# Summary report on the CIRP cooperative research on spark-erosion machining of cemented carbides (die-sinking)

# CIRP Technical Reports

## Summary Report on the CIRP Cooperative Research on Spark-Erosion Machining of Cemented Carbides (Die-Sinking)

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From 1973 to 1979 eight members of the Scientific Technical Committee "E" of CIRP carried out a cooperative research project on the machinability by spark-erosion of cemented carbides. Especially the cracking behaviour of various types of carbides under various machining conditions has been investigated. Attention has been payed to the measuring methods of the surface integrity of the machined workpieces. From the experiments appeared that machining with generator pulses of short pulse durations is favourable for the quality of the machined surfaces.

### 1. Introduction

During the CIRP General Assembly at Bled (Yugoslavia) in 1973 the Scientific Technical Committee "E" decided to carry out a cooperative research programme on the machinability of cemented carbides. After preliminary experiments, carried out at the University of Aachen the Committee accepted in 1974 a research programme in which the test procedure of the machining cemented carbide GT 20 with tungsten copper or copper was described. The aim of the cooperative research programme was to investigate the correlation between the machining parameters and the surface integrity of the machined cemented carbide pieces. In practice it has been shown that especially micro-cracks, which occur with spark-erosion machining, lead to a decrease of life endurance of the tools made of cemented carbides.
After comparative experiments, of which the conditions are given in the test procedure, the participants carried out specific investigations in order to come to directions for optimum machining conditions.
The participants of the cooperative research project were:

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|---|---|---|
| Heuvelman | (Eindhoven University of Technology) | (Refs. 2, 3, 4) |
| Ten Horn | (Philips Eindhoven) | (Refs. 5, 6) |
| König/Wertheim | (T.H. Aachen) | (Ref. 7) |
| Roethel | (University of Ljubljana) | (Refs. 8, 9) |
| Snoeys | (University of Louvain) | (Refs. 10, 11) |
| Stanek | (VUMA, CSSR) | (Ref. 12) |
| Tanimura | (Osaka Prefectural Institute) | (Ref. 13) |
| Pekelharing | (Delft University of Technology) | (Ref. 14) |

During the progress of the cooperative work a number of participants carried out equivalent research in this field. König, Wertheim et al. investigated intensively the cracking behaviour of sintered carbides. (Refs. 15, 16, 17).

### 2. The test procedure of the comparative experiments

A short specification of the test conditions (Ref. 1) laid down in the procedure reads as follows:
Workpieces: cemented carbides discs, diameter 17 mm, thickness 5 mm, material: GT 20 (85% WC, 12% Co, 3% TiCTaC).
Electrode: copper and tungsten-copper tubes, outer diameter 15 mm, diameter of hole: 3 mm.
Both workpiece and electrode are mounted axially in line.
Flushing: dielectric fluid Shell Sol TD (or Shell Sol H), pumped through the hole of the electrode with a flow-rate of 0.3 $cm^3/s$.
Pulses supplied by the generator: rectangular, pulse durations ranging from 3 µs up to 500 µs, $\tau$ = 50%, pulse current 8A and 25A, open voltage 60-100 V. The duration of each test should be 15 minutes. The first experiments have to be carried out with tungsten-copper electrodes (positive and negative polarity), later experiments with copper electrodes (both polarities).
Results: Mechanical data to be presented: workpiece metal removal rate, relative electrode wear, roughness of the workpiece $R_a$ (measuring length 4 mm, cut off 0.8 mm), maximal depth of the microcracks. All these data as a function of the pulse duration and the average discharge current as parameter. Further, the open circuit voltage and the average relative discharge duration should be presented. In the test procedure also directions for specimen preparation for studying microcracks have been given.

### 3. Results of the comparative experiments

Within the comparative experiments four series of tests had to be carried out; with tungsten-copper and copper electrodes, both with negative and positive polarity with respect to the workpiece. In each serie the pulse current was 8A and 25A respectively. Not all participants carried out all series (Refs. 2, 3, 5, 7, 9, 10, 12, 13).

The results are given in figures 1, 2, 3 and 4, in which the metal removal rate $V_W$, the relative wear $\vartheta$, the roughness $R_a$ and the maximum length of the microcracks $\ell$ are plotted versus the pulse duration $t_i$ and with the pulse current $\bar{i}_e$ as parameter.

From the diagrams appears:
1. The variations in the test results of the various participants is rather great, however the variations with tungsten-copper electrodes machining are less then those with copper electrodes.
2. With the most participants the maximum metal removal rate $V_W$ is decreasing considerably while in general the wear, the roughness and the length of the microcracks increases with increasing pulse duration.
3. The relative wear $\vartheta$ with tungsten-copper electrodes is much less than with copper; for both electrodes machining with a negative polarized electrode results in a lower relative wear and more stable operation which results generally in a higher metal removal rate and a better surface quality (lower $R_a$ and $\ell$).
4. With machining with negative tungsten-copper electrodes, the maximum metal removal rate with pulse currents of 25A is approximately 5-8 times higher than with 8A, while the relative wear, the roughness and the maximum length of the microcracks are hardly not affected.

In view of decreasing metal removal rate $V_W$ below $t_i$ = 10 µs together with decreasing roughness and length of the microcracks and favourable relative wear, it was of interest to know why $V_W$ decreases. During discussions of the participants the pulse-form of the generator was suspicious.
Oscillogrammes showed that the rise-time and the decay-time of the current pulses was sometimes greater than 3 µs, so rectangular pulses could not be obtained. In order to investigate this phenomenon, at the University of Eindhoven a new generator was designed, having rise- and decay-times of approximately 50 ns, so pulse times of 0.2 µs could be aequired. The results with this new generator are quite favourable: with short pulse times a much higher metal removal rate have been obtained while the roughness still decreases and the relative wear remains more or less constant (see figs. 1.a and 1.b: THE 2).
With these short pulse durations microcracks could not be observed anymore.

### 4. Surface integrity

The surface integrity of the machined pieces is of essential importance for the life endurance of these pieces as tool (dies etc.). The problem with machining cemented carbide pieces is to have a significant criterion for this life endurance. The occurence of microcracks seemed to be a good criterion. However the measurement of it is rather difficult and with pulse durations below 5 µs there are hardly no more microcracks.
From the diagrams it appears that the length of the microcracks is mainly dependent on the pulse duration and hardly not on the pulse current.

During the experiments another interesting phenomenon appeared. At the surface strings of holes could be observed. Between the holes microcracks could be noticed. The strings were closed, so forming grit patterns. The surface area of these grit patterns is dependent of the pulse duration and ranges between $10^4$ to $6.10^4$ $\mu m^2$. Reports on these phenomena were received from: Heuvelman, Ten Horn, Snoeys, Tanimura and Pekelharing (Refs. 2, 5, 10, 13, 14). During the meeting in January 1977, Mr. Ten Horn presented a "Contribution to the discussion of surface phenomena observed on ED-machined tungsten carbide", in which a metallurgical explanation of the phenomena was given (Ref. 6).
At the University of Eindhoven with the aid of röntgen diffraction analysis the chemical behaviour of the surface has been investigated (Ref. 4). From the diffractogrammes appeared that after machining WC and TiC changes into $(WT_i)C$. The concentration of this mixed carbide increases with the pulse duration.
At the January meeting of 1977 it was suggested by Wertheim that the transverse rupture strength (TRS) of the machined pieces might be a criterion for the life endurance. At the University of Eindhoven the TRS-values of pieces of GT 20 have been determined accordingly to the standard test method ANSI/ASTM B 406-76. (Ref. 4).
The results of the TRS-values $\sigma$ versus the pulse duration $t_i$ at $\bar{i}_e$ = 25 A is given in fig. 5.

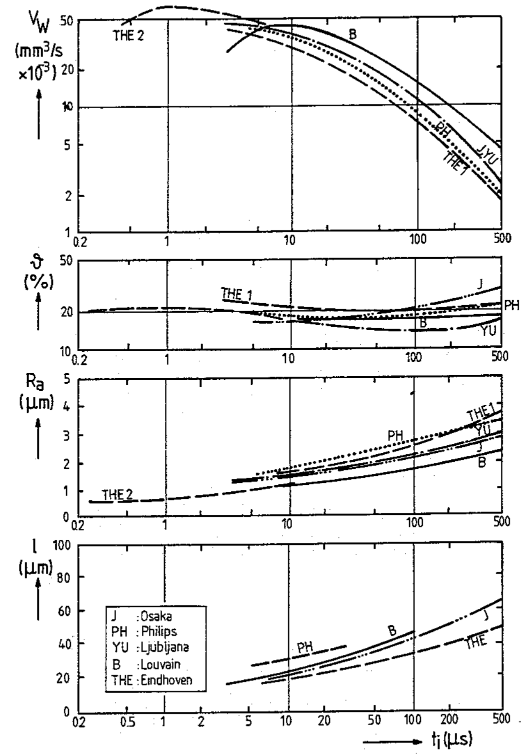


Fig. 1a. Workpiece GT20, electrode tungsten-copper (-), $\bar{I}_e$ = 8A, τ = 0.5

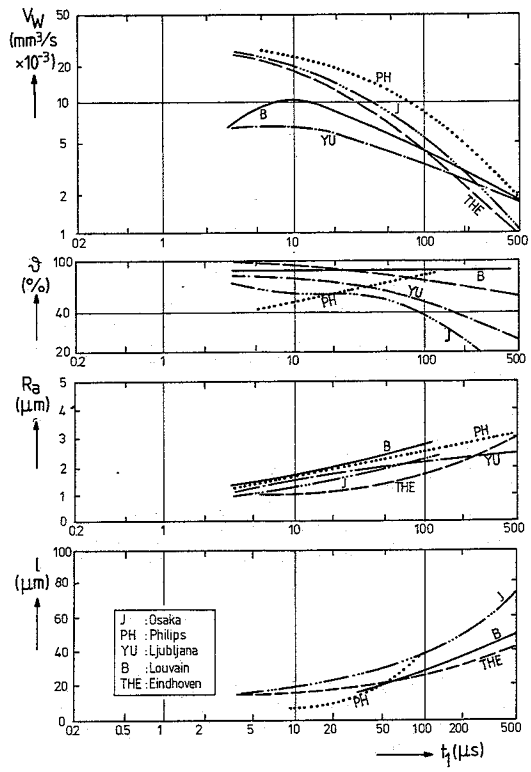


Fig. 2a. Workpiece GT20, electrode tungsten-copper (+), $\bar{I}_e$ = 8A, τ = 0.5

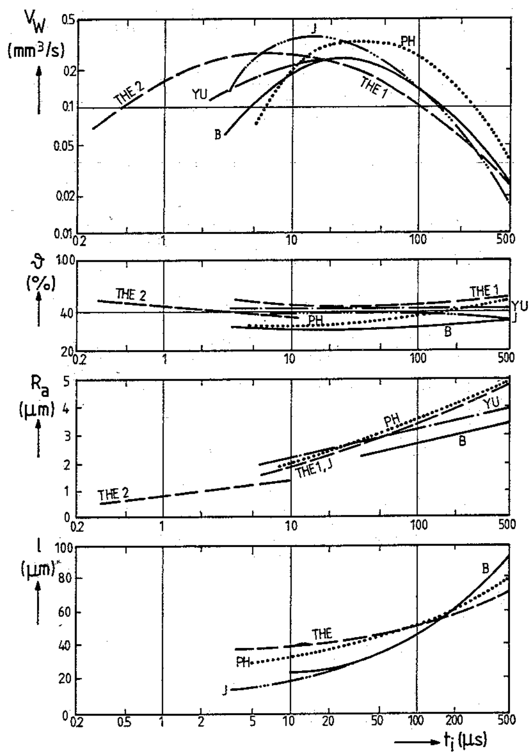


Fig. 1b. Workpiece GT20, electrode tungsten-copper (-), $\bar{I}_e$ = 25A, τ = 0.5

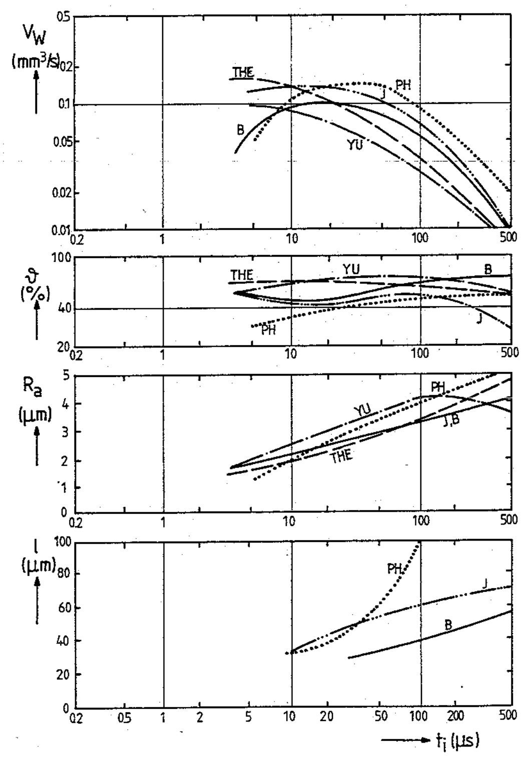


Fig. 2b. Workpiece GT20, electrode tungsten-copper (+), $\bar{I}_e$ = 25A, τ = 0.5

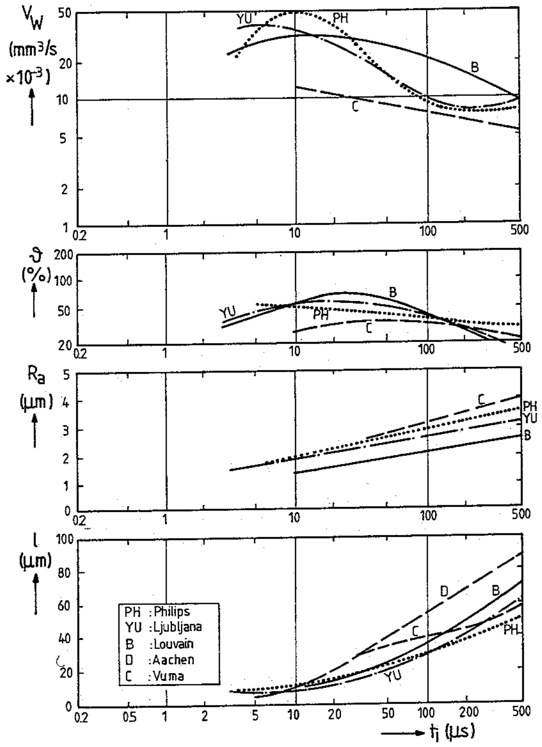


Fig. 3a. Workpiece GT20, electrode copper (-), $\bar{i}_e$ = 8A, τ = 0.5

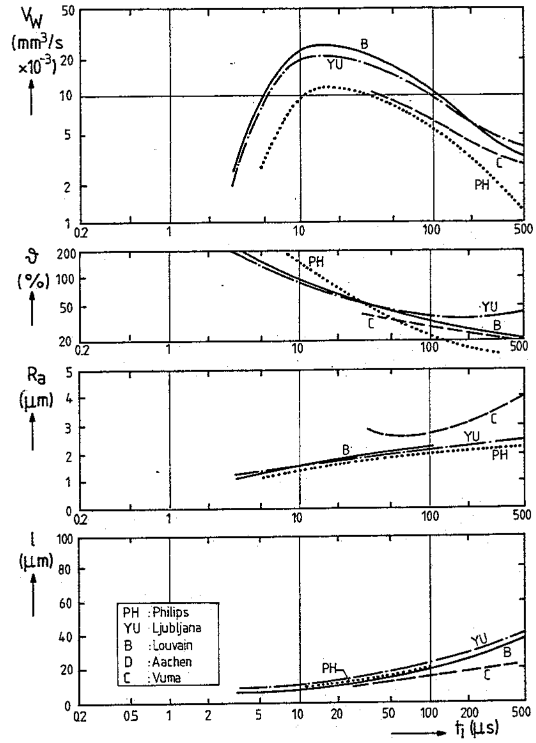


Fig. 4a. Workpiece GT20, electrode copper (+), $\bar{i}_e$ = 8A, τ = 0.5

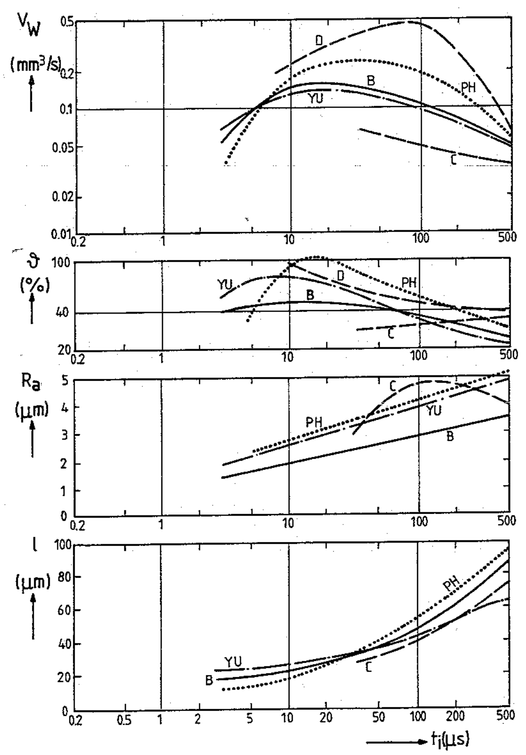


Fig. 3b. Workpiece GT20, electrode copper (-), $\bar{i}_e$ = 25A, τ = 0.5

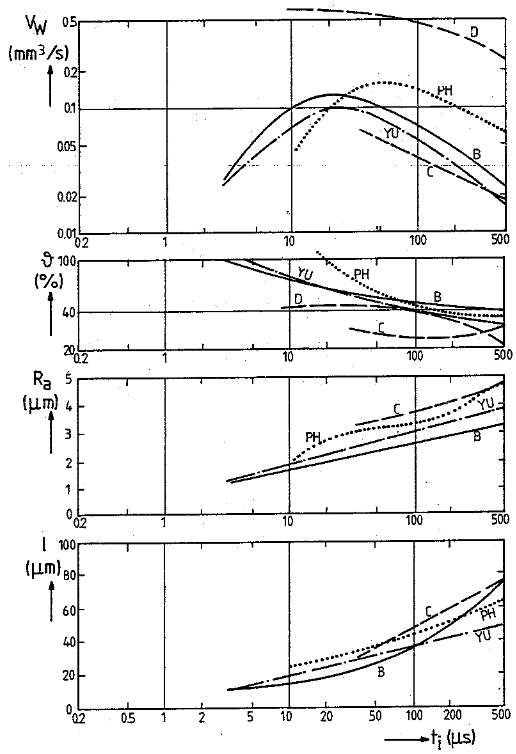


Fig. 4b. Workpiece GT20, electrode copper (+), $\bar{i}_e$ = 25A, τ = 0.5

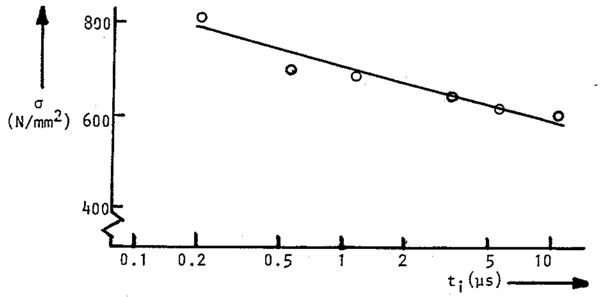


Fig. 5. The dependence of the TRS value σ on the pulse duration $t_i$.
Workpiece: GT 20, electrode: tungsten-copper(-), $\bar{I}_e$ = 25 A. (Eindhoven).

The size of the workpieces are 5 x 6.24 x 19 mm. Since no central flushing was possible, special measures for optimum machining have been taken. The TRS value of ground workpieces was σ = 1200 N/mm$^2$.

## 5. The machinability of other cemented carbide types

During a intermediate meeting at Eindhoven on 1st December, 1976, the Universities of Aachen and Louvain were requested to carry out experiments with types GT 10 to GT 60. Aachen carried out experiments with GT 40 and GT 60 in order to investigate the dependence of the tungsten carbide grade on the machinability.

At the University of Aachen experiments were carried out grades GT 10, GT 20, GT 40 and GT 60 with negative polarized copper electrodes (Ref. 7). The pulse current was 16 A. The differences in the results ($V_W$ and ϑ) with long pulse durations were not so clear, however at $t_i$ = 20 µs differences are quite significant, see figure 6.

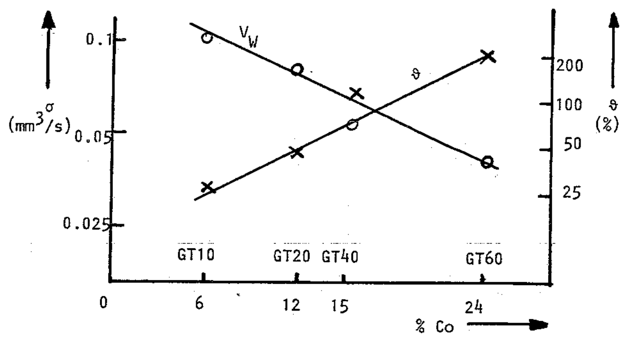


Fig. 6. Influence of the grade on the machinability.
Electrode: copper (-), $\bar{I}_e$ = 16 A, $t_i$ = 20 µs. (Aachen).

At the University of Louvain, the same trend have been observed (Ref. 11). For machining with negative polarized tungsten-copper electrode, the $V_W$, ϑ and ℓ are represented in fig. 7 ($\bar{I}_e$ = 24 A, $t_i$ = 10 µs).

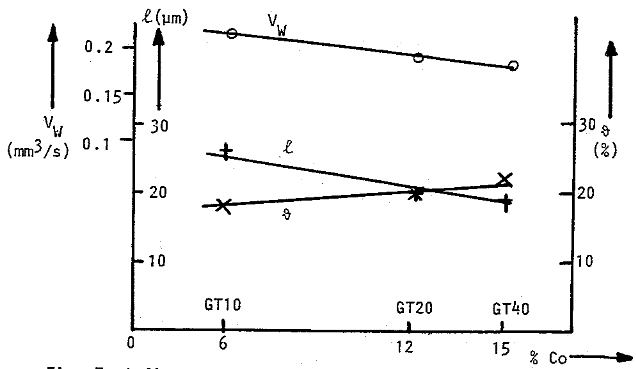


Fig. 7. Influence of the grade on the machinability.
Electrode: tungsten-copper (-), $\bar{I}_e$ = 24 A, $t_i$ = 10 µs. (Louvain).

From both investigations appears that the metal removal rate increases when the cobalt percentage decreases; at the same time the relative wear increases and the length of the microcracks increases.

## 6. Conclusions

When machining cemented carbides the following recommendations can be given:

1. Pulse duration as low as possible: the roughness and the microcracks will be minimum; however with a number of generators, the pulse form will detoriate and so the metal removal rate will decrease considerably when the pulse duration is too low. For these generators the optimum pulse duration will be 10 µs.
2. Negative polarization of the electrode results in more stable operation and a higher metal removal rate. Also the relative wear and surface roughness will be lower.
3. Machining with tungsten-copper electrodes results in a considerable lower relative wear then with copper. Figures for metal removal rates, roughness and microcracksare not significant better with tungsten-copper.
4. Higher pulse currents ($\bar{I}_e$ = 25 A) give higher metal removal rates,than lower pulse currents ($\bar{I}_e$ = 8 A); the surface roughness is hardly not higher when the pulse duration is not too long.
5. The occurrence of microcracks is a reasonable criterion for the quality of the machined surface, however, below $t_i$ = 3 µs microcracks are hardly observable. The transverse rupture strength might be a usefull and more easy test procedure.
6. The grade of the cemented carbide has influence on the machining results. Lower cobalt concentration yields a higher $V_W$ and lower ϑ; however the microcracks will be somewhat longer.

The cooperative research project has show that the behaviour of the generator is important. For machining cemented carbides the spark-erosion machines should be equiped with generator supplying pulses of short duration (down to 0.3 µs) and relative high current ($\bar{I}_e$ = 25 A). For a high total removal rate the duty cycle should be not too low (τ = 0.5 or $t_o$ = 0.3 µs). Special attention has to be given to the flushing.

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