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Improved cemented carbide properties after wire-EDM by pulse shaping

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Abstract

In many applications the wire-EDM of cemented carbides (WEDM) (WC–(TiC)–Co) is restricted by the basic properties of this family of materials. Therefore, this research was aimed at developing an optimal process energy source that produces improved material properties after WEDM.

The studies showed that it is important to use the correct parameter selection for main-cut and post-cut. Deterioration in the material properties by processing with high pulse energies can be corrected only by a limited extent in the post-cut. The primary actuating variable of pulse is the pulse duration, i.e. with pulse duration <500 ns higher current magnitudes can also be used without problems. Through the use of a new process energy source increase of bending strength of average 30% could be achieved.

Simulation of the pulse waveforms and how the thermal load of the cut surface can be reduced and the technical conditions can be adapted to a particular application are shown in this paper.

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Keywords: Wire-EDM; Optimal process energy source; Post-cut

1. Motivation and problems

The application of cemented carbide for cutting die and material-deforming tools wins in the industrial employment an increasing importance. The use of cemented carbide tools for cutting punch, cutting plate or bending elements lead to a higher piece number compared to traditional materials with significant lower abrasion resistance. Thus, costs can be reduced clearly. An intensified use by cemented carbide in the industrial sector is the future intent.

In the case of using cemented carbide tools the wire-EDM, and shape grinding are the only possible machining processes for cutting plates, punches and other cutting elements. The use of shape grinding has set geometrical boundaries, so that only the wire-EDM is usually applicable for the machining process. A special issue is the heavy mechanical tensions in the peripheral zones of the cutting punches and plates during the cutting of metal (Fig. 1).

A disadvantage of wire-EDM is the higher thermal damage done of the rim zone caused by the thermal character of the machining process. Residual stresses are induced in the rim zone generating cracks that run deep into basic material. Additional damage is generated by the electrochemical effect during the phase before the ignition occurs and when high voltage applies. Caused by the material composition (cobalt–tungsten carbide), a critical partial desolution of the cobalt takes place (Fig. 2).

Afterwards the material damages have only limited removable. Many post-cuts do not lead to considerable improvements of the mechanical properties. Fig. 3 shows the dependence of the bending strength from the process technology (shape grinding, wire-cut, first post-cut, second post-cut and third post-cut). The diagram is built on an experiment with a four point bearing of the cut rods. The experiment indicates the damage of the rim zone under the viewpoint of the strain.

However, the use of cemented carbide underlies legitimate reservations with regard to the process reliability in application. The abrupt breaking out of material in the cutting edge is a cause for cost-intensive interruptions of production. Furthermore, there is the danger that further active elements are damaged [1,2].

For a more attractive application of cemented carbide it is necessary to radically reduce the deficiencies of wire-EDM.

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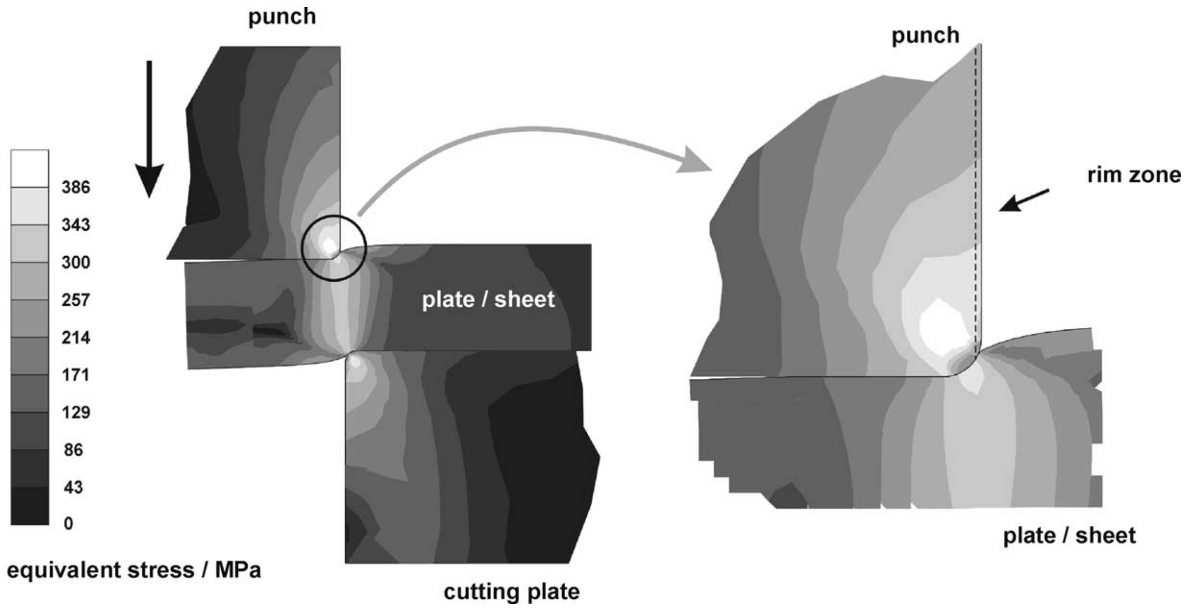


Fig. 1. Strain on the active instrument elements while the sheet cutting.

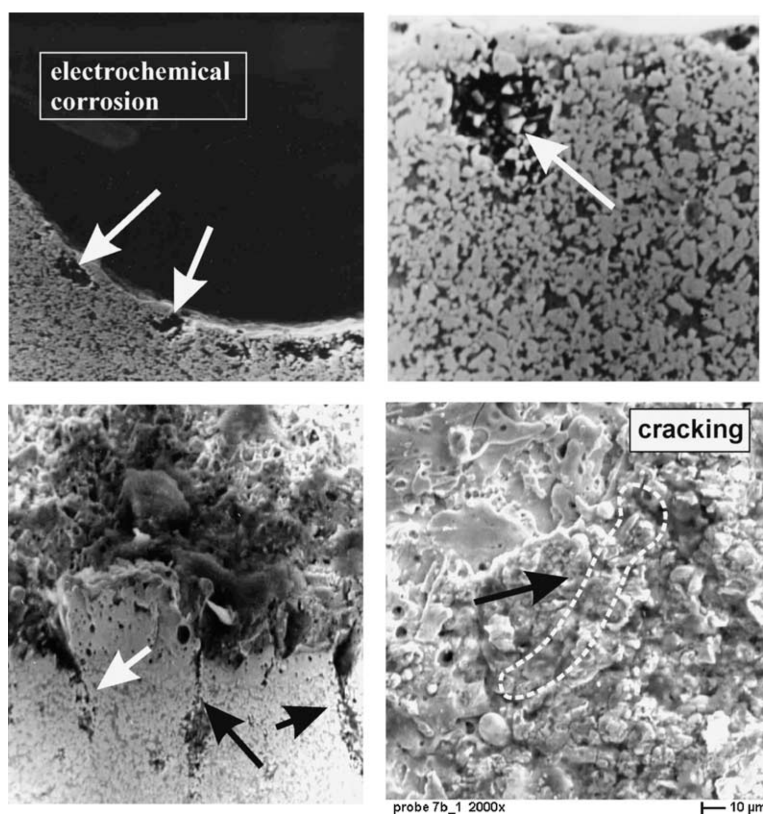


Fig. 2. Damages of the rim zone due to WEDM.

Obviously these post-cuts cannot produce any improvement in the mechanical features. Therefore, the goal of our project was to reduce the thermal damages already in the main-cut. At the same time the surface roughness should be reduced. Through this, the number of necessary post-cuts and the cycle time are reduced.

2. Approaches

2.1. Average-zero voltage

The electrochemical corrosion can be suppressed by control of the gap voltage on the average to zero. The typical

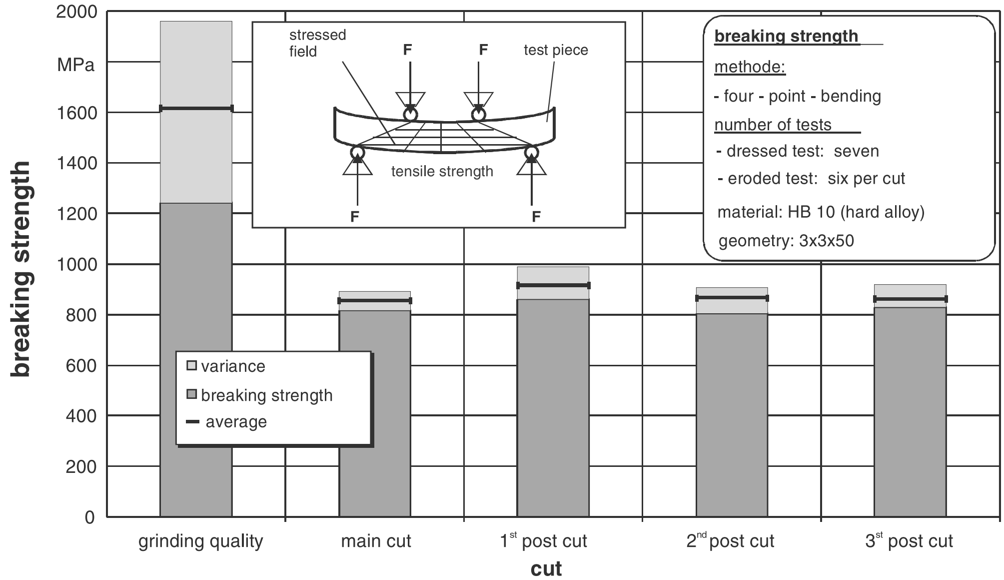


Fig. 3. Bending strength at use of a conventional technology strategy with the WEDM.

process energy sources are ac-generators, which are the actual standard for modern machines [3].

2.2. Reduction of discharge duration

An approach to reduce the damage of the rim zone because of a crack initiation is a reduction of the thermal depth effect of the discharge. The thermal simulation in Fig. 4 shows that a shortening of discharge duration minimises the depth of the thermal-affected zone significantly. Different approaches exist to reduce the thermal depth effect (Sections 2.3 and 2.4).

2.3. Reduction of pulse energy

A reduction of the cutting rate can be compensated only partially by an increase of the pulse sequence. A limit of the pulse sequence is reached by the kind of the energy source which leads to process instability and wire breaking. The productivity losses cannot be compensated completely, but the roughness can be reduced.

2.4. Isoenergetic reduction of discharge duration

The pulse duration is shortened under retention of the pulse energy. The pulse current must be increased correspondingly. The simulation of the changed pulse parameters has shown, that the thermal depth effect is weaker and the thermal-affected zone was reduced between the solid line and the liquid line of the material. For the practical experiment an isoenergetic pulse was used, because it reaches a preferably small variance of thermal pulse influences. This could be reached by a high current needle-pulse generator with free selectable current rise. The maximum current rise is 700 A/μs.

2.5. Variation of the shape pulse

A temporal change of the energy input occurs during the pulse duration. By the delay of the needle pulse and/or a group of needle pulses, the effective area of the plasma channel base is increased and a further decrease of the thermal

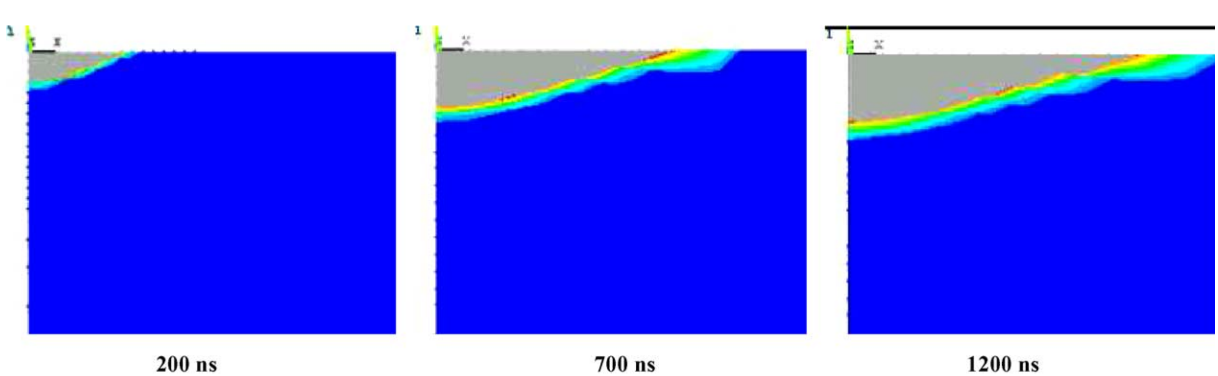


Fig. 4. Simulation of thermal influence of WEDM surfaces.

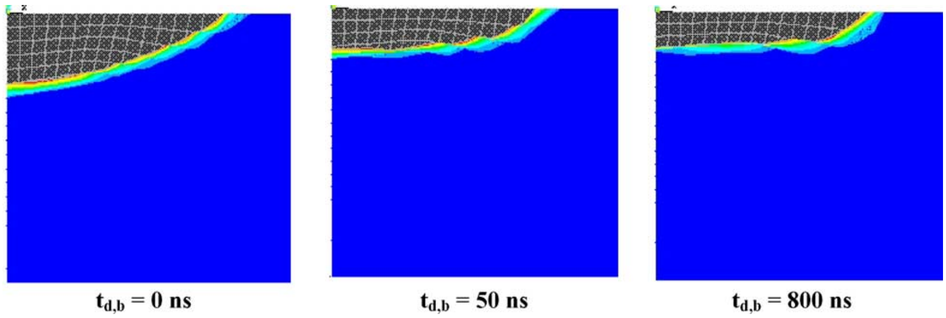


Fig. 5. Change of the thermal-affected zone by needle pulse time displacement.

depth effect (Fig. 5) is possible. In addition, this pulse shaping requires changed strategies in the process control.

Furthermore, we had to examine, whether the rim zone damages are caused through the main-cut or the post-cuts. Two experimental assemblies were used.

On the one hand main-cut tests with a discharge energy of 3.6 mJ as illustrated in Table 1 were accomplished.

Moreover, post-cuts with smaller discharge energies (1 and 0.3 mJ) were accomplished. In the experimental configuration the influence of previous main-cuts were eliminated. For this purpose a previously lapped surface with the following parameters (Table 2) was open-cut.

Process parameters and over sizes for the respective post-cuts are typical and extracted from the technology of the plant. In addition, by measurements of the respective current and voltage curves the pulse energies were also examined. Table 3 shows the pulse parameters for a second post-cut.

Table 1
Pulse parameters of the main-cut (ns)

Test	Pulse duration, t_e (μs)	Current magnitude, $\hat{i}_f$ (A)	Pulse energy, W_f (mW s)
hsh exeron C510	1.5	220	3.6
hsn1 needle pulse 1	0.710	390	3.2
hsn2 needle pulse 2	1.00	300	3.6
hsn3 needle pulse 3	1.14	280	3.5

Table 2
Pulse parameters of the first post-cut (ns)

Test	Pulse duration, t_e (μs)	Current magnitude, $\hat{i}_f$ (A)	Pulse energy, W_f (mW s)
nsh1 exeron C510	0.80	115	0.99
nsn1-1 needle pulse 1-1	0.47	188	1.04
nsn1-2 needle pulse 1-2	0.61	142	1.05

Table 3
Pulse parameters of the second post-cut (ns)

Test	Pulse duration, t_e (μs)	Current magnitude, $\hat{i}_f$ (A)	Pulse energy, W_f (mW s)
nsh2 exceron C510 2	0.52	65	0.33
nsn2 needle pulse 2	0.32	90	0.34

3. Methods of analysis

The simulation of the thermal-affected zones was carried out by an ANSYS program. It was developed on the Otto-von-Guericke-University Magdeburg and is already used in other publications [4]. The specific feature of this program is the consideration of the voltage ($u(t)$) and current ($i(t)$) curves, and for the examined materials the complete enthalpy curves $H(T)$ can be considered.

The analysis of the cemented carbide probes covers the following methods [5]:

- roughness measurement for all main and post-cuts;
- bending fracture tests for a sufficient number of probes;
- cross grinding analysis for selected probes;
- SEM surface pictures of selected probes;
- SEM surface of fracture photographs;
- analysis of the process parameters $i(t)$, $u(t)$ and $p(t)$.

For evaluation of the component damage the measuring of the thermal-affected zone is obvious. However, this approach does not permit the evaluation of the component damage from the view of the mechanical load. It was helpful to use procedures that are known from the material analysis of cemented carbides and ceramics. Thereby, bending fraction rods are loaded with bending stress. The received bending fraction stress is in the material analysis a unit for the component stability. If one applies this approach to the rim zone damage caused by processing, one receives a better statement about the damage than by the depth measuring of the changed rim zone.

In the context of these investigations the four point bending fracture test was chosen (Fig. 3). Thereby, the bending moment is constant over a larger range of the test piece length. This smoothes stochastic influences. The cemented carbide test piece was machined on the tensile strength side with the appropriate experimental parameters. The necessary number of test pieces was determined by the preliminary investigations. The cross-section for the test pieces 3 mm × 4 mm was chosen, as industries usually apply. The test piece length was 40 mm.

4. Results

A comparison of an isoenergetic equal pulse regimes with increasingly shortened discharge durations does not show an improvement of the bending fraction stress of a main-cut with a pulse energy of 3.6 mJ (Fig. 6). Because of the same energy input the values of the bending fraction stresses are equal. The results with the needle-pulse generator and the reference generator are identical. However, the results of the separated post-cuts show an enlargement of the bending fraction stress, which increases with decreasing pulse energy. In the case of a pulse energy of 0.3 mJ the bending fraction stresses enlarges to 12%.

From this it can be concluded that a reduction of the rim zone damage can be obtained only with a decrease of the pulse energy. In addition, the main-cut must be worked with pulses like those used for post-cuts. With shorter rise times a shortening of the discharge duration is possible, whereby, the pulse frequency can be raised, without provoking a wire break. In this way, process achievements in the main-cut become true with smaller pulse energy similar to the so far applied ones. The level of the productivity as before can be maintained and at the same time an improvement of the components stability can be achieved.

With the experiment of the separation of the post-cuts it could be proven that the fundamental damage with previously used post-cut sequences results already from the main-cut. Rim zone damage occurring during the main-cut cannot completely eliminated by post-cuts. That is why the main-cut produces a certain surface damage. The developed thermal zones, microcracks and pores are superimposed in

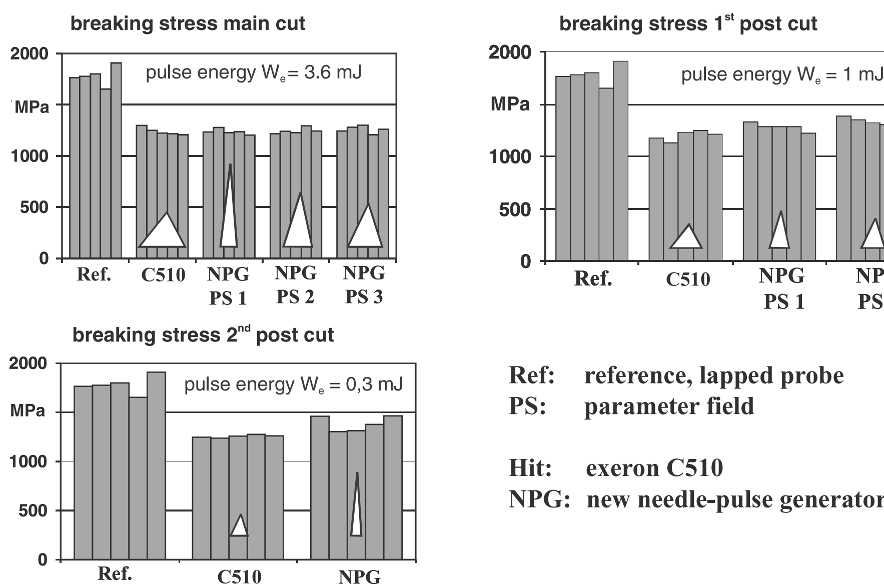


Fig. 6. Results of the bending fracture studies.

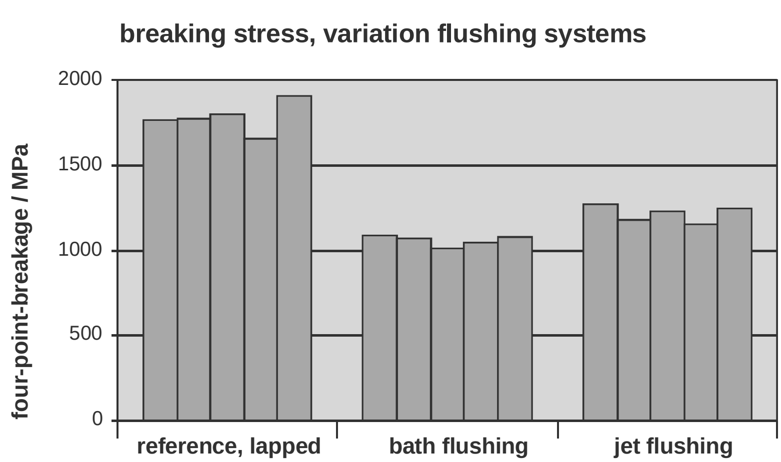
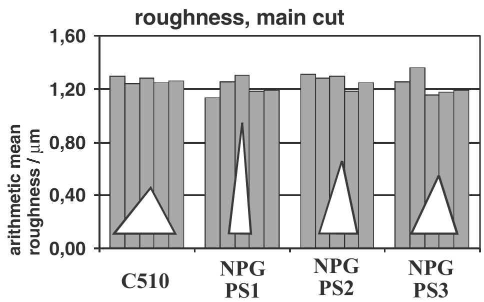
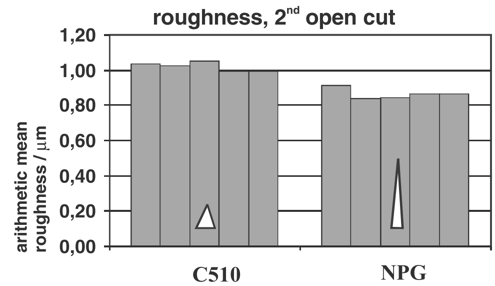


Fig. 7. Comparison of the bending fracture stress with variation of the flushing conditions in the main-cutting.



test	C510	needle pulse PS1	needle pulse PS2	needle pulse PS3
pulse parameters: pulse duration in ns pulse current in A	 1500 220	 700 390	 1000 310	 1200 280



test	Hitachi	needle pulse
pulse parameters: pulse duration in ns pulse current in A	 450 30	 320 90

Fig. 8. Results of the roughness study.

post-cut by further thermal influences. The roughness is improved, but the damages of the main-cut propagate with smaller changes of temperature and bigger internal tensions during the post-cuts.

A further reduction of the rim zone damage can be achieved by a purposeful jet flushing in the main-cut. So far the main-cuts were accomplished traditionally with bath flushing. A comparison at variation of the flushing conditions in the main-cut pointed out an improvement of the rim zone damage with the application of the jet flushing (Fig. 7).

Surface roughness remain equivalent with varied isoenergetic pulses and a pulse energy of 3.6 mJ and pulse duration larger than 700 ns. If the discharge duration is smaller than 500 ns a significant decrease of roughness is observed (Fig. 8).

5. Conclusion

By the development of a new needle-pulse energy source for the WEDM for cemented carbide, it is possible to reduce the rim damages in a significant dimension. The improved material properties of the cemented carbide after the wire-EDM can be proven by increased bending fraction stress. The increased bending fraction stress is a result of the reduced pulse energy with pulse duration smaller than 500 ns. With the increase of the pulse sequence frequency the previous productivity can be maintained. The post-cuts are only necessary to improve the surface roughness. The considerable reduction of the post-cuts leads to an increasing the total productivity of the machining and significantly lowering the costs.

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References

[1] D.F. Dauw, L. Albert, Two decades of wire-EDM evolution: a significant improvement of overall performance, in: Proceedings of the 10th International Symposium on Electromachining, ISEM 10, Magdeburg, Germany, 6–8 May 1992, pp. 300–320.

[2] 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, Bilbao, Spain, 9–11 May 2001, pp. 473–483.

[3] M. Läuter, H.-P. Schulze, G. Wollenberg, Modern process energy sources for electrical discharge maching (EDM), in: Proceedings of the Computer-aided Production Engineering, CAPE 2003, Edinburgh, 18–19 March 2003, Professional Engineering Publishing Limited, London, UK, pp. 339–348.

[4] 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 Computer-aided Production Engineering, CAPE 2001, Wuhan, China, 28–30 October 2001, Professional Engineering Publishing Limited, London, UK.

[5] G. Wollenberg, K. Künanz, H.-P. Schulze, H. Juhr, M. Läuter, Optimierung der funkenerosiven Hartmetallbearbeitung durch prozessangepasste Stromimpulsformung bei der Drahterosion, DFG-Forschungsbericht, 2001.