ELSEVIER

Journal of Materials Processing Technology 149 (2004) 316–322

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Comparison of measured and simulated crater morphology for EDM

H.-P. Schulze [a,*], R. Herms [a], H. Juhr [b], W. Schaetzing [a], G. Wollenberg [a]

[a] Institute for Fundamental Electrical Engineering and EMC, Otto-von-Guericke-University Magdeburg, Universitatsplatz 2, Magdeburg 39106, Germany
[b] Institute for Production Engineering, Dresden University of Technology, Germany

Abstract

The crater morphology has been investigated in different procedures. An analytical relation between pulse parameters and roughness has been achieved and differences between a single discharge and a sequence of discharges are described.

Simulations of thermal-affected zones are identified for a single discharge and a sequence of discharges. The characteristics describing the changed gap conditions of the discharge types in the simulation model are shown. Starting from measured current and voltage curves, the thermal channel base parameters are computed.

For single discharges with fixed base localization secure expansion parameters of the discharging channel can be determined if the geometries of measured and simulated thermal-affected regions match. The simulation of moving or jumping bases is considerably more complicated and more time-consuming. The channel movement is determined by more degrees of freedom. These additional degrees of freedom permit multiple solutions and the number of them must be reduced by further limiting conditions.

1. Introduction

A goal of spark erosion machining has been always to compute the roughness of the machining surface via the electrical parameters of machining. In this case, for selected material combinations usable results were achieved. However, the equations were not transferable to all material combinations. The thermal skin depth are computed with different methods which show, however, that there are considerable restrictions.

Therefore, the work at the OvGU Magdeburg and the Dresden University of Technology was undertaken with the aim to compare measurements and simulations. We had to find out how real removal volumes can be computed and what information can be gained from measured single discharging craters.

For the most simulated thermal loads, the necessary restrictions are not considered. For the spark erosion they are as follows:

- consideration of the exact enthalpy $H(T)$;
- source geometry of the plasma channel;
- 3D simulation;
- intermeshing density of the electrodes and of the boundary conditions to the dielectrics;
- time resolution of the transient problem;
- coupling with mechanical changes.

In the case of simulation of single discharges we have to consider the worse case scenario, which corresponds to the measurements for the single discharges in the “cold” and not contaminated dielectric. However, in the test there can be created discharging conditions which correspond to a real “warm” and contaminated discharges. An essential conclusion from these comparisons is that the craters become lower with a larger surface [1]. This modification of the crater morphology results without remarkable change of the voltage and current curves.

The base spreading and the base jumping represent a greater problem. This fact can be detected through high speed framing images and direct single crater measurements. As a result, simulations of pulse sequences are complicated.

2. Analysis methods of crater morphology

2.1. Measurement methods

For the determination of the crater parameters, different methods are possible, whereby for the tests the confocal laser scanning microscopy (CLSM) was used. Specific crater geometry analyses of the electrode arrangements are accomplished with the scanning electron microscopy (SEM). The CLSM is faster and the accuracy of ±0.5 μm is sufficiently

* Corresponding author. Tel.: +49-391-67-12944;
fax: +49-391-67-11236.
E-mail address: hans-peter.schulze@et.uni-magdeburg.de (H.-P. Schulze).

0924-0136/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.matprotec.2004.02.016

precise. 3D patterns of the crater configurations can also be drawn up.

The high speed framing camera (HSFC) permits temporal resolutions of the discharge from 5 to 200 ns what is necessary for an analysis of the discharging processes. These very short exposure times are necessary because the current rise times and the breakdown times of the voltage are in the range from 100 to 200 ns. In such short time periods different processes take place that could not be detected with exposure duration, for instance, of 2000 ns [5]. These longer exposure duration leads to a complete over-radiation of the discharging process. It is impossible to distinguish the light spot into spheres of the plasma channel or of the gas bubble. Possible motions of the cathodic and/or anodic base point cannot be recognized. However, these facts are indispensable for a further physical analysis and the determination of the simulation parameters [2,3].

In third testing equipment for single discharges on polished electrode surfaces a specific test cell was used and the single pulses generator of the HSFC configuration. The results of this peak-plate arrangement permit comparisons with the HSFC patterns and the thermal simulations of base point heating. These tests were carried through under the boundary conditions of an additional contamination, of a double pulse sequence and of different work liquids. De-ionized water and *n*-dodecane were used as work liquids. The additives belong to the class of alicyclic and aromatic compounds.

2.2. Simulation of the crater geometry (ANSYS)

The simulation of crater geometry refers exclusively to the thermal influence of the machining surface through the base of the plasma channel. A heat source is assumed that affects the workpiece and/or tool surfaces (Fig. 1).

The temporal change of the quantity of heat $Q(t)$ is determined by the drop voltage at cathode (workpiece) $u_{k(a),\mathrm{drop}}(t)$ and/or anode (tool) and the temporal ramp of the gap current $i_{k(a),\mathrm{drop}}$. Factor k is considered, whether the heat is constant or spatially unequally distributed within the channel diameter. The influences can also be examined by changed drop voltages with this k-factor. For the current tests $k = 1$ was set.

A further important factor is the dependence of the plasma channel geometry on the electrical parameters of discharge. In former simulations [4], no real connection of the radius change with the physical processes is incorporated. The recent simulations are characterized by taking into account real current and voltage curves and realistic original radii $r_{e,0}$ and radius changes $\mathrm{d}r_f/\mathrm{d}t$. Results of the different research methods (CLSM, HSFC and ANSYS) are combined in order to extend the real physical conditions for the discharging process and surface heating.

3. Results

3.1. Influence of the electrode arrangements

The fundamental criticism concerning single discharges was that the boundary conditions do not correspond with those of the real spark erosion with pulse sequences.

For this reason, three different kinds of electrode arrangements which are typical for fundamental studies were examined. In Fig. 2a it is clearly shown that the simple peak-plate arrangement is essential for deeper craters with high edge crater melting. The arrangement in Fig. 2c shows a far lower crater structure and a smaller crater depth for identical pulse parameters. The greater process near electrode arrangement

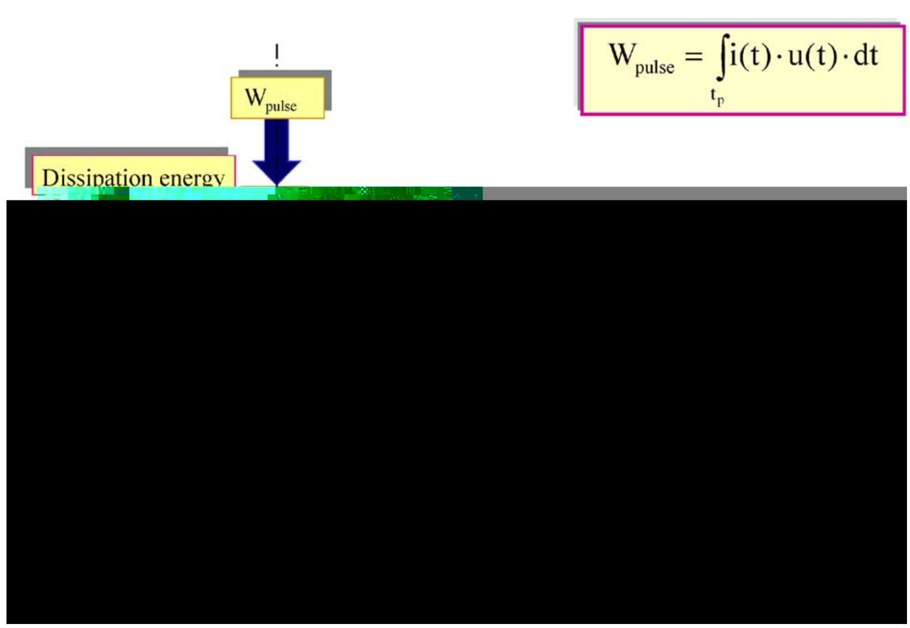

Fig. 1. Heating approach for simulation of the thermal-affected zones.

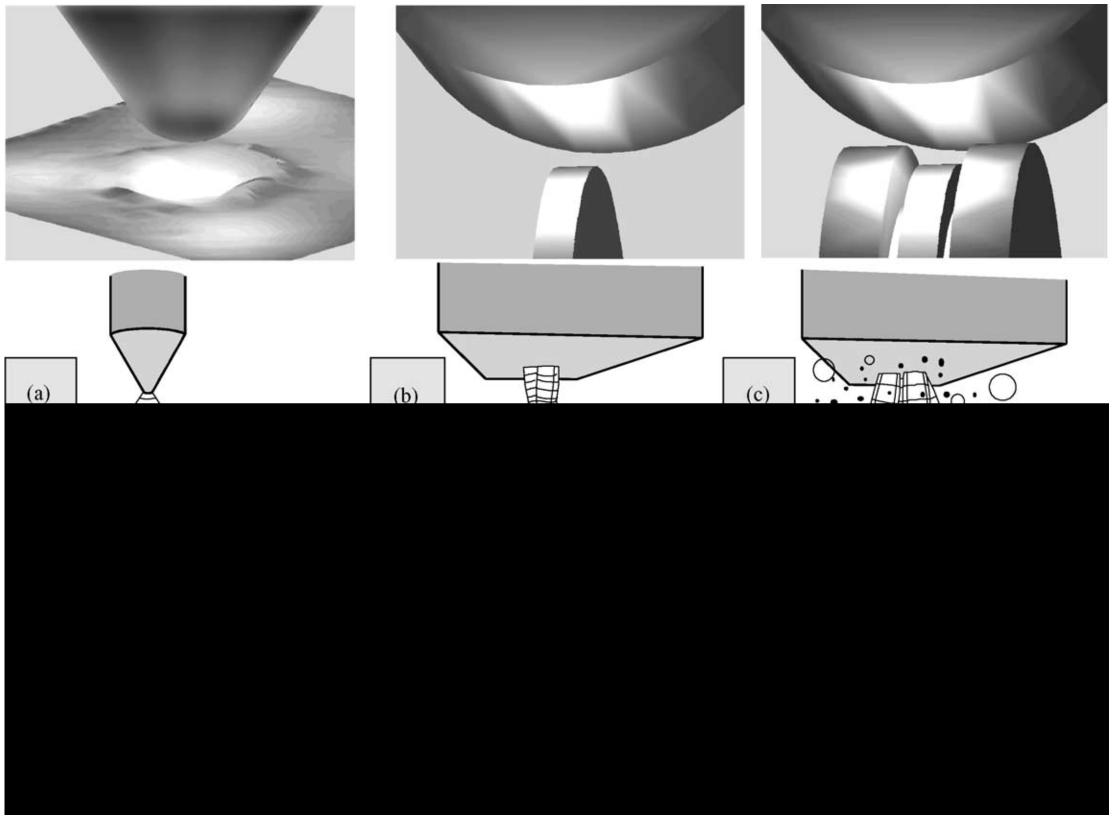

Fig. 2. Crater structure for different electrode arrangements.

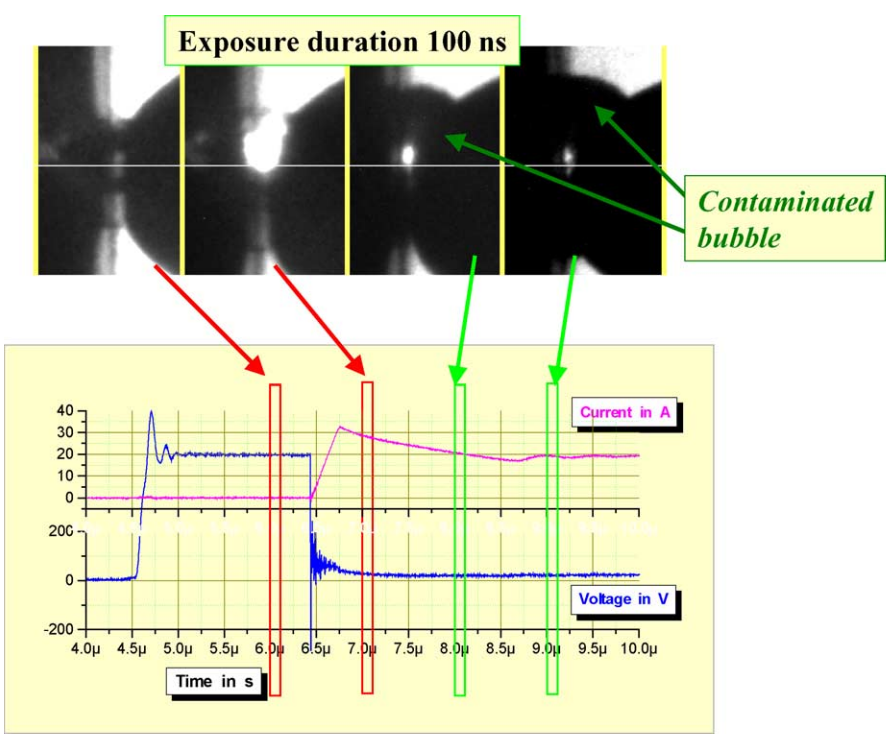

Fig. 3. Influence of the gas bubble of the emission effect of the plasma channel.

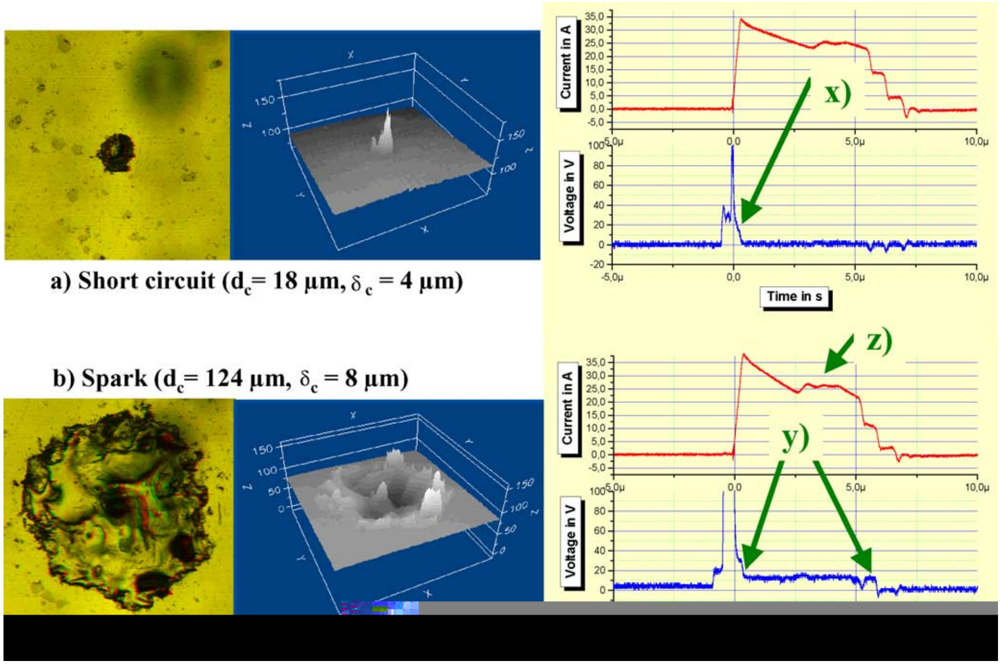

Fig. 4. Crater geometry of short circuit and spark discharge [6].

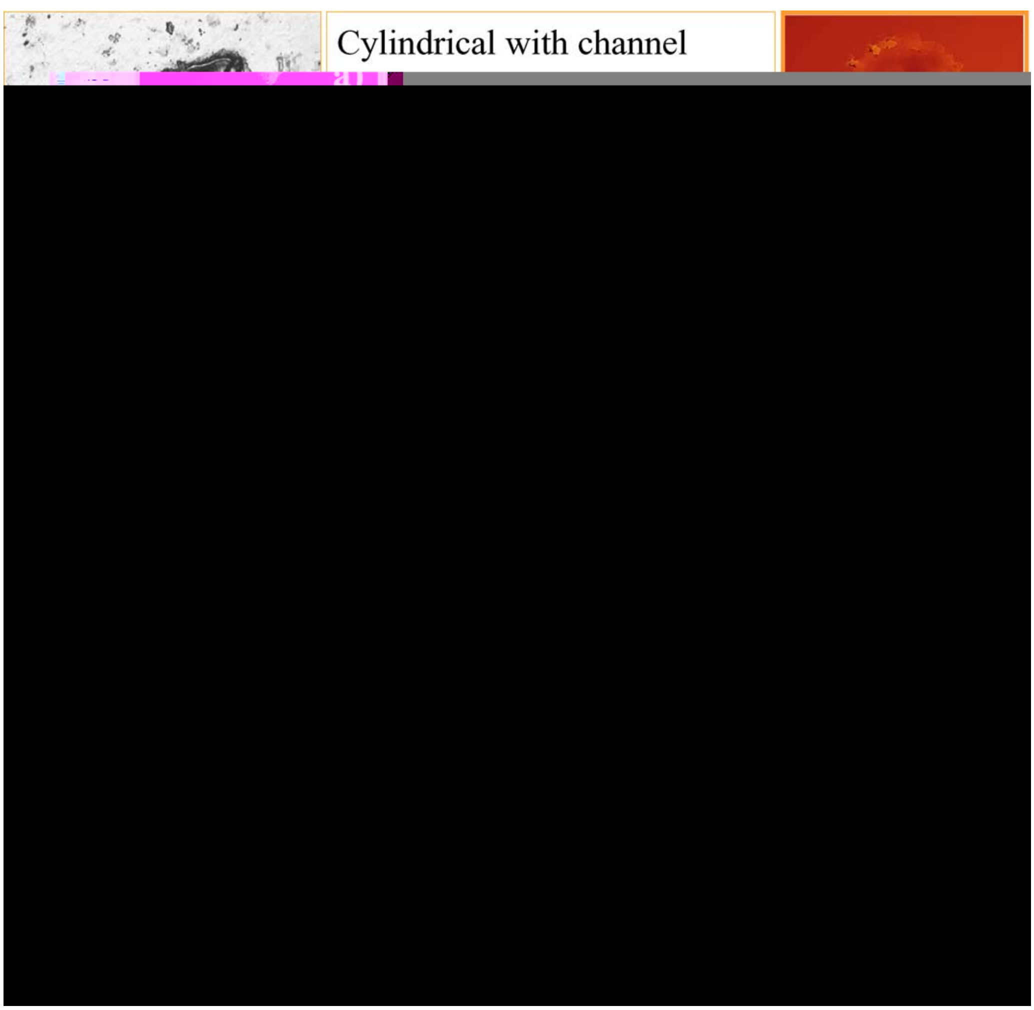

Fig. 5. Channel moving from type 1–3 [6].

shows a better correspondence of the simulated single crater geometry with the measured roughness. As a result, an explanation can be given that the arrangements (2a) and (2b) show an electrical discharge in a “cold”, not contaminated dielectric. The arrangement (2c) creates, by the pre-erosion on the external electrodes, a strong contamination also in the range of the mean target electrode and a local heating of the working fluid [4]. For the optical studies the arrangement (2c) is not applicable because the gap pollution falsifies the emission effect and the electrode arrangement makes it impossible to localize the discharge. Fig. 3 shows how strong pollution affects the optical effects (light spot). In spite of a single discharge, by high pulse energy a contamination is also produced in an initially optically pure medium that makes light spot analysis difficult.

3.2. Crater morphology

The measured crater geometry (CLSM), in connection with a complete recording of the current and voltage curves of a single pulse, permit very good conclusions about the kind of discharge. Fig. 4 shows short circuit and the eroding pulse after base movement (type 5) according to [6].

In Fig. 4a, a short circuit beginning directly after the breakdown is recognizable. The crater geometry corresponds to the (x) inserted power. In the 3D image the tear location is recognized at the bright elevation (>6 μm). The crater geometry in Fig. 4b shows a spark discharge with several bases caused by multiple jumping (z). Multiple bases mapped in the voltage curve (y) and in the 3D image.

Problems concerning a simulation arise if several bases exist and the plasma channel is moving and/or jumping (Fig. 5). A base movement can be implemented into the simulation, this, however, disturbs the condition of symmetry and leads to a prolonged calculation time. In the case of jumps, the symmetry condition is also disturbed and the local distribution of pulse energy per partial discharge must be determined. The number of the jumps also causes greater energy losses through re-ignition phases.

For calculation of a total removal it would be sufficient, but the inaccuracies for an roughness analysis or the analysis of the thermal-affected zones would be too great.

The channel movements in Fig. 5b and c correspond to the simulated processes concerning the diameter. In Fig. 5c we recognize several melting zones have the same depth according to the CLSM-image. In this case, the right crater region is interspersed by a stronger formation of gas. Because of jumps in Fig. 5d the craters become deeper, the partial diameters are reduced.

The examined discharge sequences (Fig. 6) do not show any base movements. The reason for this is the remelting processes. The short pulses (left, 4 μs) leads to an uniform surface with small regions of recrystallisation. Pulse durations from 25 μs show the combination of crater types 1–3, similar to the single crater in Fig. 5c.

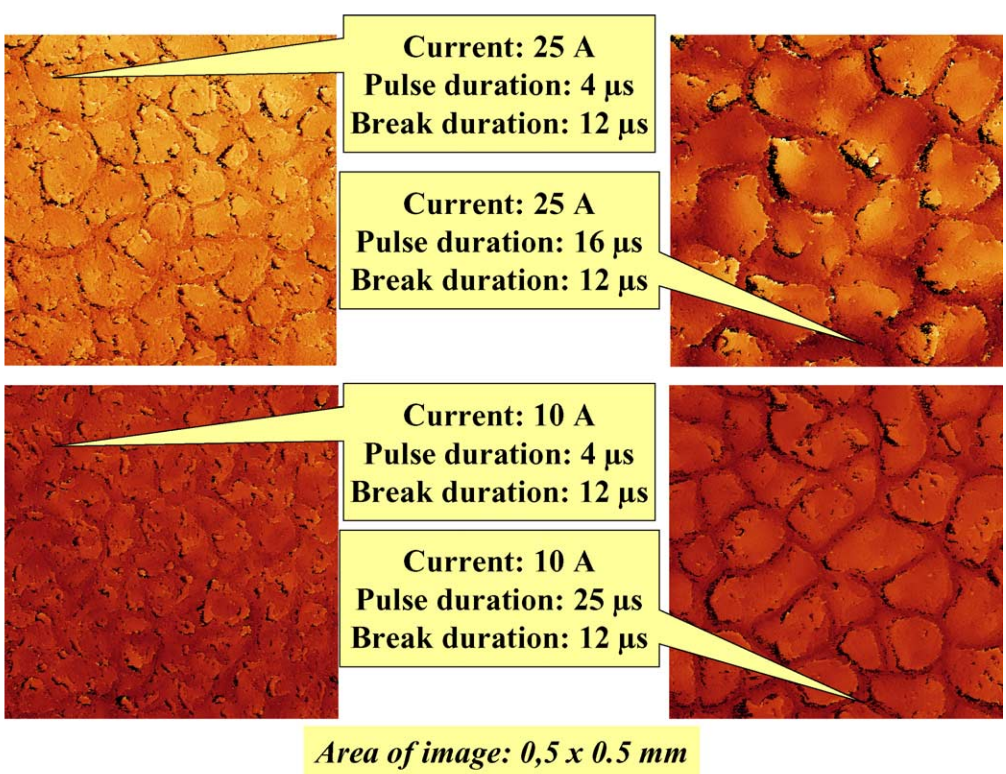

Fig. 6. ED-areas for discharges sequences.

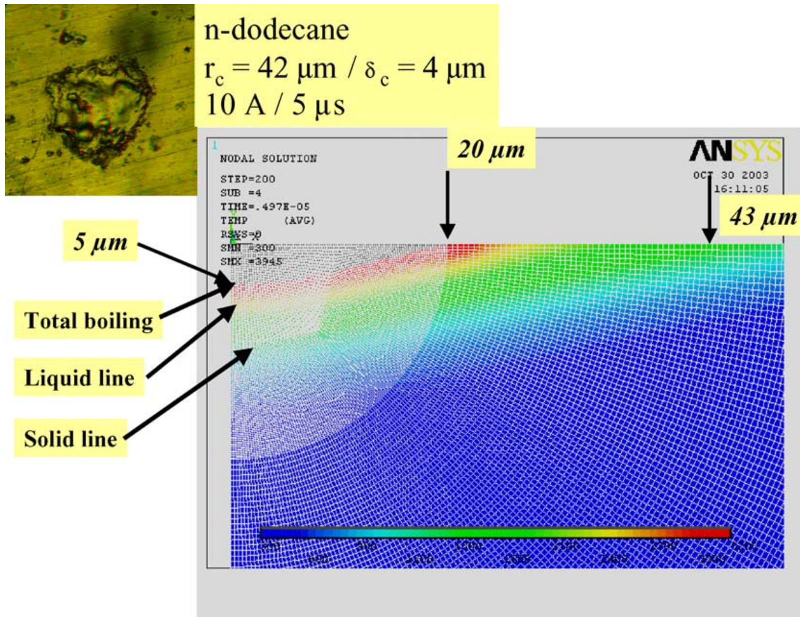

Fig. 7. Simulation of the thermal-affected zone and comparison with measured crater geometry (10 A, 5 µs).

3.3. Simulation

Simulation with different pulse parameters and the thermal effect on the processing surface shows that the radius expansion of the plasma channel influences the thermal surface effect in a large measure.

In a first case (Fig. 7) at a discharge with 10 A of eroding current and 5 µs of pulse duration shows that the measured crater parameter with those from the simulation correspond very well. Fig. 7 illustrates a total boiling volume with a diameter ∼40 µm and a depth of 5 µm. Including the melting volume a diameter of ∼86 µm is achieved. The measured single discharges result on the mean values for the diameter of 84 µm and for the crater depth of 4 µm.

In a second simulation (Fig. 8) of a discharge with 25 A of eroding current and 5 µs pulse duration it can be proved that the plasma channel parameters must change in order to achieve a correspondence of measured and simulated craters. The reason for this is the changed current rise rate that causes changed spreading of the plasma channel and changed starting conditions (breakdown effects).

In a third simulation it could be proved, that the “cold”, non-contaminated single discharges can and the “warm”,

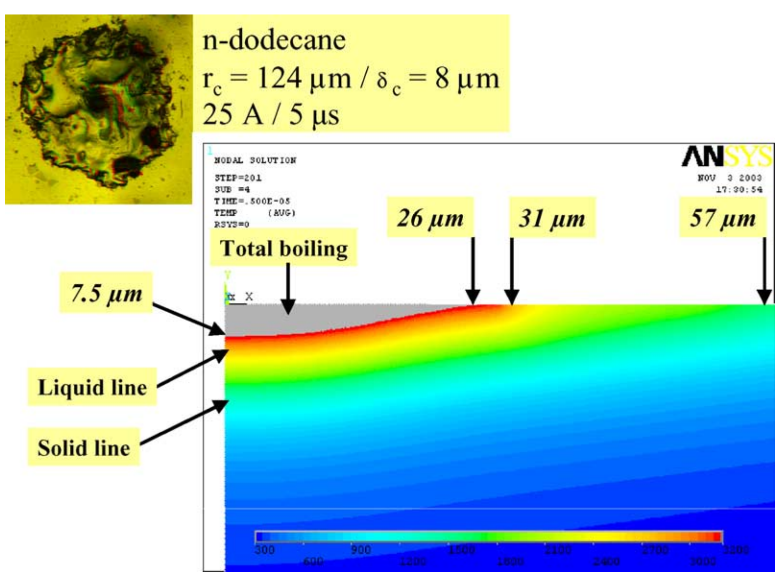

Fig. 8. Simulation of the thermal-affected zone and comparison with measured crater geometry (25 A, 5 µs).

contaminated discharges as well can be obtained only by changing of plasma channel geometry. The change of plasma channel geometry shows a relatively high sensitivity onto the different regions of the thermal surface influence. That also explains the relatively great dispersion of the measured single craters. In principle, all these effects are detectable in the measured current and voltage curves. The only technical demand is a sufficiently high upper cut of frequency of oscilloscopes and sensors.

4. Conclusion

The comparison of measured crater geometry with simulated ones is a very important method to determine the connections of the physical processes during the discharge and spark and the parameters of the process energy source. The change of the pulse parameters also leads to purposeful changes in the plasma channel parameters which can be determined partly from the HSFC images. The physical effects that be considered are Pinch effect, temperature and pressure dependence of the enthalpy, specific heat capacity, heat conductivity, and the distribution of the energy parts in the plasma channel and on the electrode faces.

In the simulation the influence of different electrode arrangements (gap conditions) can be implemented through variation of channel geometry. These changed physical conditions also affect the change of the channel parameters. Additional effects directly in the gap can be taken from the current and voltage curves.

References

[1] H.-P. Schulze, K. Mecke, W. Schätzing, H. Juhr, W. Rehbein, Crater geometries of single pulse discharges as criterion of evaluation of pulse removal rate models, in: Proceedings of the Third International Conference on Machining and Measurement of Sculpture Surfaces, September 24–26, 2003, Krakow, Poland.

[2] G. Wollenberg, H.-P. Schulze, M. Läuter, Process energy supply with pulses smaller than 200 ns and their thermal effects an Micro-EDM, in: Proceedings of the 17th International Conference on Computer-aided Production Engineering (CAPE 2001), Wuhan, China, Professional Engineering Publishing Limited London and Burry St. Edmunds, UK, 2001.

[3] F. Van Dijck, Physico-mathematical analysis of the electro discharge machining process, Katholieke Universiteit te Leuven, Ph.D. Thesis, 1973.

[4] R. Perez, N. Chiriotti, R. Demellayer, R. Flükiger, A. Zryd, Investigation of physical processes in Wire-EDM by means of single and multiple discharge measurements and analysis, in: Proceedings of the 13th International Symposium for Electromachining ISEM XIII, May 9–11, 2001, Bilbao, Spain, pp. 473–483.

[5] A. Karden, Funkenerosive Senkbearbeitung mit leistungssteigernden Elektrodenwerkstoffen und Arbeitsmedien, Dissertation, RWTH, Aachen, 2000.

[6] H.-P. Schulze, M. Läuter, W. Rehbein, K. Mecke, G. Wollenberg, Channel spreading during the spark discharge for selected conditions and working fluids, 2003 Annual Report Conference on Electrical Insulation and Dielectric Phenomena CEIDP, IEEE Dielectrics and Electrical Insulation Society, 2003, pp. 297–300.