ASSESSMENT OF COPPER-TUNGSTEN ELECTRODE EDGE RADIUS WEAR FOR EDM OF AISI H13 TOOL STEEL

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Abstract. *The Electrical Discharge Machining (EDM) represents one of the key machining processes in die and mold-making industry. In finish EDM regimes to assure the accuracy of work piece's dimension and shape, it is important to apply adequate electrical parameter settings as well as an efficient flushing method to the pair of electrode and work piece materials. The prevention of electrode wear is another essential aspect to be controlled in EDM. The measurement of electrode wear is normally carried out at stationary state. This means that electrode wear is measured just after the EDM of a work piece is completed. However, the wear of the electrode proceeds with machining time M_t. Thus, in precise EDMachining it is important to pay attention to the changes of electrode wear as machining is being executed. In this work the changes of a copper-tungsten electrode edge radius as the machining time proceeds are experimentally evaluated. The measurements to 100 min machining time M_t were carried out divided in eight stages. The major conclusions can be summarized as follows: at the beginning of the EDM the electrode radius edge wear is remarkable; the four edge radius wear of the electrode presented slightly differences; the depth of the work piece cavity tends towards to be linear as the M_t proceeds; it was observed little adhesion of EDM byproducts over both the work piece cavity and the electrode frontal and side faces.*

Keywords*: EDM, finish machining, CuW electrodes, electrode edge radius wear*

1. INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional machining process used from rough to finish operations in any material that conducts electricity (0,01 S/cm). It is used when the conventional machining processes, such as turning, milling etc, are not able to produce high 3D geometrical complex shapes, dimensions and tight tolerances in hard work piece materials, as remarked by König and Klocke (1997).

Crookall and Khor (1972) point out that the material removal from the tool electrode and work piece is primarily based on a thermal phenomenon. Thus the mechanical properties of the materials exert just a few influences on the EDM process. However, the thermophysical properties remarkably influence the EDM performance, e.g. work piece material removal and electrode wear. When considering the tool electrode there is a wide range of materials that can be used. It can be mentioned copper, copper-graphite, graphite and its special grades, brass, tungsten, silver, silver-tungsten alloys, tellurium-copper alloys, copper-tungsten alloys etc. Each one of those materials has its own advantages and disadvantages.

According to Drozda (1998) there are four ways to analyze the electrode wear: (i) volumetric relative wear, (ii) relative linear frontal wear, (iii) relative linear corner wear and (iv) relative linear edge wear. Mohri *et al.* (1995) and Suzuki *et al.* (1992) remind that the measurements of the aforementioned electrode wear ratios are normally carried out at stationary state, i.e. after the EDM of the work piece is completed. Nevertheless, to attain high precision on geometry and tolerances of the work pieces machined by EDM is very important to evaluate the electrode wear as the machining time M_t proceeds.

In the present research work the electrode edge radius wear was experimentally evaluated while the machining time M_t proceeded. The first objective was to gather technological information on the electrode wear while finish EDM machining. The second one was to attain some understanding on the electrode wear phenomenon. With this purpose it was used a CuW (30% Cu, 70% W) alloy as electrode material and AISI H13 quenched and tempered work piece samples during a machining time M_t = 100 min divided in eight stages.

2. EXPERIMENTAL PROCEDURE

(i) *Conditions of the experiments:* Table 1 summarizes the machine tool, equipment and materials used to carry out the tests. It was used a Charmilles ROBOFORM 30 CNC machine equipped with an isoenergetic generator. A universal hydrocarbon dielectric fluid (3 cSt at 40 ^{0}C) simultaneously with a jet of fluid directly to the gap plus and immersion of the pair electrode/work piece was applied as flushing method. It was used AISI H13 tool steel square samples 25 mm wide and 15 thick with Ra = 0,42 µm on the surface to be EDM . The chemical composition of AISI H13 tool steel is the following: 0,40% C, 1,0% Si, 1,0% Mn, 5,2% Cr, 1,5% Mo, 0,9% V and 0, 00765 [g/mm³] density at 20^0 C. The

AISI H13 work pieces were quenched and tempered to an average 45 HRC. The EDM variables (i_e, t_e, $\hat{u}_i$, τ and polarity) used for the experiments represents adequate process parameters for finish machining.

Table. The conditions for the experimental tests.

EDM machine tool	Charmilles ROBOFORM 30 CNC
Machining dielectric fluid	Arclean Hydrocarbon fluid with 3 cSt at 20 ^{0}C
Electrode material	Copper-Tungsten (30% Cu 70%W)
Work piece material	Quenched and tempered AISI H13 tool steel (45 HRC)
Polarity of electrode	Positive
Discharge current i_e	8 A
Discharge duration t_e	50 µs
Open circuit voltage $\hat{u}_i$	200 V
Flushing method	Jet plus immersion flushing
Duty factor	0,5

With the purpose to rather improve the flushing efficiency an alternation between periods of machining U [s] and periods of tool electrode retraction with no discharges R [s] were introduced, as shown in Fig. 2. The values of U and V were defined after pilot tests.

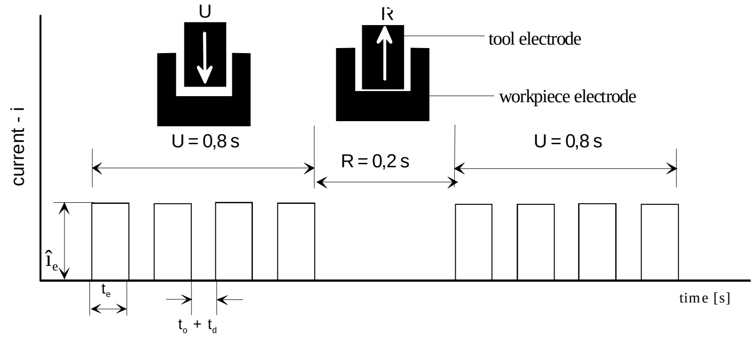

Figure 2. Series of pulses U followed by a pause time R.

(ii) *EDM tool electrode*: Figure 3 shows a schematic representation of the Copper-Tungsten (30% Cu 70% W) square bar electrode 70 mm long and 7 mm wide. The six faces of the electrode were produced by wire EDM from rough machining to four trim cuts to generate Ra = 0,3 µm surface roughness which was then polished. The initial $r_{ei} \approx 11$ µm electrode edge radius was produced. In Fig.4 the actual assembly method of the CuW electrode and work piece is shown. The electrode was precisely installed at a tool holder which was mounted directly to the EDM machine headstock. This method made possible an easy removal of the whole assembly. As a result the measurement of the electrode edge radius wear was done without losing the repositioning accuracy of the tool holder assembly to the EDM machine headstock. This method guaranteed an adequate continuation of the EDM machining.

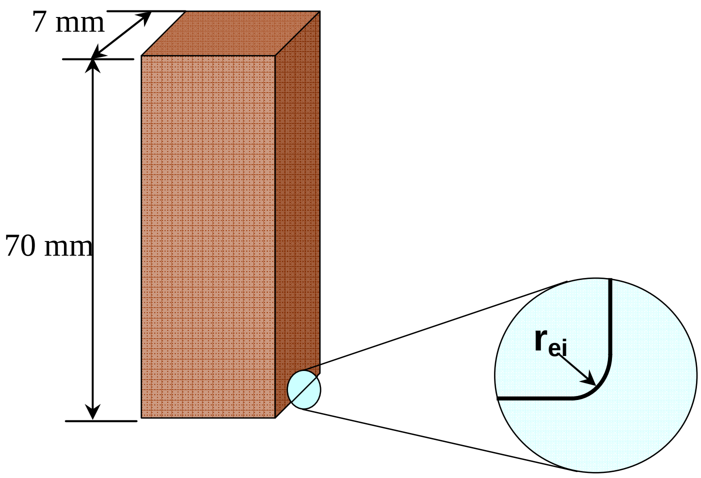

Figure 3. Schematic representation of the work piece sample depicting the initial electrode edge radius ($r_{ei} \approx 11 \mu m$).

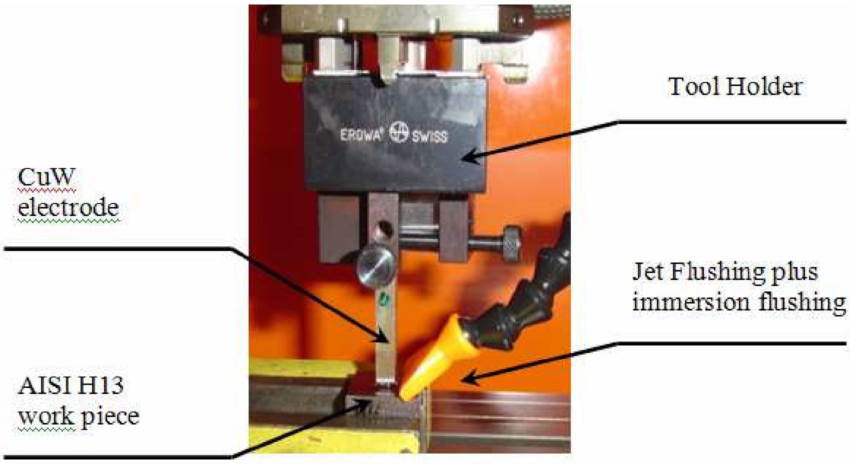

Figure 4. The picture shows work piece and the pair electrode/tool holder assembly at the EDM machine headstock.

(iii) Procedure for the measurement of electrode edge radius wear. To accurately scan the edge radius wear the following technique was used while the machining time M_t proceeded: the measurements were done for M_t of 5, 10, 20, 30, 40, 60, 80 and 100 min from the initial edge radius $r_{ei} \approx 11$ µm. After each one M_t the process was interrupted and the electrode/tool holder assembly was drawn from the machine headstock. This assembly was properly positioned on the working table of a NIKON MM40 optical microscope equipped with QC software (Fig. 5). This software is able to capture three or more points on the electrode edge and then calculate and present the value of the edge radius. To each one of the four edge radius of the electrode three measurements were done. This procedure continued until the total machining time M_t was performed.

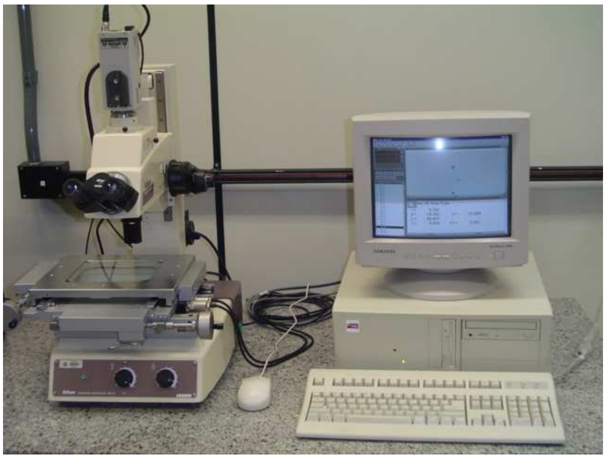

Figure 5. NIKON MM40 optical microscope (resolution = 1µm) used to measure the electrode edge radius wear.

3. RESULTS AND DISCUSSIONS

Figure 6 shows the results of the electrode edge radius wear versus the machining time M_t. It is observed that for the first 20 min of machining the radius wear increases abruptly from 11 µm to about 200 µm. It probably happens for two reasons: (i) although the frontal faces of the pair electrode/work piece were adequately positioned parallel to each other, when the EDM operation starts it takes some time to become stable. This means the reduction of the occurrence of arcs and short circuits through the edges and the frontal faces of the pair electrode/work piece (ii) the second reason can be correlated to higher frequencies of discharges on the edge radius of the electrode than on the frontal face.

As the M_t proceeds from 20 to 60 min the ascendance of the radius wear is a little more regular. Here it probably takes place because the electrode is already burning along its frontal face, since the cavity is deeper than the one at the beginning of the process. Consequently the discharges are adequately dispersed. From 60 to 100 min machining time M_t just a few differences on the values of the electrode edge radius wear are observed. It is likely related to fact that the arc size of the edge radius has become large enough that needs longer machining times M_t to promote a higher increase of the edge radius wear. It can be noticed in Fig. 6.

It is important to remark that some slight divergences on the values of the wear for the four edges radius are observed in Fig. 6. It is possible to be associated to the hydrodynamic behavior of the dielectric fluid as the cavity becomes deeper. This suggests that the contamination of the working gap is not uniform, as remarked by Schumacher (1990).

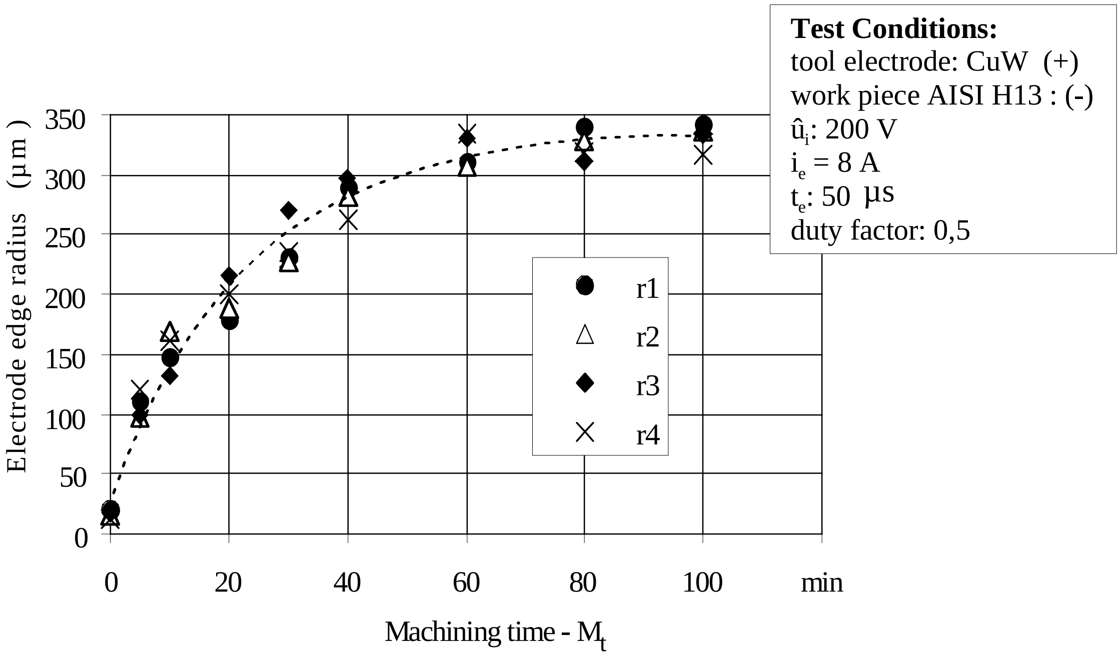

Figure 6. Results of the four electrode edge radius wear (r1, r2, r3, r4) as the machining time M_t proceeds.

The depth of the cavity created as the machine time M_t advances is shown in Fig.7. The penetration of the electrode into the cavity is linear while the M_t proceeds, as depicted in Fig. 7. It is due to the stability of the EDM operation. It means that flushing is adequate and little arc discharges and short circuits have occurred, as pointed out by König & Klocke (1997). The high resistance of CuW (30% Cu and 70% W) against the thermal wear phenomenon is probably to be the key factor to explain this performance. This linear progression of the cavity depth (11 mm) and size (7 mm wide) over machining time demonstrates that CuW as tool electrode material promotes good conditions for EDM of deep cavities no matter the frontal dimension of the electrode.

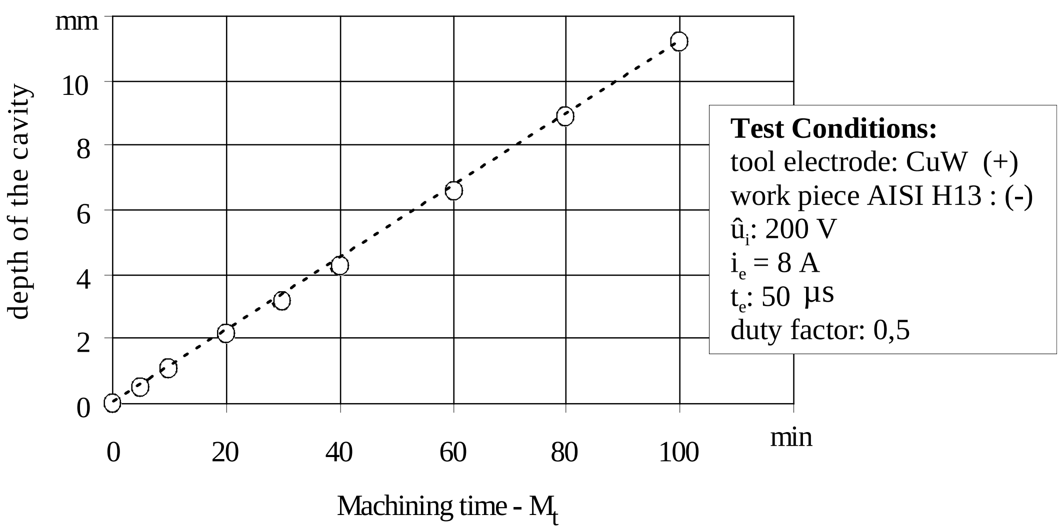

Figure 7. Results of the work piece cavity depth while machining time M_t proceeds.

4. CONCLUSIONS AND FINAL REMARKS

In this work an experimental investigation on the CuW electrode edge radius wear when EDM of AISI H13 while the machining time M_t proceeds was carried out. From the results the following conclusions can be drawn:

(a) At the beginning of EDM operation (M_t up to 20 min) the electrode edge radius wear is remarkable ($r_e \approx 11$ to 200 μm). As the machining time proceeds (M_t = 20 to 100 min) the radius wear doest not increase at the same proportion. It is due to the good stability attained as the electrode sinks into the cavity. It promotes adequate evacuation of the eroded particles away of the working gap.

(b) The four edge radius wear of the electrode presented slightly differences of results, which is an important aspect concerning the work piece geometry. It happens because the good flushing conditions.

(c) The depth of the work piece cavity tends towards to be linear as the machining time (M_t) proceeds. It is due to the high resistance of CuW (30% Cu 70% W) against the thermal wear phenomenon.

(d) It was observed little adhesion of EDM byproducts over both frontal and side walls of the CuW electrode as well as for the work piece cavity.

5. ACKNOLEGMENTS

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