SURFACE FORMING FEATURES OF NEW COMBINED WIRE ELECTRICAL DISCHARGE-ELECTROCHEMICAL MACHINING TECHNOLOGY

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ABSTRACT: There are presented the results of the complex studies of the structure and microgeometry of the surface layers formed on a wide spectrum of regimes of electrical discharge cutting and sequential electrochemical machining (ECM) with the same wire electrode. The studies were conducted on tool steel, medium carbon steel and technically pure iron ARMCO. It was clearly established the presence of the heat affected zone (HAZ) when using wire electrical discharge machining (WEDM) on pure technical iron ARMCO. It is shown the possibility of using a sequential WEDM and ECM with the same wire electrode to controllably and almost completely eliminate the HAZ. The established regularities broaden the idea of the surface formation mechanisms and substantiate the proposed schemes of surface formation using the newest combined technology. The obtained data correlate well with the known results of research in the field of electrophysical and electrochemical methods of materials processing.

KEYWORDS: wire electrical discharge machining, electrochemical machining, surface roughness, recast layer, heat affected zone

1. INTRODUCTION

Wire electrical discharge machining (WEDM) refers to nonconventional technologies. However, it is widely used in tool industry in the manufacture of molds` parts, elements of cutting dies and others. The demand for macro- and micro- products and components of difficult-to-machine materials such as tool steel, carbides, super alloys and titanium alloys has been rapidly increasing in automotive, aerospace, electronics, optics, medical devices and communications industries. These materials pose many challenges to conventional machining processes (such as turning and milling). WEDM offer a better alternative or sometimes the only alternative in generating accurate parts and components of these difficult-to-machine materials [1].

The material removal in WEDM occurs due to the thermal effect of the electrical discharges with the lack of mechanical pressure on the object, and therefore the hardness, viscosity and other mechanical properties of the material do not affect its machinability. This kind of finishing has it`s own peculiarities in shaping the surface roughness and the appearance of heat affected near-surface layers.

In recent years, WEDM is often used in the micro-processing field. The more and more rapid development of micro- and nanotechniques will cause the processing method through electrical erosion to face new requirements, new challenges [2]. Therefore, the research and development of methods for improving surface quality after WEDM are relevant.

Typically, surface quality improvement is achieved by optimally choosing the technological factors that influence the surface roughness [3], using of a certain working fluid composition [4] and/or using of multi-pass WEDM [5]. However, it is obviously not possible to completely remove the HAZ.

The most successful is a promising combination of electroerosion and electrochemical technologies with their sequential use [6,7]. With the combined technologies of electroerosive and electrochemical machining with a wire electrode, the part is made during one installation on an electroerosive machine with the same electrode tool [8]. It uses high accuracy and performance of the WEDM and high quality of surface integrity of the output surface after electrochemical machining.

The purpose of the work is the development of scientific principles for the expanding the use of combined electrodischarge and electrochemical machining with a wire electrode.

2. EQUIPMENT AND MATERIALS

The study of changes in the parameters of the surface of the parts was carried out in the process of electroerosive wire cutting and subsequent electrochemical processing by a wire electrode on a SELD-02 machine-tool (Ukraine) – electro-discharge cutting machine on linear actuators. Linear motors used as drives, granite guides, gas-lubricated supports provide minimal displacement error. The wire rewinding path is provided with smoothing compensators and together with the V-shaped guides minimizes vibration of wire electrode.

Surface samples were formed on rough trim cutting and using multi-pass WEDM technology. The main parameters of pulses generator GKI 300-200A are shown in Table. 1. Rough cutting: regime 2.2; three passes: regimes 2.2, 2.1, 3.4; five passes: regimes 2.2, 2.1, 3.4, 5.4, 5.2. The treatment was carried out in the environment of tap water.

Table 1. Technological parameters of WEDM pulses.

Regime code	Frequency, kHz	Pulses duration, µs	Amplitude of current at load 0.1 Ohm, A
2.2	22	3 ± 0.3	180
2.1	22	3 ± 0.3	130
3.4	44	2 ± 0.2	45
5.4	200	0.9 ± 0.15	30
5.2	200	0.9 ± 0.15	24

Table 2. Parameters of ECM regimes using wire electrode.

Regime number	Duration of working impulse, µs	Pulse period, ms	Amplitude of voltage, V
No.1	250	6	8.6
No.2	100	2	11

A wire electrode with diameter of 0.20 mm Cobra Cut B (AGIE, Switzerland), hard brass CuZn37 was used.

Electrochemical machining was carried out by the same electrode in aqueous solution of 1M NaCl in potentiostatic mode. Parameters of regimes are shown in the Table. 2.

The heights of the machined workpieces were 18-40 mm and the materials were used: tool stamping steel H12F1 (analog DIN X155CrVMo12-1), tool carbon steel U8A (analog DIN 1.1525), medium carbon steel 45 (analog DIN 1.0503), technically pure iron (ARMCO).

Microgeometry of the surface was studied using the TIME 3221 profilometer and the DataView TIME3R Series software, which provides more than 40 surface parameters according to ISO, DIN, ANSI, JIS standards. Manufacturing and research of metallographic microsections were carried out according to well-known standard methods.

3. RESULTS AND DISCUSSION

Figure 1 shows the microsection of the H12F1 steel`s surface after the WEDM rough cutting in 2.2 regime. The thickness of the "white layer" is uneven (1.5-9 µm) and is much smaller than the thickness of the similar layer obtained by the die-sinking EDM. This can be explained by the relatively lower power of electric pulses used in WEDM. The authors of [9] argue that it is possible to obtain a surface without a "white layer" when applying pulses with duration less than 500 ns. In detail, the structure, chemical composition and mechanical properties of the "white layer" obtained in the process of WEDM, are studied in [10].

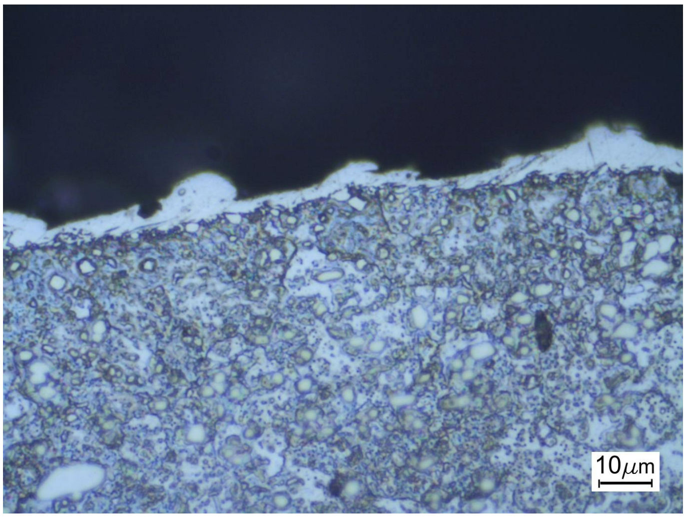
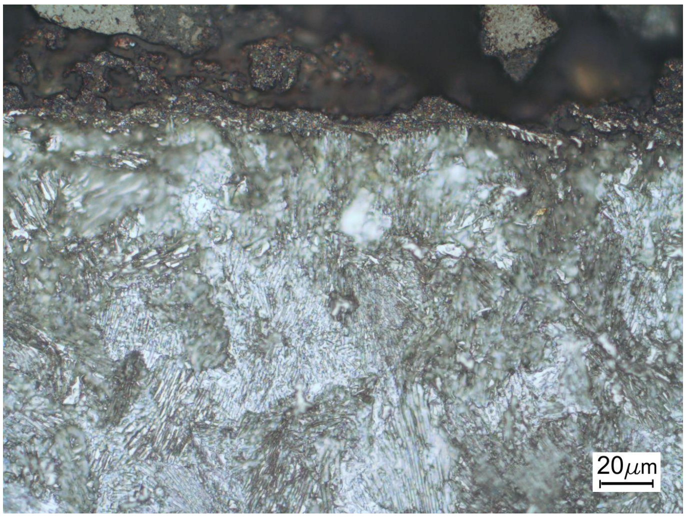


Figure 1. Obtained on the surface of steel H12F1 "white layer" after a WEDM rough cut

After a rough electroerosive cutting of steel U8A (regime 2.2), 25 µm thick recast layer is formed on the surface (Fig. 2a). Its formation, cooling occurs in uncontrolled conditions, so it is difficult to accurately predict its properties and usually this layer should be removed.

When designing the next stage of ECM with a wire electrode, it should be taken into account that the coefficient of electrochemical machinability of a near-surface recast layer differs from the coefficient of electrochemical machinability of the main material. In order to accurately calculate the thickness of the removed layer during the anodic dissolution of the wire electrode, the technique observed in [8] was used.



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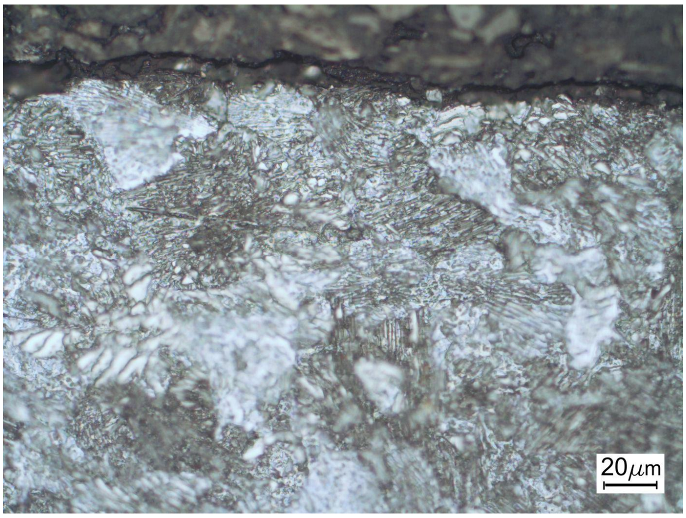

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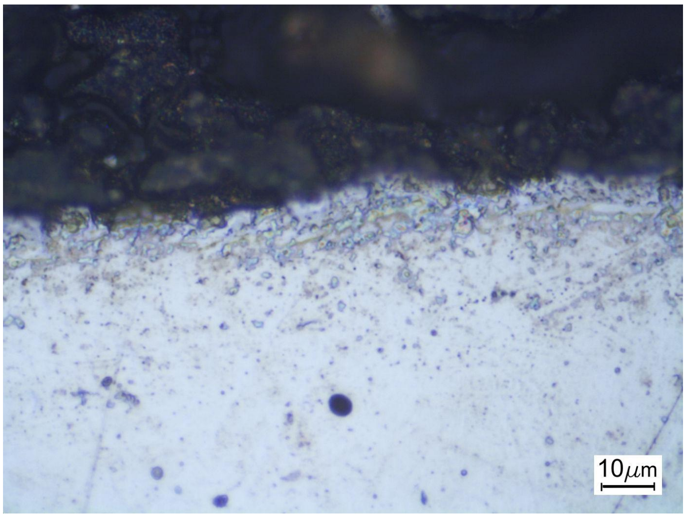
Figure 2. Evolution of the surface of the steel U8A after combined machining technology: a – recast layer after rough WEDM cut; b – removed layer due to 1 pass of ECM.

Fig. 2b depicts the surface with the removed recast layer as a result of ECM (regime No.1).

WEDM is used for the manufacture of magnetic optics elements from technically pure iron ARMCO. Heat treatment of the surface of ARMCO iron due to the impact of spark discharges can not lead to the formation of hardened surface layers. However, the formation of HAZ up to 10 μm thick is well illustrated in Fig. 3a. In the further ECM (Regime No.1) with the wire electrode, this zone can be significantly reduced (Fig.3b) or even removed by calculating regimes to remove the appropriate thickness of the layer.



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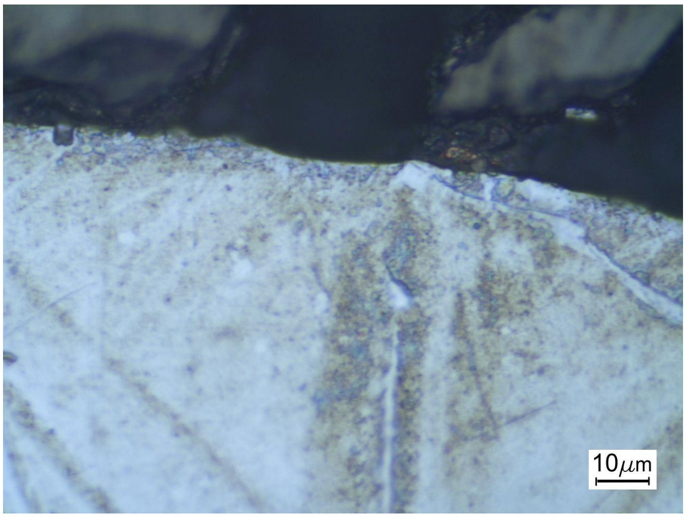

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Figure 3. ARMCO iron surface after machining by combined technology: a - HAZ after rough WEDM cut; b - minimized HAZ as a result of 1 ECM pass

The surface roughness parameter Ra measured in the perpendicular direction to the wire electrode, after the WEDM rough cut, is in the range of 3.1 – 3.7 μm. Typically, surface roughness, measured in the direction parallel to the wire electrode, has lower values. The difference in the roughness indexes is obviously due to the vibrations of the wire electrode in the direction perpendicular to the electrode movement during the electroerosive cutting [11].

The use of one roughness parameter is possible only for the evaluation of one type of surfaces machining with the same method under the same conditions. The analysis of a complex of parameters was performed to assess the dynamics of surface microgeometry changes with a sequential machining method.

Fig.4 shows profilograms of the steel 45 surface, by which one can follow the dynamics of surface changes due to the one-pass (a), triple-pass (b) and five-pass (c) WEDM. The roughness parameter Ra decreases with an increase in the number of passes:

3.58 – 2.54 – 0.93 µm. The skewness parameter Rsk of the surface profile, which is used to determine the ratio of the number of peaks and hollows, decreases from 0.52 to values close to zero. With an increase in the number of passes, there is a tendency to increasing the number of peaks on profilograms. Parameter Rpc – peak count, represents the density of peaks on the surface. A typical increase in the Rpc parameter ranges from 70.8 pks/cm after the first pass of WEDM to 108.3 pks/cm after three passes and then a much increase to 270.8 pks/cm after five passes.

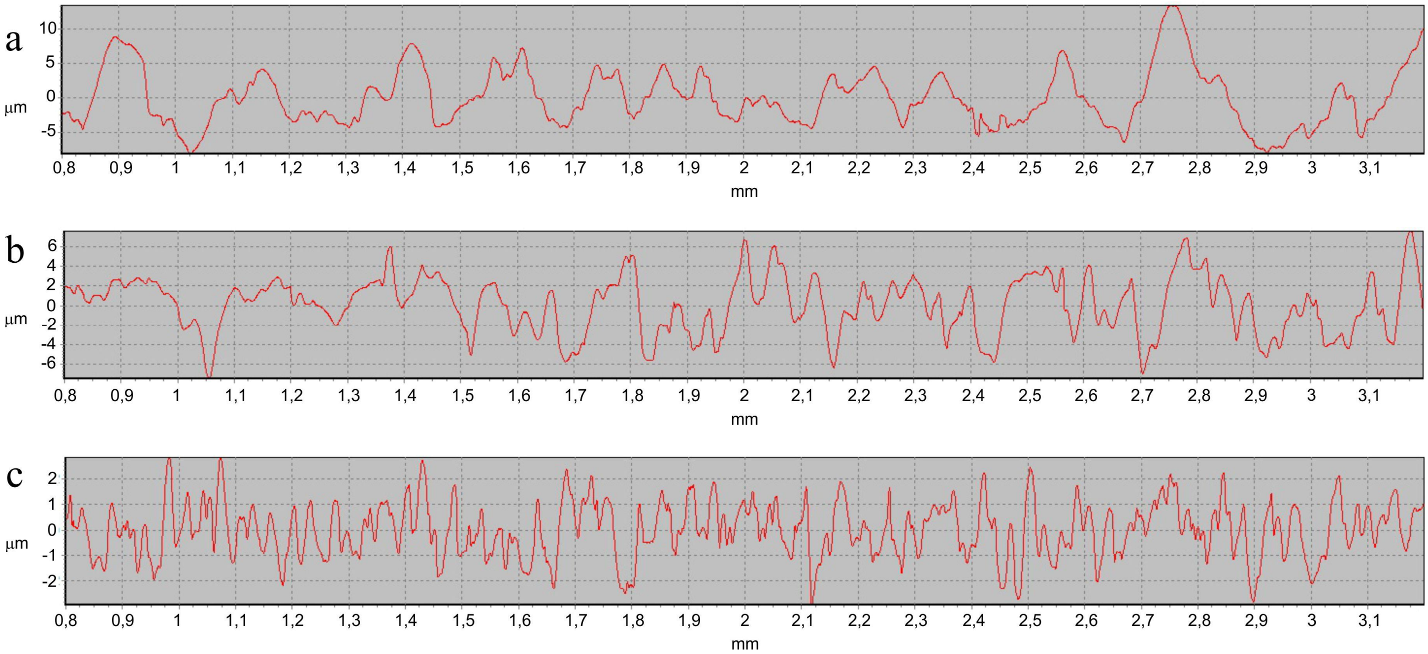

Figure 4. Changing of microgeometry parameters of surface of steel 45 after multipass WEDM: a – first rough cut: Ra=3.58 µm, Rsk=0.52, Rpc=70.8 pks/cm; b – three passes: Ra=2.54 µm, Rsk=-0.12, Rpc=108.3 pks/cm; c – five passes: Ra=0.93 µm, Rsk=-0.03, Rpc=270.8 pks/cm

Fig.5 shows profilograms of the steel 45 surface when using ECM with a wire electrode after rough electroerosive cutting. The surface roughness parameter Ra decreases to 1.35 µm after the first pass of ECM and then to 0.83 µm after the second pass. That is, in the two passes of the ECM reached about the same value as the five WEDM passes. It is an obvious benefit in the effectiveness of surface finishing.

There are significant differences in the nature of the change in the surface profile after ECM. The skewness coefficient Rsk decreased to almost zero after the first pass and gained a negative value of -0.28 after the second pass. The transition of skewness coefficient from a positive to a negative value indicates a change in the surface from peaky to plateau-like shape. Probably, electrochemical machining removes protrusions after the first operation WEDM, but deep hollows remain untouched.

Peak density also decreases to Rpc=50.0 pks/cm.

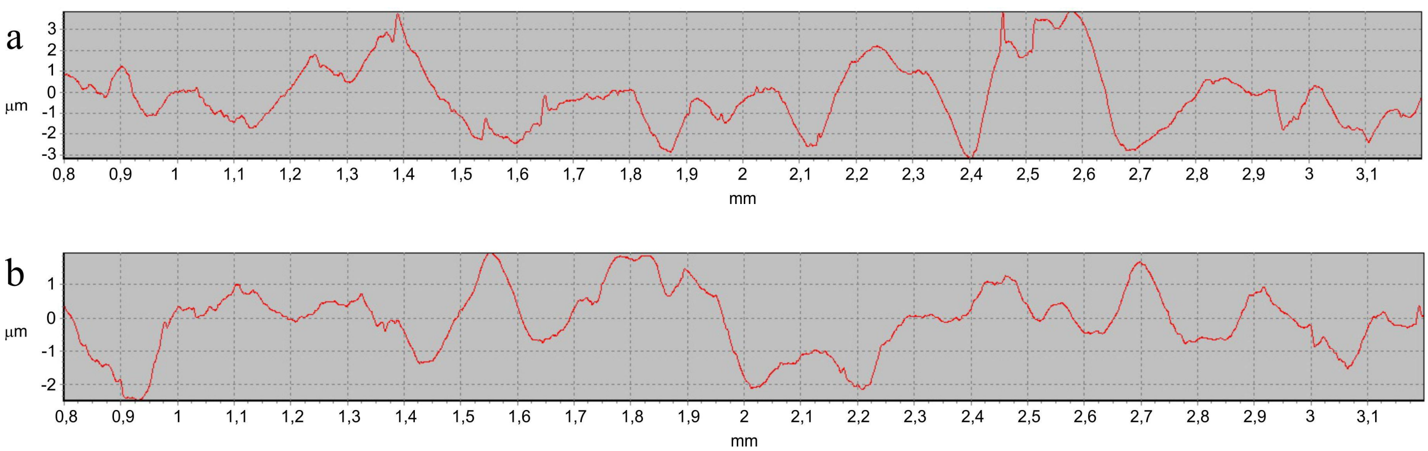

Figure 5. Changing of microgeometry parameters of a steel 45 surface using ECM by a wire electrode after a rough cut of WEDM: a – first pass (regime No.1): Ra=1.34 µm, Rsk=-0.01, Rpc=58.3 pks/cm ; b – second pass (regime No.2): Ra=0.83 µm, Rsk=-0.28, Rpc=50.0 pks/cm

Fig. 6a and 6b shows material ratio curves of the profile (Abbott-Firestone curves) for the surface after WEDM and wire ECM respectively. The relative bearing area in the upper cross-sections increases significantly with the use of ECM. This means that wear resistance of the surface after ECM is higher.

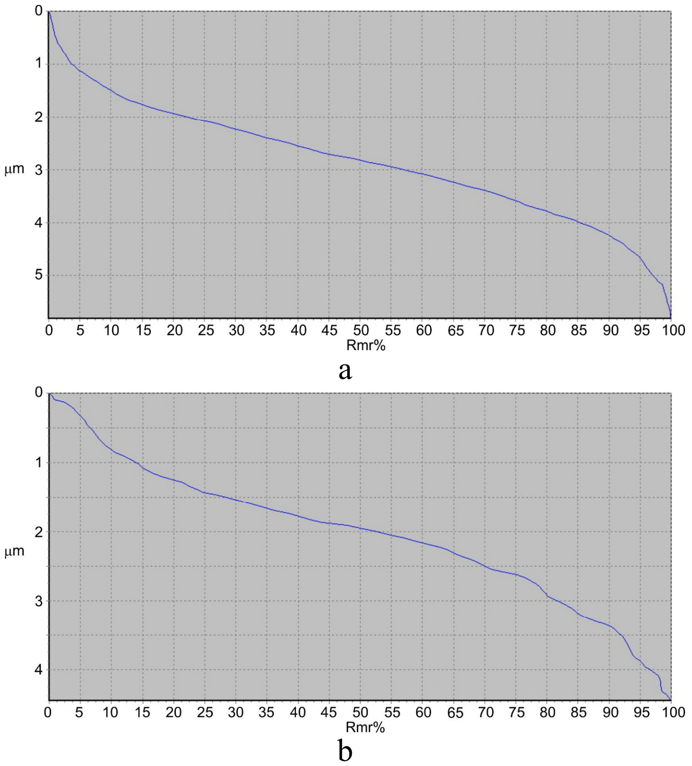

Figure 6. Abbott-Firestone curves of the finished surfaces of steel 45: a - after 5 passes of the WEDM; b - after the rough pass of WEDM and the following 2 passes of ECM

The obtained experimental results give an opportunity to advance in understanding the mechanisms of surface formation by the combined technology of sequential use of electrodischarge and electrochemical machining with a wire electrode. On Fig. 7 there are presented schemes of forming the surface of parts, which principally correlate with the results of many other researchers. WEDM leads to a surface constituted of a chain of small craters, each crater being the result of an electrical discharge [3, 12]. Surface texture, roughness parameters obtained ones by craters with touching boundaries and craters with overlap [13].

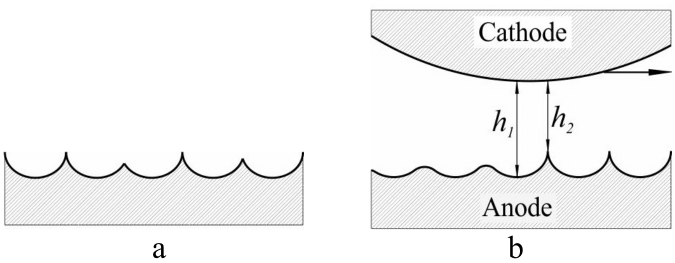

Figure 7. Scheme of surface forming of the workpiece: a – by overlap of craters formed as a result of WEDM; b – by smoothing the surface by preferentially dissolving the peaks due to ECM by a moving wire electrode

The simulation results of the craters formation [14, 15] indicate that the shape and volume of the crater depend on the energy of the discharges. At WEDM's last passes, electrical pulses of lower power and higher frequency are used. This leads to the appearance on the treated surface of more overlapping craters of lower depth. Therefore, the surface roughness decreases, and the number of peaks per unit length increases with each subsequent WEDM pass.

In the ECM stage, a wire electrode, used as a cathode, predominantly dissolves the peaks on the surface of the anode-part (Fig. 7b). The distance from the cathode to the cavity at the anode is greater than the similar distance to the peak ($h_1 > h_2$). Therefore, the intensity of the electric field between the peaks and the cathode will be greater, there will be a concentration of current density on the peaks, and according to the Faraday's law, in other equal conditions, more intense dissolution of peaks on the surface of the part will be more intense. This naturally leads to a change in the surface profile from the peaked to the plateau-shaped.

4. CONCLUSION

1. There was performed the systematic complex of investigations of the structure and microgeometry of surface layers of tool steels, carbon steels and technical pure iron ARMCO, formed on a wide spectrum of WEDM regimes, and after the sequential use of WEDM and ECM with the same wire electrode.

2. There were established the regularities of the regimes influence of the WEDM and ECM with unchanged wire electrode on the surface layers structure and microgeometry of surfaces in the selected material group. The clear presence of the heat affected zone using the WEDM of pure technical iron ARMCO is showed.

3. It is proved that it is possible to controllably eliminate the HAZ by using a sequential WEDM and ECM with a constant wire electrode.

4. There is extended the idea of the surface formation mechanisms by the combined technology of sequential use of WEDM and ECM with the same wire electrode.

5. The proposed schemes of surface formation principally coincide with the results of well-known studies.

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