RELATIVE ELECTRODE WEAR AT EDM OF TOOL STEEL

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The technology of electroerosive machining with a shaped tool electrode utilizes thermal energy when removing the material. It results from the continuous repetitive electrical discharges of high intensity between the workpiece and a tool electrode in the presence of a dielectric fluid. The gradual removal (erosion) of metal particles occurs both from the workpiece and the tool electrode, in response to the periodically repeated electric discharges. There is, however, important to emphasize that it is only desirable material removal of metal particles from the workpiece. The removal of metal particles from the tool electrode is considered to be a negative accompanying phenomenon in the case of electro-erosion machining because it causes wear. Its scope can be fairly accurately quantified using a pointer relative electrode wear. The paper describes the results of experimental research on the relative electrode wear and electrode wear rate of electrode machining tools made of Cu and G used in the electro-machining of alloyed tool steels.

KEYWORDS

Electrical Discharge Machining (EDM), Relative Electrode Wear (REW), Material Removal Rate (MRR), Main Technological Parameters (MTP), tool steel

1 INTRODUCTION

Electric discharge machining (EDM) with a tool shape electrode is one of the progressive advances in machining of electrically conductive materials. It is based on the principle of periodic repetitive high-intensity electrical discharges [Salcedo 2017] between the workpiece and the tool electrode. Due to the effects of electric discharge, thermal energy [Corny 2014] is released, which helps to melt (electroerosize) the metal particles [Swiercz 2017] from both the workpiece and the tool electrode. With EDM, however, it is only desirable to remove material from the workpiece.

The removal of material from the tool electrode during EDM [Straka 2006] is considered a negative concomitant phenomenon [Zitnansky 2013], also called electrode wear (EW). It is impossible to completely remove the material from the tool electrode during the EDM. [Hasova 2016] It is therefore necessary to eliminate [Prislupcak 2014] it at least to the lowest possible level. Frequently used parameters that accurately quantify the wear range of the tool electrode are relative electrode wear (REW) and electrode wear rate (EWR).

The problem with the wear of shaped tool electrodes in EDM has been spent in the past by many researchers. To solve the problem of excessive wear of shaped tool electrodes, the optimal selection of the combination of workpiece and electrode materials was considered. For example Uhlmann and Roehner have conducted extensive experimental research to reduce the wear of tool electrodes boron doped CVD-diamond (B-CVD) and polycrystalline diamond (PCD) [Uhlmann 2008].

Tsai and Masuzawa turn, studied the effects of thermal properties of the material to wear electrodes. Based on the results of experimental research have shown that the melting point of the electrode material plays an important role in the mechanism of wear during EDM [Tsai 2004]. Bleys et al. again presented options for compensating tool electrode wear during EDMs based on sensing and evaluating the current intensity of the discharge pulse [Bleys 2004]. The aim of the paper is to describe the results of experimental research on the size of REW and EWR shape tool electrodes made of Cu and G used in EDM alloyed tool steels.

2 REW OF TOOL ELECTRODE AT EDM

As mentioned earlier, the wear of the tool shape electrodes [Straka 2013] in EDM is considered an undesirable accompanying phenomenon [Panda 2013]. However, an appropriate choice of main technological parameters (MTP) can eliminate the extent of wear to an acceptable level [Straka 2017].

In addition to MTP, the range of wear of shaped tool electrodes is also dependent on the mechanical, physical and chemical properties of the electrode material used [Malega 2017], but also the workpiece. These are in particular parameters such as the strength limit [Zhang 2017], melting point, thermal and electrical conductivity, magnetic properties [Wang 2017], homogeneity [Straka 2016], and the like.

Detailed evaluation of the tool electrode wear during EDM takes into account the value of material loss from important locations [Krenický 2015], transitions, various projections, sharp corners and edges, recesses [Micietova 2013], and the like.

In Fig. 1 shows selected tool electrode shapes used in EDM, the functional parts of which are susceptible to increased wear.

Figure 1. Electrode shapes for EDM prone to wear

An important parameter in quantifying the wear range of shaped tool electrodes is the electrode wear rate (EWR). It is a parameter that expresses the intensity of material removal from the shape tool electrode [Straka 2014].

Typically, it indicates the volume of material removed from the shape tool electrode V_{TE} (usually in mm^3) per unit of time (usually min, s).

This dependence is mathematically described by formula (1):

$$EWR = \frac{V_{TE}}{t} \ (mm^3 \cdot min^{-1}) \quad (1)$$

where:

V_{TE} – the volume of material removed from the workpiece (mm^3),

t – time EDM (min).

Another important parameter in quantification of the wear range of the tool shape electrodes used in EDM is the relative electrode wear (REW). It is a complex parameter which, in addition to the unwanted removal of material from the shape tool electrode, also involves the desirable removal of material from the workpiece. This parameter is usually given in percent and represents the ratio of the material volume drop from the V_{TE} shaped tool electrode to the loss of volume of material taken from the V_W workpiece. This dependence is mathematically described by the formula (2):

$$REW = \frac{V_{TE}}{V_W} \cdot 100 \ (\%) \quad (2)$$

where:

V_{TE} – the volume of material removed from the shape electrode (mm^3),

V_W – the volume of material removed from the workpiece (mm^3).

As already mentioned in the beginning, REW parameter is during EDM except MTP settings, they also depends on the combination of materials [Stephen 2011] and their physical properties. Of these, the electrical and thermal conductivity, but also the melting temperature of the material, are primarily affected. Higher values of these parameters lead to low REW values, which was positively reflected in lower wear of the tool electrode shape. On the contrary, low values of these parameters leads to high REW which may have a positive impact on the size of workpiece removal, but it increases the wear level of the tool shape electrodes. Therefore, in EDM, the usege of different combinations of shaped tooling tools for machining particular materials seems to be advantageous. In practice, there is a wide range of materials used in the production of shaped tool electrodes, such as the copper and its alloys, graphite, molybdenum, tungsten, and the like. In Tab. 1 is an overview of selected physical properties of materials often used in the manufacture of shaped tooling electrodes for EDM.

Each of these materials has advantages and disadvantages for EDM. For example, Cu is widely used for EDM roughing and finishing operations because of its high electrical and thermal conductivity value. Graphite has a high melting temperature and low density, which is an advantage for large shape electrodes. Its disadvantage is the fine dust created during the EDM. It is gradually deposited on the functional parts of the machine [Baron 2016], acting as an adhesive blend. These deposits have a negative impact on its accuracy. The use of Cu and Tungsten alloys has its advantages in machining fine details and high-precision EDM operations. This material has a high density but also high strength and good thermal and electrical conductivity. Its properties predetermine it for EDM applications that require precise and smooth surface finishes [Mouralova 2016]. In the machining of metal materials, combinations of Cu and graphite electrode tools are often used. Cu has a high thermal and electrical conductivity value, which means a low EWR. Graphite has in turn a higher melting point, which is also reflected by the low EWR value and hence the lower wear of the shape tool electrode. Conversely, steel has lower thermal and electrical conductivity values than Cu and graphite, which is reflected by higher material removal from the workpiece. By using such a combination of workpiece material and shape tool electrode at EDM, positive results can be obtained in terms of process efficiency. In this combination [Vagaska 2013], to higher performance of material removal from the workpiece while relatively low wear of the shape of the tool electrode. In Tab. 2 gives a basic overview of the physical properties of selected workpiece materials suitable for EDM.

From this report in Tab. 2 is the assumption that the largest material removal from the workpiece and the greatest cutting power will be the silicon carbide and carbon steel in the EDM, because they have the highest values of the thermal conductivity and the electrical resistance of the materials. The smallest material removal will be in EDM of aluminum. Moreover, during EDM of aluminum [Dubjak 2016] it is produced a high degree of contamination of the dielectric fluid [Tavodova 2014, Yan 2018] which subsequently causes excessive filtering.

Table 1. The basic physical properties of materials shaped tool electrodes frequently used in EDM

Electrode material	Density ρ_0 (g.cm^{-3})	Electrical conductivity σ (S.m^{-1})	Electrical resistivity ρ (Ωm)	Thermal conductivity λ (W m^{-1} K^{-1})	Melting point θ (K)	$\rho.\lambda.\theta$ (WΩ)
Copper	8.96	5.90×10^{7}	1.70×10^{-8}	400	1357	0.0092
Brass	8.5	1.59×10^{7}	6.30×10^{-8}	150	1173	0.0111
Graphite	2.26	2.50×10^{5}	4.00×10^{-6}	140	3823	2.1409
Molybdenum	10.28	1.75×10^{7}	5.70×10^{-8}	139	2896	0.0229
Tungsten	19.25	1.77×10^{7}	5.65×10^{-8}	163	3673	0.0338

Table 2. Basic overview of the physical properties of selected workpiece materials suitable for EDM

Workpiece material	Density ρ_0 (g.cm^{-3})	Tensile strength Rm [MPa]	Young´s modulus E [GPa]	Electrical conductivity σ (S.m^{-1})	Electrical resistivity ρ (Ωm)	Thermal conductivity λ (W m^{-1} K^{-1})	Melting point θ (K)	$\rho.\lambda.\theta$ (WΩ)
Carbon steel	7.70	540	210	5.90×10^{6}	16.9×10^{-8}	90.0	1673	0.0254
Stainless steel	7.90	650	195	1.37×10^{6}	73.0×10^{-8}	16.3	1723	0.0205
Silicon carbide	3.10	2000	410	0.42×10^{5}	0.24×10^{-4}	120	2073	5.9702
Aluminum	2.70	250	70	3.69×10^{7}	2.70×10^{-8}	237	933	0.0059

3 DESIGN AND IMPLEMENTATION OF EXPERIMENTS

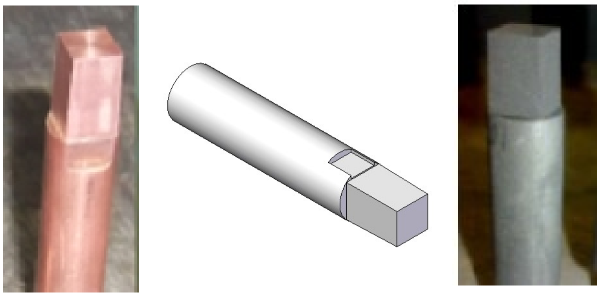
The experiments were performed on the CNC electroerosion device Agietron IMPACT 3 (Fig.2) of Agie Charmilles Ltd. in production plant 1. PN Presov, Ltd.

Basic technical parameters of used Aggregron IMPACT 3 electroerosion equipment

Max. workpiece dimensions *X* x *Y* x *Z*	500 × 350 × 500 mm
Worktable dimensions *X* x *Y*	800 × 600 mm
Machine dimensions *X* x *Y* x *Z*	2855 x 2135 x 2965mm
Distance worktable-pinola	min. 200-max. 700 mm
Max. workpiece weight	800 kg
Max. electrode weight	200 kg
Generator power	72A
Machine weight	2210 kg
Dielectric tank	620 l
Machine weight	3900 kg

Figure 2. CNC electroerosion device Agietron IMPACT 3 of Agie Charmilles

In the experiments, the shaped tool electrode made of a circular rod of ϕ15.0 mm and a length of 60.0 mm with a functional part of a square cross-section of 10.0 x 10.0 mm and a length of 15.0 mm, were used. For the production of tool electrodes was used Cu with a purity of 99.9% and designation EN CW004A (DIN E Cu 58-Cu ETP, W.-Nr. 2.0060) and graphite designated R8500. Fig. 3 shows a shape tools electrode of Cu and graphite, including their 3D model used in the experiment.



a) b) c)

Figure 3. Cu and graphite shaped tool electrode used in the experiment a) electrode E Cu 58-Cu ETP, b) electrode model, c) electrode R8500

The following Tab. 3 shows an overview of the basic mechanical and physical properties of materials EN CW004A (Cu-electrode) and R8500 (graphite electrode) used in the production of shaped tool electrodes for experimental purposes. The experiments were performed on samples of EN 90MnCrV8 tool steel (W.-Nr. 1.2842) with tensile strength Rm 770MPa at hardness of the base material of about 62HRC. It is a low-alloy manganese-chromium-vanadium tool steel. In Tab. 4 is the basic chemical composition, together with the mechanical and physical properties of the low-alloy manganese-chromium-vanadium tool steel EN 90MnCrV8 (W.-Nr. 1.2842), which was used for the purposes of the experiment.

Table 3. Basic mechanical and physical properties of materials tool electrodes EN CW004A and R8500, which were used in the experiment

Material designation	Density ρ_0 (g.cm^{-3})	Tensile strength Rm [MPa]	Young´s modulus E [GPa]	Electrical conductivity σ (S.m^{-1})	Electrical resistivity ρ (Ωm)	Thermal conductivity λ (W m^{-1} K^{-1})	Melting point θ (K)
EN CW004A	8.91	200-340	130	58.0×10^{6}	0.017×10^{-6}	390	1356
R8500	1.77	50	10.5	0.07×10^{6}	14.28×10^{-6}	80	3823

Table 4. Basic chemical composition and selected mechanical and physical properties of steel 90MnCrV8 (W.-Nr. 1.2842)

Steel designation	Chemical composition in %							
	C	Mn	Si	Cr	Ni	V	P_{max}	S_{max}
EN 90MnCrV8 (W.-Nr. 1.2842)	0.85–0.95	1.80–2.20	0.10–0.40	0.20–0.50	max 0.35	0.05–0.20	0.03	0.030
	Mechanical and physical properties							
	Density ρ_0 (g.cm^{-3})	Tensile strength Rm (MPa)	Young´s modulus E [GPa]	Electrical conductivity σ (S.m^{-1})	Electrical resistivity ρ (Ωm)	Thermal conductivity λ (W m^{-1} K^{-1})	Melting point θ (K)	
	7.85	770	215	2.85×10^{6}	35.0×10^{-8}	30	1783	

Table 5. Setting the MTP during EDM with Cu electrode shape EN CW004A and graphite electrode shape R8500

MTP	Type of shape tool electrode E Cu 58-Cu ETP and R8500		
	EDM operation		
	roughing	semifinishing	finishing
Peak current *I* (A)	20	15	5
Pulse on-time duration t_{on} (μs)	150	100	30
Pulse off-time duration t_{off} (μs)	30	20	10
Voltage of discharge *U* (V)	60	65	70
Dielectric fluid	IonoPlus IME-MH		

As already mentioned above, except the basic physical and mechanical properties [Straka 2016] of the materials which were used, the combination of the MTP setting has also a significant influence on the size of the REW parameter during EDM with a shaped tool electrode. The following Tab. 5 shows the MTP setting values used in the experimental research with the Cu electrode EN CW004A and the graphite electrode R8500.

4 THE RESULTS OF THE EXPERIMENT

With the monitored output parameters within the experiment, the volume of V_W material was removed from the workpiece and the V_{TE} material volume was removed from the shape electrode. Based on these parameters, the values of EWR and REW were then determined using formulas (1) and (2). The results of the monitored output parameters obtained in the experiment with the use of shape electrodes EN CW004A a R8500 for EDM steels EN 90MnCrV8 are shown in the Tab. 6.

The following graphical dependence in Fig. 4 shows the progress of monitored output parameters EWR, REW and MRR at machining time t, its obtained at the EDM of EN 90MnCrV8 steel using E Cu 85-Cu ETP and R8500 shape electrodes.

From the graphical dependencies of Fig. 4, a significant change in the monitored output parameters EWR, REW and MRR can be observed for individual EDM operations (roughing, semifinishing and finishing) using Cu as well as using a graphite shape electrode. Lower values of these parameters were recorded for EDM finishing and vice versa for EDM roughing. At the same time, it can be observed that when E Cu 85-Cu ETP shaped tool electrode material was used, the lower values of the monitored EWR and MRR output parameters for individual EDM operations were compared with the graphite electrode material R8500.

Also, when using Cu electrodes, lower REW values were recorded compared to using a graphite electrode. The REW values for the EDM with the Cu electrode were between 0.879 and 1.552% and for the EDM with the graphite electrode were between 1.293 to 2.224%. The results obtained also confirmed our preliminary estimates. At the same time, it can be stated that the obtained results confirm the same material picking mechanism for the tool electrode (EWR) as well as for the workpiece (MRR). These results are described in several authors' work (Uhlmann 2008, Tsai 2004).

Table 6. Values of the monitored output parameters obtained in the experiment during EDM of tool steel EN 90MnCrV8 with using shaped electrodes EN CW004A a R8500

Watched Output Parameters	Type of shape tool electrode					
	E Cu 58-Cu ETP			R8500		
	EDM roughing	EDM semifinishing	EDM finishing	EDM roughing	EDM semifinishing	EDM finishing
V_{TE} (mm^3)	1.7952	1.6781	0.6325	4.3824	4.6665	1.4950
V_W (mm^3)	115.636	138.662	71.885	196.987	263.141	115.613
t (min)	8	17	25	8	17	25
EWR (mm^3.min^{-1})	0.2244	0.0987	0.0253	0.5478	0.2745	0.0598
MRR (mm^3.min^{-1})	14.454	8.156	2.875	24.623	15.478	4.624
REW (%)	1.552	1.210	0.879	2.224	1.773	1.293

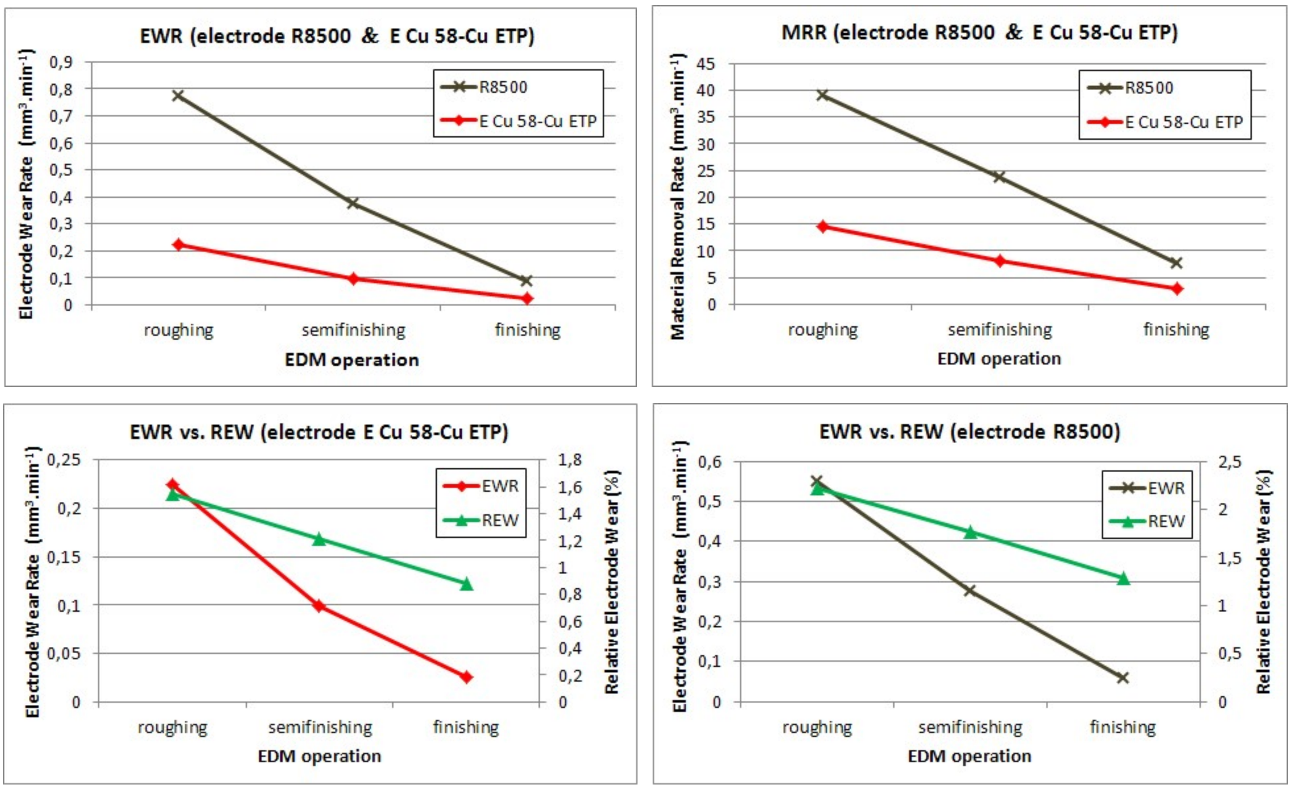


Figure 4. Dependence of the monitored output parameters EWR, REW and MRR to the type of operation (roughing, semifinishing and finishing) EDM the steel EN 90MnCrV8 using the shape of the electrodes E Cu 58-Cu ETP and R8500

5 CONCLUSIONS

An important factor in EDM is, in addition to MRR, the EWR parameter, which characterizes the intensity of material removal from the shape tool electrode. From this parameter, the wear and tear depended significantly on the individual EDM operations. In assessing the wear of the tool electrode shape it is also an important parameter REW. The size of the parameters depend on the choice of a suitable combination of materials of the workpiece and shaped tool electrode. When choosing an inappropriate combination, the risk of excessive wear of the tool shape electrode during the individual EDM operations is greatly increased. At the same time, the resultant surface quality is deteriorated. In addition to the chemical composition of the material used and its physico-mechanical properties, these parameters are substantially dependent on the mutual combination of MTP settings. By appropriately optimizing MTP settings during EDM, the wear of the shape tool electrode can be eliminated, but cannot be totally excluded. At the same time, eliminating the wear rate of the tool electrode, the quality of the machined surface is proven to improve, which has a significant impact on the efficiency of the production process itself. The aim of the paper was to describe the results of experimental research aimed at assessing the dependence of monitored output parameters EWR, MRR and REW on individual EDM operations (roughing, semifinishing and finishing). The research was conducted on tool steel EN 90MnCrV8 using Cu (EN CW004A) and graphite (R8500) shaped tool electrodes. By evaluating the results of experimental research, using a Cu-shaped tool electrode, some values of the monitored EWR and REW parameters were found for individual EDM operations compared to the graphite shape tool electrode.

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