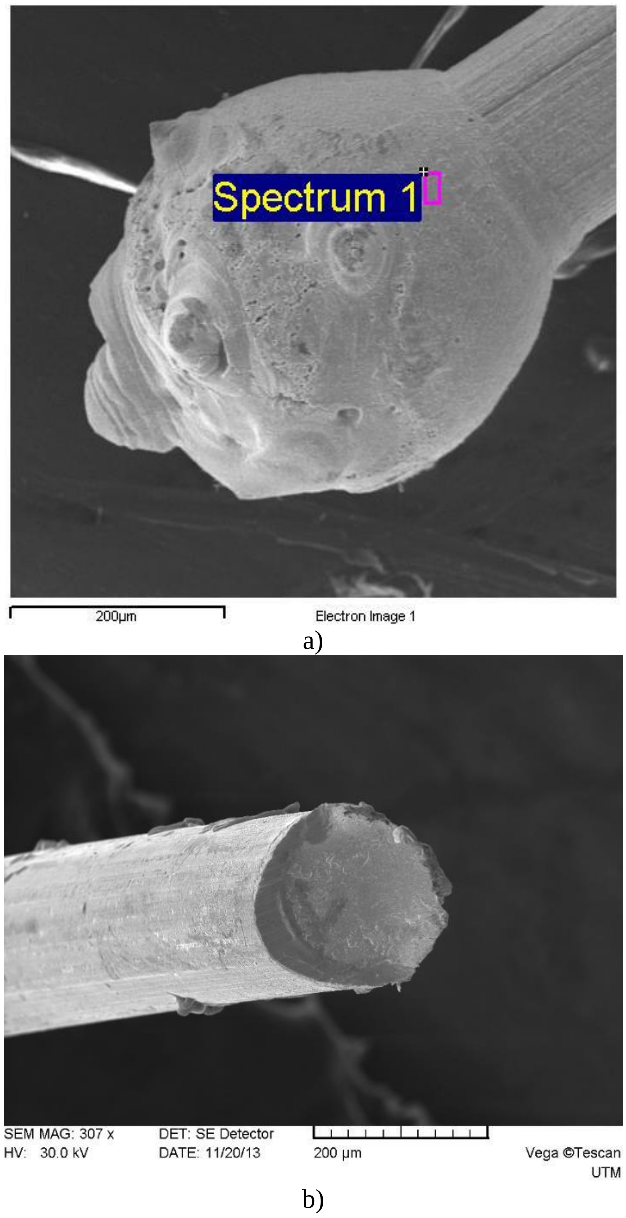


Fig. 4. SEM images of tool-electrodes made of W+Re10% that participated in the treating process: U= 60V, C=200 μF, $Ø_{tool}=Ø_{piece}$=0.2mm; S=0.2mm, n>1; a) the tool-electrode connected as anode; b) the tool-electrode connected as cathode

presence of many channels leads to the formation of more asperities during one power discharge. This phenomenon is stronger when more electric discharges in pulse are applied (Fig. 5) or the voltage among electrodes is equal to 80V and higher (valid for the material and conditions described above).

Power parameters define the possibility of extracting cones. It was practically stated that no cones are obtained on the surface of the used sample at voltages lower than 30V. The influence of the capacity is not so significant, the cones are obtained as successfully at C=200μF as at C=600μF. However in cases of increasing capacity value, the obtained asperities have a bigger diameter.

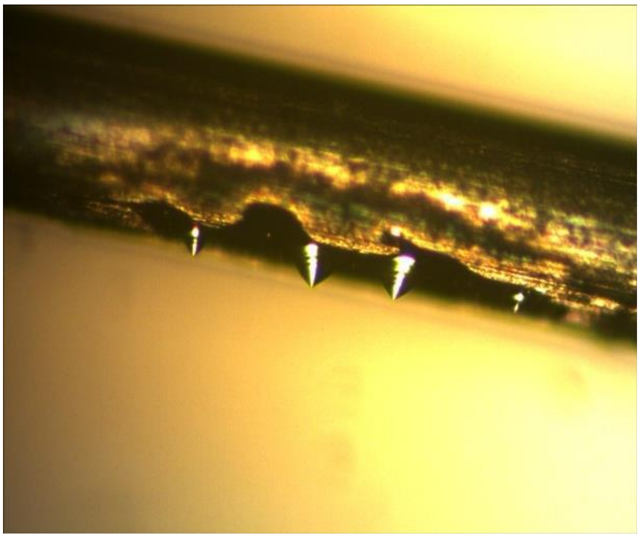
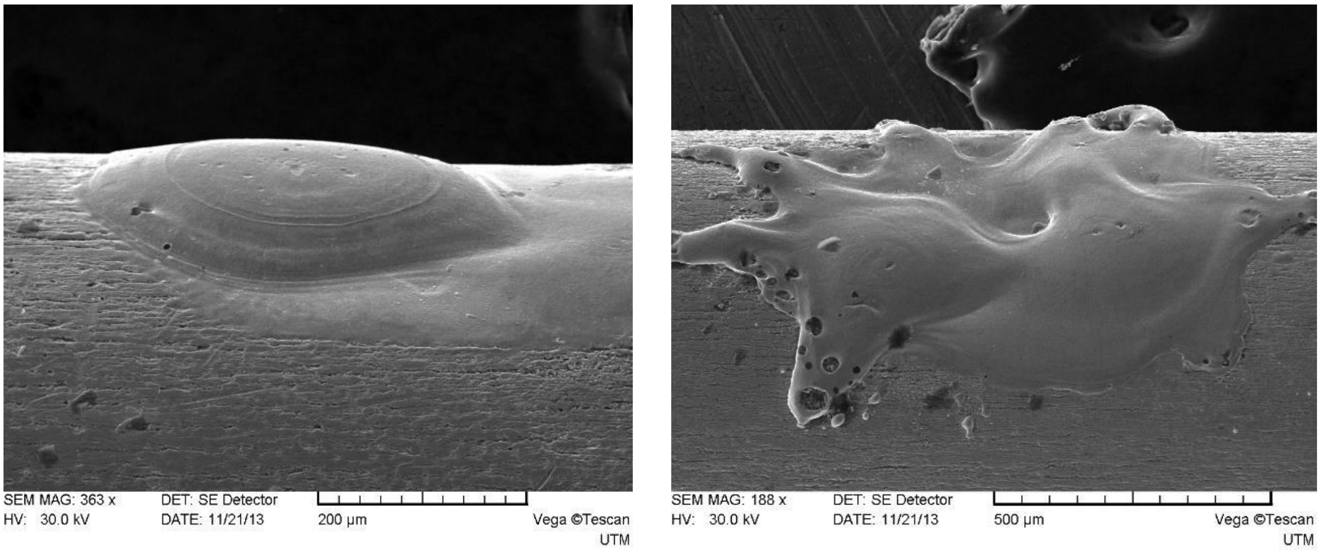


Fig. 5. Optical image of piece electrodes that participated in the treating process: W+Re 10%; U=60V; C=200µF; S= $Ø_{tool}=Ø_{piece}$=0.2mm; n=2.

Cones are not obtained at treating cylindrical samples (anode) with tool-electrodes (cathode) with diameters equal to 0.4mm in the same power regimes on the treated surface; we can only notice electrode spots, waves or torn drops (Fig. 6a). This phenomenon is explained by the fact that in this case the impulse energy is distributed on a bigger surface.

As the volume of the melted metal in this case is about four times bigger, the weight force and the superficial tension surpass the electro-dynamic forces so that they prevent the cone formation. The increase of the electric field strength could become the solution of the problem but its excessive application leads to the overheating and evaporation of the sample material (Fig. 6b). It is however possible to extract cone asperities on such pieces by increasing the current density, it means increasing the impulse current or using narrower tool electrodes.

No conic asperity was formed on the cylindrical sample with d=0.4mm connected as anode and treated by applying the tool-electrode with d=0.4mm. It is however possible to obtain a conic meniscus but in more optimum electric regimes.



a) b)

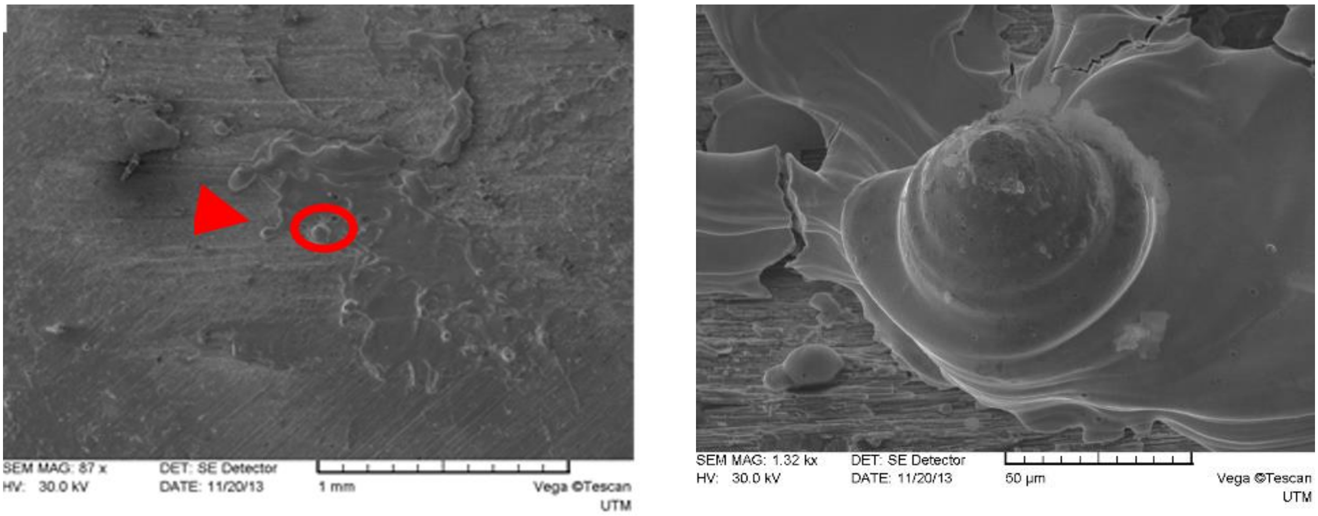
Fig. 6. SEM images of samples that participated in the treating process W+Re10%:
a) tool-electrode (anode) - U=60V, C=200µF, $Ø_{tool}=Ø_{piece}$=0.4mm; S=0.2mm;
b) tool-electrode (anode) - U=60V, C=200µF, $Ø_{tool}=Ø_{piece}$=0.4mm; S=0.2mm.

It has been proved that it is more important for, at least, one of the electrodes to have a smaller active surface area.

However the situation when the active surface area of the cathode (the tool) is smaller due to the increase of the electric field strength and that of the temperature one on the anode surface (the piece) is more efficient. The tool-electrode (cathode) with the diameter equal to 0.2 mm was applied under the conditions of realized experimental endeavors. In this case, the active surface area is $3.14\cdot^{-8}m^2$. Using the same cathodes we can extract Taylor cone shaped asperities even on flat surfaces, but in this case it is more difficult to adjust the energetic parameters (Fig. 7).

The number and size of sample conic asperities depend on the irregularities present on the surface of both electrodes, on their area and on the initial form of the working piece and do not depend on the thickness and volume of the electrodes.

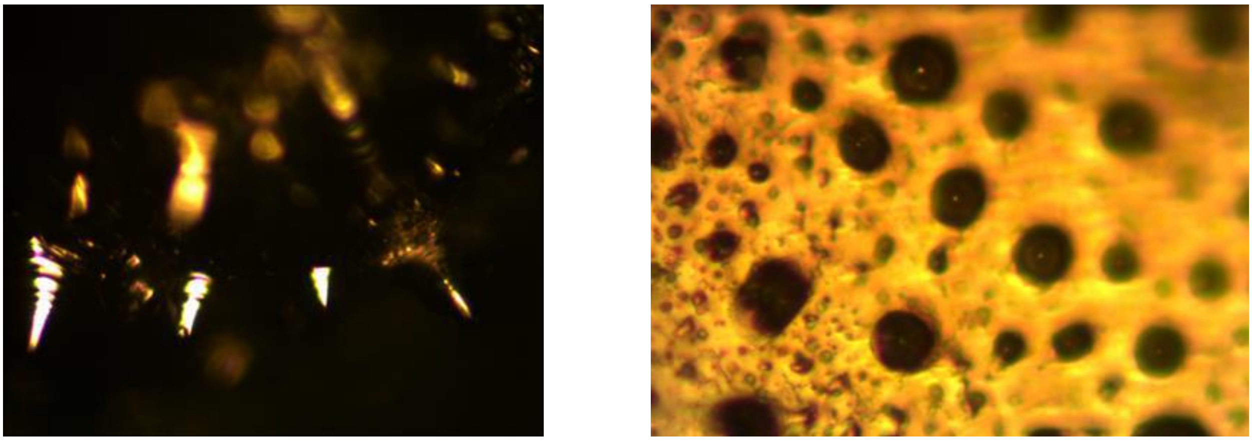
In the next two experiments, the tool-electrode with the diameter of 4mm of the same material (present in Table 1) was used as a sample for cylindrical pieces with the same diameter of 4mm, one with a flat work surface and the other with a sharp one (the angle at the top is ≈30^{o}). The electrode-pieces were connected as anodes in the same energetic regime.



a) b)

Fig. 7. SEM images of flat samples that participated in the treating process:
a) magnification 87x; b) magnification 1.32kx.

As a result, a multitude of asperities were obtained on the sharp end after ten consecutive power discharges, comparatively larger (Fig. 8a) than on the flat end where more semi-spherical craters with small cones in the centre were formed (Fig. 8b).



a) b)

Fig. 8. Surface morphology of anodes that participated in the treating process: W+Re10%; U=240V; C=600µF; S=0,3mm; $Ø_{tool}=Ø_{piece}$=4mm; n=10.

It follows that to obtain Taylor cones using EDI thespatial dimensions (3D) of the samples are not so significant as the surface dimensions (2D) and the initial roughness of the treated surface. After the glazed flat surface of the same sample was treated, we obtained cones that were several times smaller than those on the sharp surface. In the first case (Fig. 8a), the cones are much bigger compared to the craters. In the second case (Fig. 8b), the end of the cone is at the same level with the semi-spherical crater.

The application of modern equipment of investigation (SEM) permits us to state that the lateral surface of the formed asperities is a complicated one and presents micro and nano-scale waves (Fig. 9). These

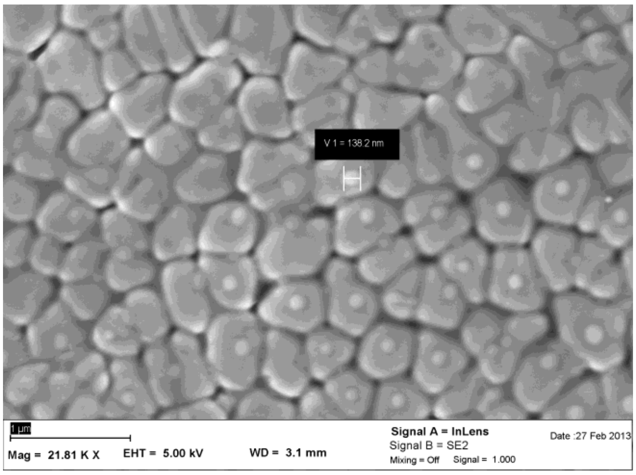


Fig. 9. SEM image of mosaic blocks on the lateral surface of a Taylor shape cone.

waves are possibly caused by the variation of current in electric discharge. It has already been demonstrated that EDI is multichannel [5]. Some channels of discharge die while others are formed. Because of this, the current of solitary electric discharge have a pulsotronic character [6]. The waves of lateral surface increase the area of the active surface.

Further analysis of the lateral surface of Taylor type cones has demonstrated that during the process of solidification and formation of solid material grains asperities of nano- scale dimensions are additionally crystallized on their surface. The faze structure and analysis of their material require additional investigation.

4. CONCLUSIONS

Having analyzed the results obtained were resulted the following conclusions:

a) The use of the EDI method to modify the micro-geometry of metal surfaces permits the increase of its active area by several times.

b) The extraction of conic asperities in the process of treatment with EDI is more favorable if the piece is connected as anode. However the successful extraction of asperities from the cathode in conformity with the theory of developing capillary waves is not excluded;

c) Supplementary capillary waves with mosaic blocks of nano-scale asperities are attested on the lateral surface of the Taylor cones;

d) When voltage higher than 80V is applied, more conic asperities are extracted at one or more electric discharges in impulse;

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