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ON INFLUENCE OF WORKPIECE GEOMETRY AT HYDRAULIC MECHANICAL REMOVAL MECHANISM OF ULTRASONICALLY AIDED EDM FINISHING

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ABSTRACT: The paper deals with finite element modelling (FEM) of material removal mechanism due to ultrasonically induced cavitation in the working gap at finishing modes of electrical discharge machining. The influence of some workpiece geometries (shape and dimensions) was studied from the point of view of the optimum value of ultrasonic pressure exerted by shock waves produced by cumulative microjets stage, aiming at obtaining a decrease of machined surface roughness at electrical discharge machining finishing aided by ultrasonics (EDM+US). This is in strong correlation with the consumed power on ultrasonic chain, a key-parameter of working finishing mode. By its appropriate adjustment, the surface roughness at EDM+US can be reduced with almost 50% against that from classic EDM. All these technological issues were supported by FEM results.
KEYWORDS: electrical discharge machining, ultrasonics, finishing, surface roughness, workpiece.

1. INTRODUCTION

The surface quality at EDM and its machining precision are two issues very present nowadays with an obvious trend of focusing on ultra-miniaturization in the range of micro (1…999 µm) and even nanometers (1…999 nm) [1, 2].

The ultrasonic assistance of electrical discharge machining (EDM+US) has major advantages at finishing and micromachining, which are characterized by high instability of material removal process due to very narrow gap conditions. EDM+US is able to significantly improve the main technological parameters – surface roughness, volumetric relative wear/precision and machining rate – according to many reports [3, 4]. Nevertheless very few researches reported the decrease of surface roughness (Ra/Rz) as effect of ultrasonic aiding [5].

The understanding of EDM process at scale of µm and nm becomes of utmost importance in order to increase its technological performances [6, 7].

The problem of (Ra/Rz) decrease, correlated to precision increase, and machining rate (V_W) increase by US assistance consists in finding an optimum value for the key-parameter, power consumed on ultrasonic chain (P_{cUS}). The main three parameters improvement has to match contradictory conditions of energy level transferred between electrode-tool and workpiece. These current researches are focused on determination of P_{cUS}, in relation with workpiece geometry, being aware that this parameter depends also on other real working conditions.

2. EXPERIMENTAL DATA

Disk samples from X210Cr12 of different shapes were machined comparatively on Romanian ELER 02 machine with the following dimensions: 1) radius (R) - 15 mm, height (H) - 10 mm; 2) R=15mm, H=20; 3) R=12.5mm, H=25 mm; 4) R=15mm, H=30. The electrode-tool from copper with disk shape of R=11.5 mm, and H=3 mm was used, included in the ultrasonic (US) chain, at its end.

The working parameters of technological system (fig. 1) were: current step, I=3 A, positive (tool) polarity; injection pressure, p_{hl}=0.04 MPa (through workpieces); consumed power on ultrasonic chain, P_{cUS}=0-120W; maximum amplitude, A=2µm (A depending on P_{cUS}), producing ultrasonic cavitation in the gap; tool's longitudinal ultrasonic oscillations of 20 kHz, and no oscillations – classic EDM.

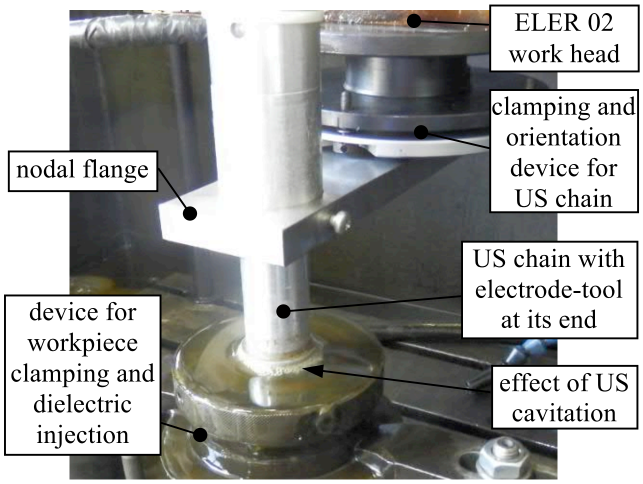

Figure 1. Technological system elements at EDM+US tests

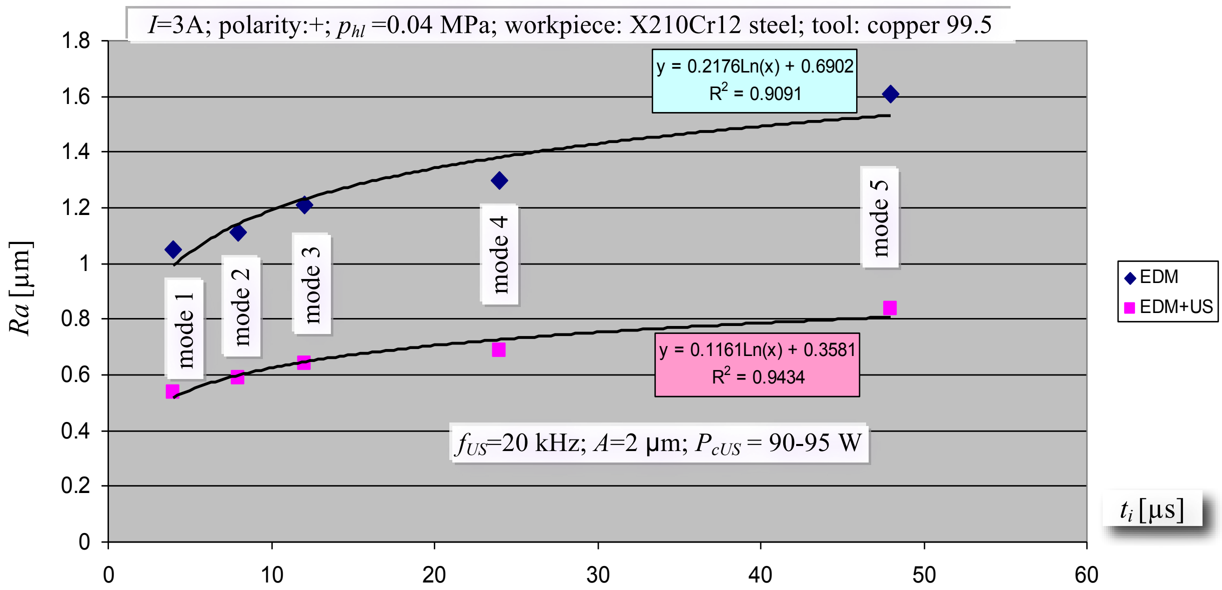

Figure 2. Average surface roughness (*Ra*) as function of pulse time (t_i) at EDM+US and classic EDM, finishing modes

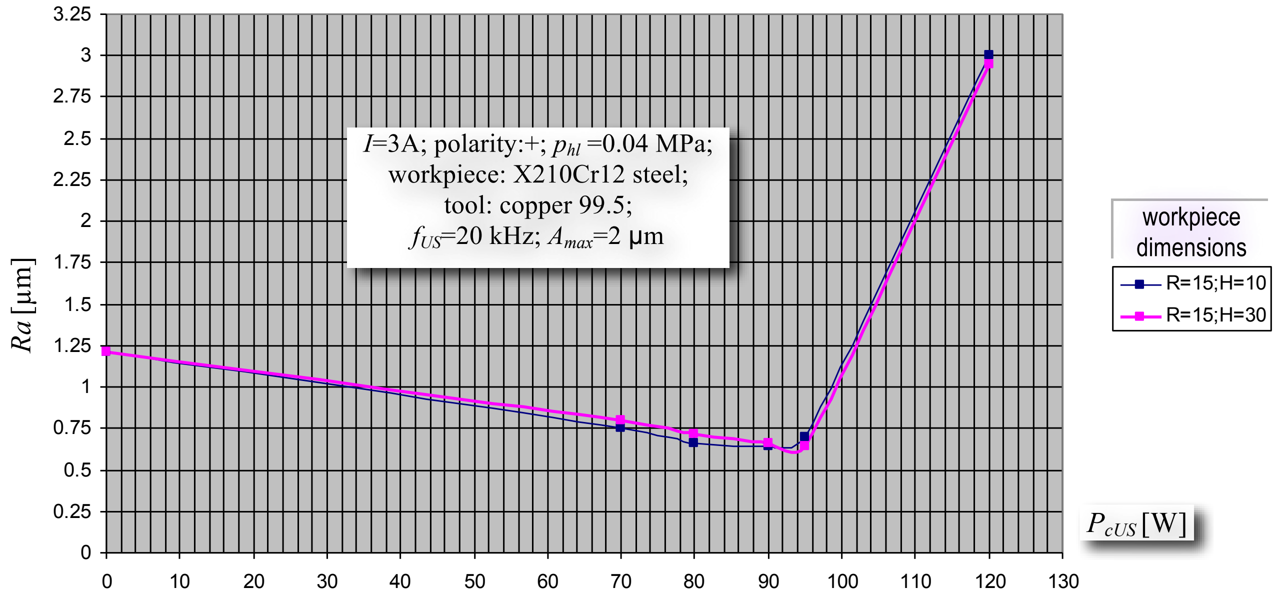

Figure 3. Surface roughness (*Ra*) vs. consumed power on US chain (P_{cUS}) at t_i=12 µs, t_0=6 µs - different workpiece geometries

The surface roughness (*Ra*) as function of pulse time (t_i) averaged on all workpieces geometry types at EDM+US and classic EDM, is presented comparatively (fig. 2) , using the finishing working modes: mode 1, t_i=4 µs, t_0=2 µs (pause time); mode 2, t_i=6 µs, t_0=4 µs; mode 3, t_i=12 µs, t_0=6 µs; mode 4, t_i=24 µs, t_0=12 µs; mode 5, t_i=48 µs, t_0=24 µs.

The decrease of *Ra* due to ultrasonic assistance is maintained in the range of 47-49%, using values of consumed power on ultrasonic chain (P_{cUS}) in the range of 90-95 W - optimum values for each workpiece geometry under a medium working mode (i.e. mode 3). The variation of machined surface (Ra) as function of P_{cUS} on two types of workpiece geometry is presented in fig. 3. The rest of workpiece geometries have P_{cUS} values very close to those of samples with R=15 mm, H=10 mm, so they were not represented. As it can be noticed, some differences between optimum values of P_{cUS} power were recorded. At a workpiece with greater volume, it is necessary to use higher optimum P_{cUS} value to obtain minimum value for surface roughness Ra.

Some samples of microtopography obtained by classic EDM and EDM+US finishing in mode 3 are presented comparatively in fig. 4, 5. Reichert Univar microscope and Buehler OmniMet Enterprise software were used for images achievement, and Taylor-Hobson surface instrument for measuring crater depths. Their corresponding profiles of microcraters produced by discharges under the same finishing mode at classic EDM and EDM+US are presented comparatively in fig. 6, 7.

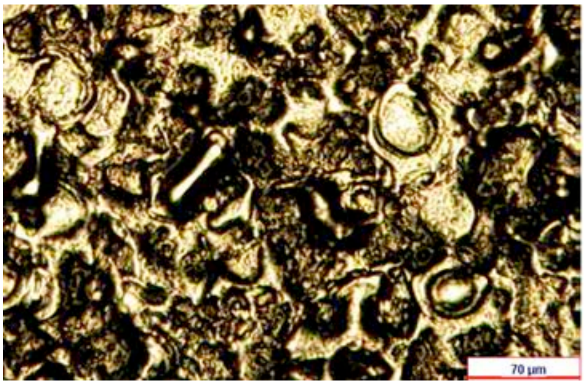

Figure 4. EDM microtopography with Ra=1.21 µm at I=3 A, t_i=12µs, t_o=6µs, positive (tool) polarity

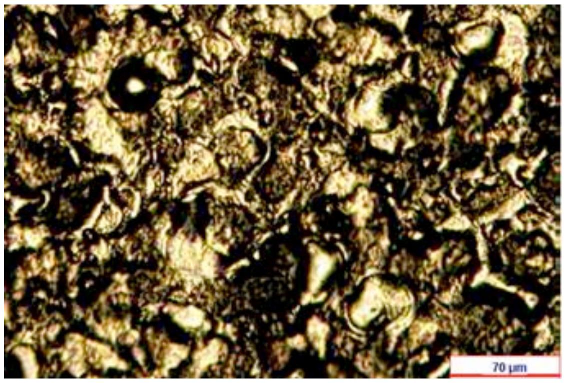

Figure 5. EDM+US microtopography with Ra=0.64 µm at I=3 A, t_i=12µs, t_o=6µs, positive polarity, P_{cUS}=90 W

Figure 6. EDM average dimensions of crater at I=3 A t_i=12µs, t_o=6µs, polarity +

Figure 7. EDM+US average dimensions of crater at I=3 A, t_i=12µs, t_o=6µs, polarity +, P_{cUS}=90 W

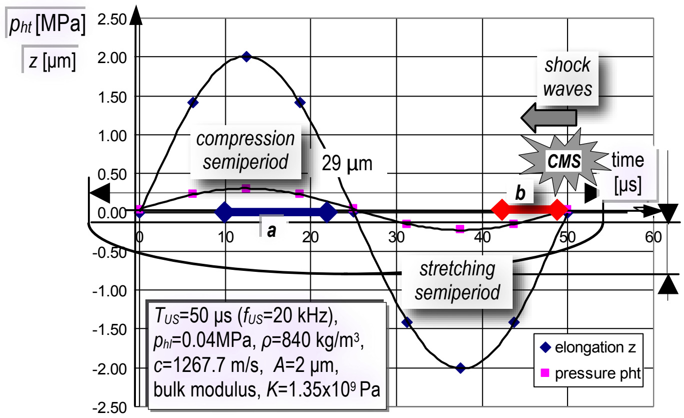

Figure 8. Elongation (z) and total pressure (p_{ht}) in the gap

The average crater dimensions are smaller at EDM+US against classic EDM, although as expected, the material volume removed by discharge is greater at EDM+US. But the crater dimensions are reduced by *cumulative microjets stage* (CMS) - collective implosion of the gas bubbles from the gap, occurring at each stretching semiperiod final due to pressure (p_{ht}) increase (fig. 8), calculated with:

$$p_{ht} = 2\pi \cdot c \cdot \rho \cdot f_{US} \cdot A \sin \omega t + p_{hl} \quad \text{[Pa]}, \qquad (1)$$

where: c is sound velocity in dielectric liquid [m/s]; ρ - dielectric liquid density [kg/m^3]; f_{US}-ultrasonic frequency [Hz]; A-amplitude of elongation z, [m]; $\omega=2\pi f_{US}$ [s^{-1}]; p_{hl} - local hydraulic pressure [Pa].

CMS produces shock wave oriented along the gap, parallel to machined surface, having pressure (p_{US}) of 100 MPa order of magnitude. So, the micropeaks of profile microgeometry (crater margins) very sensitive of shearing loads (fatigue pulse cycles) are removed, and hence Ra / Rz decreased if p_{US} is optimized [8]. These assumptions will be supported below by modelling the removal mechanism.

3. FEM MODELLING OF HYDRAULIC MECHANICAL REMOVAL MECHANISM

The material removal mechanism of EDM+US comprises two components: (1) a thermal one which is produced by electrical discharges in two situations (fig. 8): (a) discharges outside CMS time interval, very similar to classic EDM with material removed by boiling; (b) close to CMS time interval and removal by melting – case (a) and (b) are essentially differentiated by life time of gas bubble surrounding the plasma channel [8]; (2) a hydraulic mechanical one, which is produced by ultrasonic assistance.

Comsol Multiphysics, Structural Mechanics with Time Dependent variant was used for modelling the component (2) of EDM+US removal mechanism. A 2D parametric model was created taking into account the machined geometry properties and cavitational phenomena as it is presented in fig. 9.

▾ Parameters

Name	Expression	Value	Description
rwp	15[mm]	0.015 m	radius of workpiece
hwp	30[mm]	0.03 m	height of workpiece
acr	14.5e-6	1.45E-5	radius of initial crater
bcr	4.84e-6	4.84E-6	depth of initial crater
rms	0.25e-6	2.5E-7	radius of resolidified material on crater margins
modulE	2.1e11	2.1E11	Young' modulus of X210Cr12
pus	116[MPa]	1.16E8 Pa	current ultrasonic cyclic load of CMS
tus	1e-6	1.0E-6	duration of shock wave

Figure 9. Parameters assigned for the model of hydraulic mechanical removal at a definite workpiece geometry

A variable cyclic load as pressure (p_{US}) in the range of 100-200 MPa was applied gradually on one flank of craters profile produced by EDM, a boundary condition (fig. 10.a) in order to estimate the volume removed through shock waves produced by CMS.

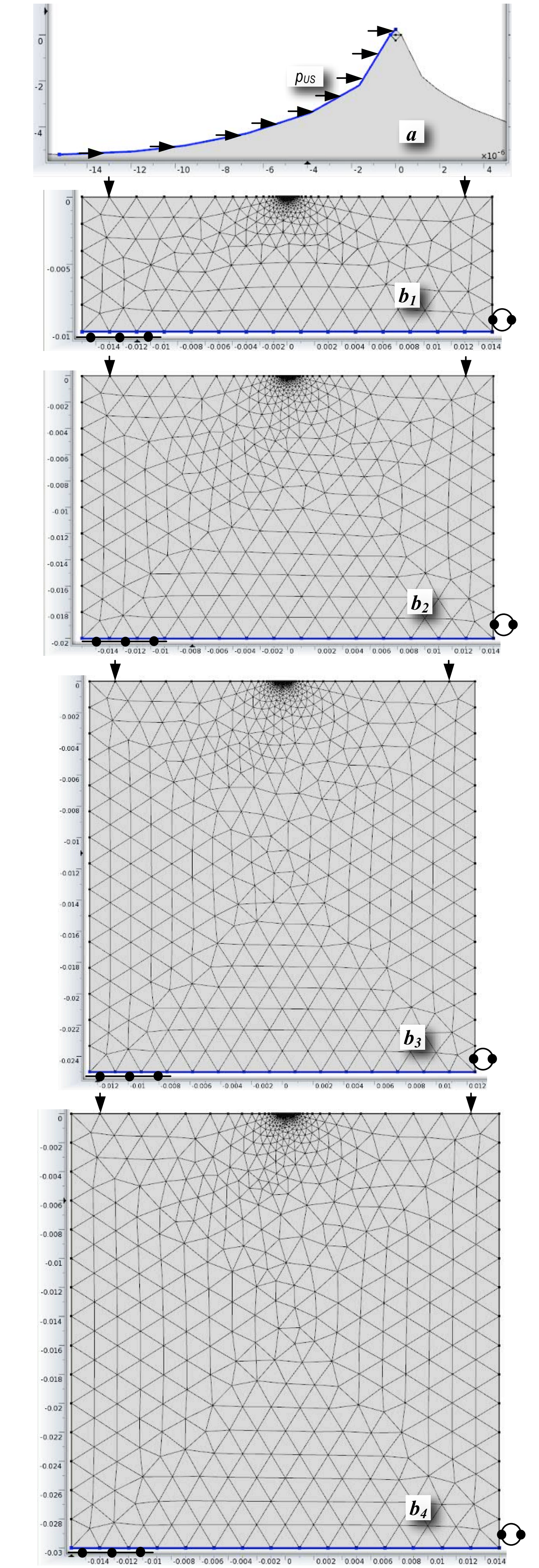

Figure 10. Boundary conditions and meshing: (a) pressure cyclic load on microcrater profile; (b) fixed constraint at bottom, clamping force on top of different samples geometries

Since duration (t_{US}) of CMS (shock wave) is only around 1 μs, the case (a) has much higher probability of occurring. So, the material melted by discharge is already solidified at gas bubble collapse, the end of T_{US}, the resolidification being completed within 1 μs after pulse end [8]. Hence, the material removal by ultrasonics is achieved in solid state, this component (2) is the main in terms of taking place probability. The roughness decrease, the major objective at EDM finishing is attained only if the pressure (p_{US}) exerted by ultrasonic shock waves is optimized, removing only some parts of the peaks of microgeometry profile, i.e. margins of craters, modelled by a_{cr}, b_{cr}, r_{ms} (see fig. 8).

The second boundary conditions was fixed constraint on the workpiece inferior plane since vertical forces were applied for clamping - the orientation was on workpiece bottom plane and lateral cylindrical surface, using a bushing with inbuilt clearance (fig. 10.b).

The material properties were of D3 (UNS T30403), corresponding to X210Cr12, taken from Comsol library and completed with time dependent ones.

The meshing was achieved with up to 3926 triangular elements, average quality of 0.97 on 0-1 scale, and smaller elements in the interest zone, where a higher precision is required (fig.10. b).

The ultimate tensile strength at fatigue pulsing cycle (σ_0) was calculated for estimation of volume removed by US, using the relation [10]:

$$\sigma_0 = 1.12(40 + 0.16\,\sigma_r), \quad \text{[MPa]} \qquad (2)$$

where: σ_r is the usual ultimate tensile strength; in this case, σ_r=1500 MPa. It results: σ_o =313.6 MPa.

4. FEM RESULTS

Some examples of Von Mises stress distribution are presented, above σ_0, i.e. the coloured zone, showing the volume of material removed by CMS, influencing the obtained surface roughness at EDM+US (fig.11. a-e).

Two zones of material removal are highlighted: (1) the micropeak, in this case, the surface roughness (Ra) being reduced; (2) the microvalley, in this case, Ra is increased.

When ultrasonic pressure p_{US} exerted by shock waves has lower values, the material is removed only from the micropeak zone (fig. 11. a, b – the case of workpiece with radius of 15 mm, and height of 10 mm). When p_{US} has progressively higher values, the material begins to be removed also from the microvalley (fig. 11. c-e), and Ra grows.

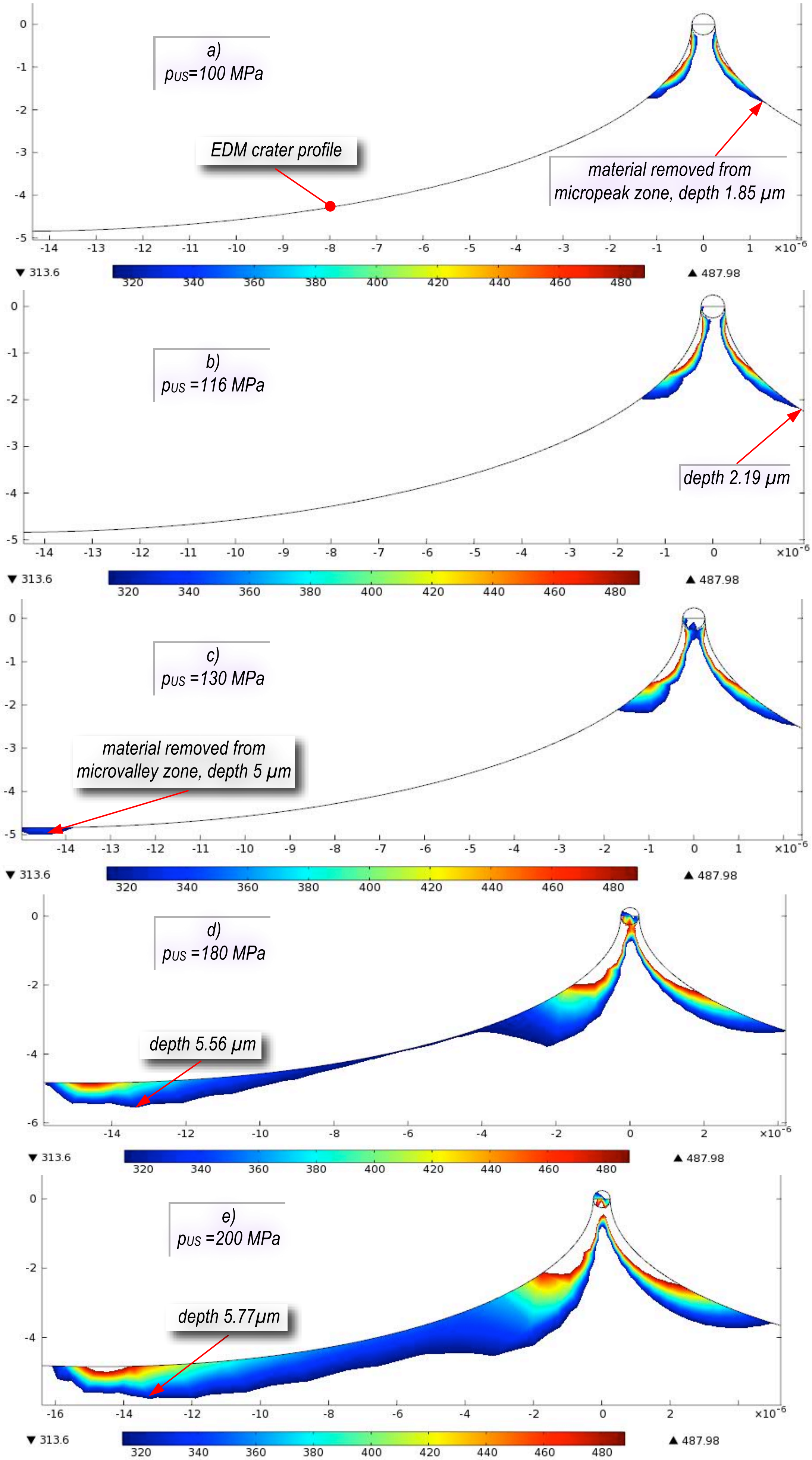

Figure 11. Von Mises stress [MPa] higher than σ_o=313.6 MPa on sample microgeometry of disk shape workpiece (R=15 mm, H=10 mm) from X210Cr12, resulted from EDM with pulse time t_i=12 μs , at different ultrasonic pressures exerted by shock waves

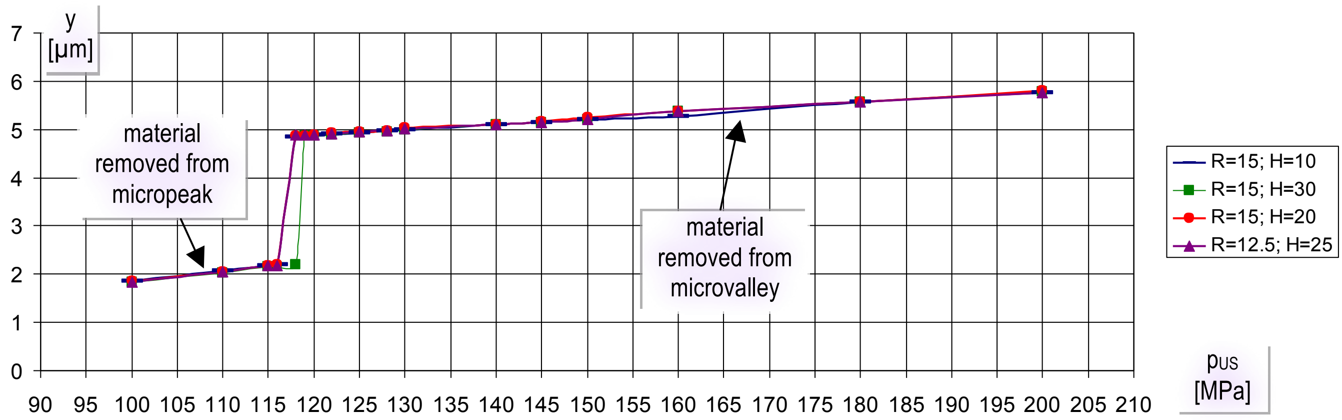

Figure 12. Depth variation (y) of layer removed as function of ultrasonic pressure of shock wave (p_{US}) at different sample shapes

The layer depth removed by ultrasonic shock waves as function of their pressure p_{US} is presented in fig. 12. It is emphasized a threshold located in the range of 116-119 MPa (p_{US}), different values determined by workpieces geometry. The threshold shows the change of material removed zone from micropeak to microvalley, increasing severely the machined surface roughness.

5. CONCLUSIONS

The hydraulic mechanical component of EDM+US material removal mechanism is able to remove the workpiece material in solid state, and thus decreasing the surface roughness. Finite element modelling results pointed out a threshold in terms of ultrasonic pressure exerted by ultrasonic shock waves, corresponding to change of material removal microgeometry zone, from micropeak to microvalley, which increases the surface roughness sharply. The threshold is located at higher values when workpiece dimensions are greater.

In technologic terms, the threshold corresponds to an optimum value of consumed power on ultrasonic chain (P_{cUS}), which is also dependent on real machining conditions. Some fine adjustments of P_{cUS} on US generator user interface in the range of 90-95 W were needed for optimization, taking into account the workpiece dimensions.

6. ACKNOWLEDGEMENT

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