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## Further study of carbon fibres electrodes in micro electrical discharge machining

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### Abstract

Electro-discharge machining has been intensively developed since its early days. New materials for electrodes to improve certain technological factors like electrode wear or roughness parameters of machined surface are found. However, it is also common that some aspects of the process, its conditions or modifications enforce the changes in machine tool and even its new design to manage the research tasks. Such approach was in this case. A special experimental stand was built to perform a number of trials assuring, as well, repeatability of machining conditions.

In this paper further study of carbon fibres electrodes in micro electrical discharge machining will be presented. As it was signalled before, in the previous ISEM paper, carbon fibres can be used in the function of tool electrode in microEDM. Preliminary trials of micro sinking as well as the discussion of experimental results revealed some problems and outlined further research tasks which will be presented in this paper. The present paper will focus on the carbon fibres behaviour under EDM condition, especially the tool wear which is the key feature for a material to be considered a good tool material for electrodes. Experiments and results of different machining parameters that have a major influence on the process will be introduced. The analysis answers the question of electrode wear which is different comparing to standard electrodes and determines the best parameters for machining.

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**Keywords:** carbon fibres electrodes; EDM; micro electro discharge machining;  $\mu$ EDM

### 1. Introduction

The continuous trend for miniaturisation of components, machine parts and devices forces the search of new and improvements of existing methods of their production. Micro-electrical discharge machining is one of non-conventional manufacturing techniques which is believed to have a strong research and application capability and importance [1]. One of the main issues concerning electrical discharge machining in general is a tool wear. Discharges occurring between electrodes affect both surfaces the workpiece as well as the tool electrode. There have been developed many strategies to overcome this effect of machining [2-3]. The other idea that could minimize tool wear is an application of a new material for tool electrode [4]. Also different materials

are used in forms of coatings for electrodes that reduces material removal rate from the tool electrode [5-6].

In micro-electrical discharge machining carbon fibres electrodes have been successfully used to manufacture micro cavities [7]. Very first results enable to concentrate on the crucial issues. One of which is a tool wear. Carbon fibres as a novel material in micro-electrical discharge machining have not been fully examined in this aspect. Thorough knowledge of this material under  $\mu$ EDM conditions will help to develop strategies and solutions that will minimize tool wear.

### 2. Experimental Setup

To perform experiments a special experimental setup has been designed. Very first results were executed under microscopic observation without an automated

feed motion [7]. Configuration of this setup is presented in Fig. 1.

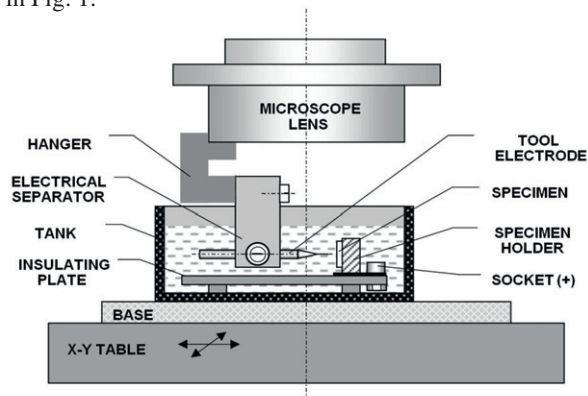


Fig. 1. Configuration of setup for  $\mu$ EDM experiments with short carbon fibre tool electrode [7]

This configuration has been a starting point for the design of a new setup. The horizontal position of the electrodes was preserved to enable microscopic observation.

The setup consists of RC generator for  $\mu$ EDM, step motor and motor control with user's panel and comparator. The diagram of the setup configuration is presented in Fig. 2.

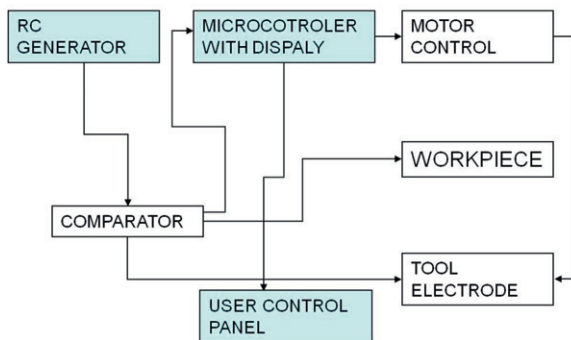


Fig. 2. Block diagram of experimental setup (shaded blocks indicate user's modification mode)

The experimental setup also has a digital camera for monitoring of the machining process and a dial indicator for movement monitoring. The setup is placed in a heavy casing which provides a stable position and isolation from external vibrations. The whole system is presented in Fig. 3.

For electrodes a special, exchangeable electrode holder was designed. It allows ensuring a horizontal position and is adapted for a different size of electrodes shanks. The holder can be used alternatively or simultaneously with two electrodes at the same time - Fig. 4.

The perpendicular position to the electrode movement was achieved by the micrometer screw which enables to

set a new location for the next experiment. The feed during the process is controlled by a microcontroller according to signals from the comparator.

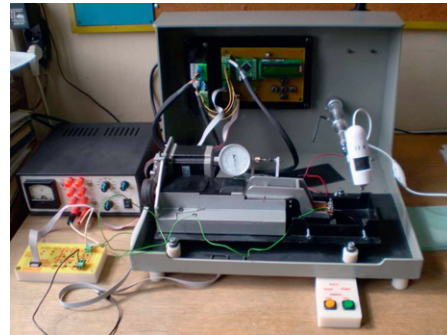


Fig. 3. Newly developed experimental setup for  $\mu$ EDM experiments with short carbon fibre tool electrode

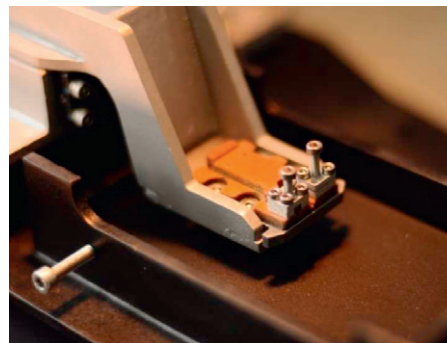


Fig. 4. Electrodes holder for different size of shanks

Details on designing process and solutions used in experimental setup can be consulted in [8]

### 3. Carbon fibre electrodes

To perform the experiments short carbon fibres were designed and manufactured.

#### 3.1. Carbon fibres

The carbon fibres used for the experiments were based on PAN (polyacrylonitrile) precursor and were chosen from commercially available on the market. Data of same properties of the carbon fibres are collected in Table 1.

Table 1. Carbon fibres used during experiments

Property	Value	Unit
Filament diameter	0.007	mm
Density	$1.80 \pm 0.02$	$\text{g/cm}^3$
Elongation	$1.50 \pm 0.2$	%

Sizing Contain	$1.4 \pm 0.3$	%
Tensile strength	$450 \pm 210$	MPa
Tensile modulus	$227 \pm 10$	GPa

Same additional properties like tensile strength or modulus can be found, however they are not so crucial in EDM conditions.

### 3.2. Electrodes preparation

The first carbon fibre electrodes were fabricated by inserting a single carbon fibre into a brass shank where a shallow hole was drilled and filled with metal alloy. A small microhole was drilled in the alloy and then the fibre was placed and fixed by the plastic deformation of the connecting alloy - Fig. 5. These procedures had many additional operations so another procedure was developed. Achieving an alignment of carbon fibre with the drilled microhole was very important for the proper preparation of tool electrode.

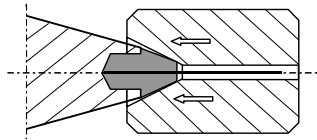


Fig. 5. Procedure of electrode preparation [7]

The new procedure to fabricate electrodes was developed. Shanks with already existing deep microhole were used. Omitting of drilling operation was possible. A carbon fibre was inserted into the shank and soldered. Such a procedure allows achieving both mechanical and electrical connection. The procedure also reduced time of preparation - Fig. 6, 7.

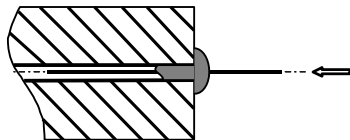


Fig. 6. Schematic procedure of electrode preparation

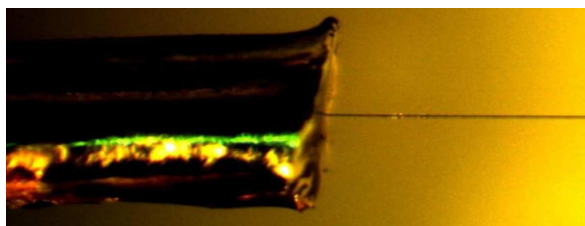


Fig. 7. An example of fabricated electrode

An axial alignment was achieved by inserting enough long part of a carbon fibre into the deep hole of the

shank which lay on the inside wall of the hole. In the previous procedure the axial alignment was mostly achieved by the careful plastic deformation of the connecting alloy. Here, a longer fibre inside remains parallel to the shank axis during soldering.

With this procedure it is also important to avoid soldering the fibre itself further along its axis. Single droplets of solder can be left like in Fig. 8. Then the procedures to evaporate the remaining solder must be performed.



Fig. 8. Solder droplets remaining along the fibre axis after electrode preparation

## 4. Experimental procedures

Prepared electrodes were carefully observed and measured. All of them were also trimmed to similar length which was about 10 mm.

The designed experiments are supposed to answer the question about the tool wear during micro electrical discharge machining with carbon fibres electrodes. The experiments were planned according to the statistical design of experiments [9].

Many relationships in manufacturing technologies can be described as exponential dependences. For the experiments of EDM where RC generator is used a suitable plan of experiments for such exponential relation was chosen. The key factors which determinate energy ( $U$ ,  $C$ ) as well frequency of the discharges ( $C$ ,  $R$ ) that influence the tool wear are considered. The values of each parameter were chosen after preliminary experiments. The conditions of the feed were also selected. The input factors are presented in Table 2.

Table 2. Input factors during experiments

Variable	Level High	Level Low
Voltage $U$	135 V	115 V
Capacitance $C$	47 pF	10 pF
Resistance $R$	2,2 k $\Omega$	22 k $\Omega$

The variables were coded at different levels according to Table 2 and collected in Table 3. The higher value of input factor is described as a plus sign and the lower as a minus sign. The tests were performed according to the Table 3. Other input factors like feed motion were the

same in all experiments. For the dielectric fluid kerosene was chosen.

Table 3. Plan of the experiments where  $X1$ ,  $X2$ ,  $X3$  corresponds with  $U$ ,  $C$ ,  $R$  respectively

Run	$X1$	$X2$	$X3$
1	+	+	+
2	+	-	-
3	-	+	-
4	-	-	+
5	+	+	-
6	+	-	+
7	-	+	+
8	-	-	-

During the experiments time of machining was recorded. Depending on selected conditions it varies from one to a few minutes. After the machining the electrodes length was measured. Basing on the data the linear tool wear was calculated. The diameters of electrodes are a few orders of magnitude smaller than their lengths, so this parameter instead of standard EWR (Electrode Wear Rate) was chosen to describe a tool wear.

The values of coded input factors were obtained from the following formula:

$$X_i = \frac{2 \cdot (\ln A - \ln HL)}{\ln HL - \ln LL} + 1 \quad (1)$$

were  $HL$  is High Level and  $LL$  is Low Level of respective input factors and  $A$  represents the factor  $U$ ,  $C$ ,  $R$ .

Further, the formula (1) was used to describe the tool wear  $Y$  in formula (2):

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 \quad (2)$$

where  $Y$  is the tool wear [ $\mu\text{m/s}$ ] and  $b_i$  regression coefficients that can be calculated from formula (3):

$$b_i = \frac{1}{N} \sum_{j=1}^N X_{ij} Y_j \quad (3)$$

where  $N$  is a number of experiments,  $i$  will be from 0 to 3,  $j$  represents following runs in experiments from 1 to 8.

## 5. Results and discussion

For the performed experiments the average value of linear tool wear from two series of experiments was

considered. After calculation according to formula (2) the relationship describing the effect of the examined input parameters was obtained:

$$Y = 1.85 \frac{U^{0.250}}{C^{0.102} R^{0.025}} \quad (4)$$

The exponent value in formula (4) characterising voltage  $U$  is almost 2.5 times higher than the exponent of capacitance  $C$  and 10 times higher than this of resistance  $R$ .

Thus, the contribution of this parameter in the tool wear in the case of carbon fibres electrodes is significant. The capacitance  $C$  which is responsible as well as voltage  $U$  for the energy provided during discharges is also responsible for the frequency is less noticeable. Finally, for resistance  $R$  the impact is even lower.

For  $RC$  generator, which was used in this case, the frequency of discharges is inversely proportional to  $R$  values and the same expectation should be for the tool wear.

Also very low values of exponents for factors in these types of designed experiments can be statistically insignificant. According to [9], in the formula (4) exponent lower than 0.1 is negligible. Considering the difference of orders of magnitude for exponents between experimental parameters such a case could be accepted by omitting those of less significance.

For the obtained formula (4) an example of calculated relationship is presented in Fig. 9

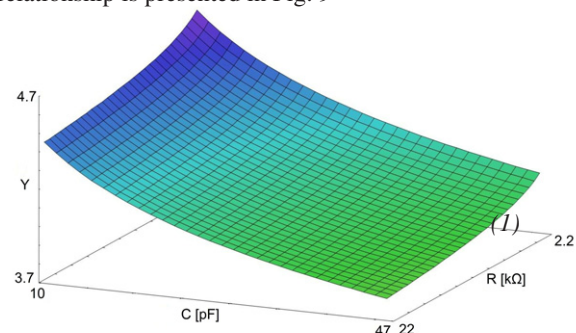


Fig. 9. Example of the surface representing formula (4) for lower value of voltage  $U$  115 V

For lower values of resistance  $R$  and capacitance  $C$  the tool wear of the electrode is higher. Those two parameters are responsible for frequency of discharges in case of  $RC$  generator. This relationship is very well represented in Fig. 9 where for the lowest values of  $R$  and  $C$  the plotted surface reaches its maximum – the highest tool wear.

Another relationship was obtained using a coarse estimation of carbon fibre electrode wear basing on an



experimental setup functionality. During the experiments the path length of the electrode holder is estimated. Taking into account very low values of MRR (Material Removal Rate) the recorded results can be regarded as a tool wear parameter. Using formula (2) a similar relationship was obtained:

$$Y = 1.45 \frac{U^{0.312}}{C^{0.129} R^{0.120}} \quad (5)$$

However, this time higher values of exponents are noticeable. Still the formula (5) represents the considered relationship well.

Another experiment was also performed. This time for different values of input parameters. Voltage  $U$  was 130 V and 100 V, capacitance  $C$  was 47 pF and 10 pF, resistance  $R$  was 100 kΩ and 47 kΩ. The following formula was obtained:

$$Y = \frac{U^{34.6} R^{0.7}}{C^{1.2} e^{166}} \quad (6)$$

Both parameters voltage  $U$  and capacitance  $C$  agreed with previous trials. The value of voltage  $U$  is almost 30 times higher than other parameters exponents. Thus, the contribution of this parameter in tool wear in this trial is extreme. Moreover, these input factors caused much more short circuits than those where the formula (4) was achieved. Secondly, in many trials pauses occurred during the machining. Sometimes even carbon fibre was bent but not short circuit – no signal for comparator initiating the backward movement. It could be caused by products of decomposing kerosene which insulated the fibre from the workpiece. These factors could have influenced on the change of relationship presented in formula (6).

The experiments were performed with the same feed for each experiment but the back movement of electrode when the short circuit was detected was different for each trial. It strongly depends on frequency. In some cases the number of short circuits was estimated from 3000 to 4000 and in some less than 500. This was calculated when the comparator detected a certain set value of voltage that was assumed as a short circuit. Those numbers can only be treated as estimation.

## 6. Summary

The planned tests were also used to verify the newly designed experimental setup. During the trials certain problems occurred. Sometimes a deflection of the fibre after short circuit was noticeable. The values of voltage threshold for detecting short circuits should be carefully

chosen. The back movement of the electrode which occurred frequently in certain trials consumed time that can be used for the proper machining. This also influences the calculated value of linear tool wear which have taken into account the total time of experiment. It was impossible to estimate or measure the back movement time. Nevertheless, the setup for experiments with carbon fibres electrodes was able to manage with planned experiments and for certain values of input parameters the relationship of linear tool wear was considered.

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