Effect of Electrical Parameters on Performance of Cu-TiC Mixed Ceramic Compact Electrode in EDM Process

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ABSTRACT

Electrical discharge machining (EDM) is one of the most extensively used non conventional material removal processes to machine very hard material. Such materials like hardened tool steel, titanium and its alloy, Hastelloy which were hitherto difficult to machine can be easily processed with EDM. Tool electrode being the main component of the machine can be produced by a number of techniques. This paper evaluates the machining performance of powder metallurgy (PM) electrodes compacted from titanium carbide and copper powders with selected EDM parameters on mild steel material. The Cu-TiC electrodes made up of 70% of titanium carbide and 30% of copper were compacted at a pressure of 6,000 psi (41.34 MPa). Machining was conducted with the peak current, pulse duration and pulse interval as the electrical input variables. The output variables of the investigation were the material removal rate (MRR) and tool wear rate (TWR). The general behaviors of the outputs under the influence of the electrode with the EDM variables have been presented in terms of their 3-D surface plots. Analysis of the results carried out with Design Expert software showed that both the peak current and the pulse duration influences the level of MRR attained. The highest MRR of 9.93mg/min was obtained with the current of 6.5A and pulse duration of 7.5 µs. The TWR are generally high compare to the MRR, with the lowest being 11.30 mg/min. This is one of the attributes that make such electrodes suitable for layer generation on workpiece. All the three input variables show significant influence on the TWR values obtained.

Keywords-EDM; Cu-TiC compact electrode Powder Metallurgy; Material removal rate; Tool wear rate

1. INTRODUCTION

Tool electrode is one of the principal components of electrical discharge machine (EDM). It provides the appropriate shape or profile to the finished workpiece surface. The basic EDM system normally comprise of the workpiece, the dielectric fluid and the electrode as the cutting tool in the machining process. Both the cutting tool and the workpiece are required to be electrically conductive. The process takes place through the erosive action of the spark discharges between the pair of workpiece and the electrode under substantially high potential difference [1]. These discharges occur hundreds of thousand times per second in order to sustain the removal of material from the surface within the machining gap area [2]. The hardness, toughness and strength of the workpiece material do not necessarily influence the material removal rate (MRR) as the EDM is not a mechanical process. Therefore very hard or very flexible materials of complex intricate shapes and sizes can be machined with the process. EDM finds application in numerous areas such as the production of dies for forging, extrusion, die casting, injection molding, and large sheet-metal automotive body components.

The most common dielectric fluids are mineral oils, although kerosene, distilled and deionized water also are used in specialized applications [3; 4]. The electrodes for EDM are usually made of graphite, brass, copper, or copper-tungsten alloys. The tools can be shaped and produced by forming, casting, powder metallurgy (PM), rapid prototyping or CNC machining techniques [5]. The electrodes' fabrication technique affects its manufacturing time, cost and EDM performance [6]. The electrodes produced by PM method can be used in sintered, pre-sintered or green compact forms [7; 8]. In their production process, the materials can be controlled to give the desired properties through powder composition and compacting pressures [7]. In this regard, a number of PM compacted electrodes were developed to enhance the machining efficiencies in terms of MRR, Ra etc [9]. Others were used to modify the surface of the workpiece through electrical discharge coating, EDC [10] and surface alloying [11; 12].

Researches have been conducted with PM electrodes made from composites of different powders [13] or with single compacted powders [14], so as to utilize the benefit of individual components. This paper reports the investigation conducted on the machining performance of Cu-TiC compact electrode with selected EDM parameters on mild steel material. The process parameters used to investigate EDM outputs (Material removal rate (MRR) and electrode wear rate (TWR)) were peak current, pulse duration and pulse interval as the electrical input variables. Cu-TiC compact PM electrode is a relatively new addition to the EDM process and it machining performance is yet to be reported in literatures, except for a single effort in applying it for surface modification through electrical discharge coating (EDC) [15].

2. EXPERIMENTAL METHODS AND MATERIALS

The electrode materials used are TiC and Cu powders in percentages of 70 and 30 respectively. The extremely hardness (about 9.0-9.5 Mohs) property of TiC powder and its melting point of 3140 °C was explored in this investigation. Also, the high thermal and electrical conductivity of Cu coupled with its binding ability during compaction were part of the reasons for using it. They were compacted at 6,000 psi (41.34 MPa) using a Carver Model 4350L compaction machine. The PM electrode was attached to a metallic copper with glue, while a mild steel material with 60 mm x 60 mm x 5 mm dimension was used as the workpiece. The workpiece composition and properties are presented in Table 1.

The effect of three input factors on the process outputs was investigation using design of experiment (DOE), with response variables as MRR and TWR. A two level factorial design was used to plan the experimental runs. The enables the main effects and possible interactions between them to be determined. The factors and their levels are shown in Table 2, while the design matrix is presented alongside the responses in Table 3.

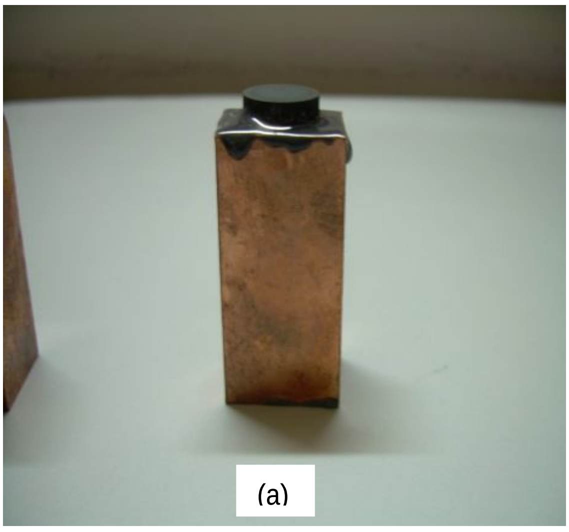
Machining was conducted with the electrode as a green compact on a die-sinking EDM machine with kerosene dielectric fluid. A Mitsubishi EX 22 model C11E FP 60E was used for the investigation. The electrode/workpiece set-up is shown in Fig. 1. In this work, the material's loss in weight per time after machining was used to obtain each of MRR and TWR. After machining, the results were used to generate models which identify the main and interaction effects. Using these models, the general behavior of the electrode in conjunction with the machining parameters is presented in section 3.

Table 1. Chemical composition and mechanical properties of the mild steel

Chemical Composition (%)					
Fe	*Mn*	*S*	*P*	*C*	
98.81-99.26	0.6-0.9	0.05	0.04	0.14-0.2	
Physical Properties					
Yield strength (MPa)	Tensile strength (MPa)	Thermal conductivity (W/m K)	Melting Point (°C)	Hardness (HB)	Specific Heat Capacity (J/g °C)
275	475	51.9	1523	143	0.472

Table 2: The Factors and the Levels

Parameter	Level	
	-1 (Low)	*+1 (High)*
Current, I (A)	3.50	6.50
On-time, t_i (μs)	6.00	7.50
Off-time, t_o (μs)	6.50	8.50



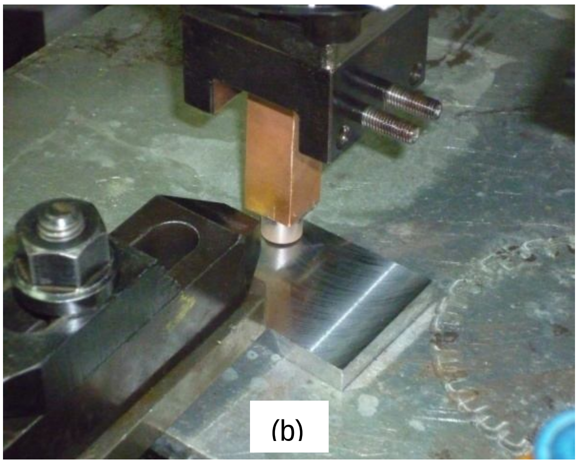


Fig. 1: Experimental Arrangement: (a) electrode attached to the holder; (b) the workpiece/electrode set-up

3. RESULTS AND DISCUSSION

3.1. Analysis of the Results

The results of the output responses are presented in Table 3. From the table, it can be observed that the highest MRR obtained with the PM electrode is 9.93mg/min with the current of 6.5A and pulse on-time of 7.5 μs. TWR are generally higher compare to the MRR, with the lowest being 11.30 mg/min. In conventional EDM, this output is supposed to be lower. However, this characteristic of PM electrode makes them suitable for layer generation on workpiece. Efforts are currently being made to investigate the capability of the same PM electrode in surface modification of aluminum material through EDC [15].

Table 3: Design matrix with the responses

	Factor 1 A:CURRENT (A)	Factor 2 B:ON TIME (μs)	Factor 3 B:OFF TIME (μs)	MRR (mg/min)	TWR (mg/min)
1	3.5	6.00	6.50	0.639	3.85
2	3.5	7.50	8.50	0.878	3.51
3	6.5	6.00	8.50	3.374	8.54
4	6.5	7.50	6.50	9.936	11.30
5	3.5	7.50	6.50	3.701	6.30
6	6.5	7.50	8.50	8.236	10.92
7	6.5	6.00	6.50	4.472	10.36
8	3.5	6.00	8.50	0.305	1.74

Using the analysis of variance (ANOVA), the responses (MRR and TWR) were subjected to different diagnosis with design expert software to determine the main effect factors and the interactions that are statistically significant. These models obtained from the analysis were used to describe the behavioral trends in the 3-dimensional (3-D) surface plots. Table 4 shows ANOVA for the selected factorial model of MRR. The model F-value of 39.35 implies that it is significant. It can be seen from the Table that the terms A, B and AB yield "Prob>F" less than 0.0500. Thus, they are the significant model terms. Therefore they were used in the model to generate the surface plot of the machining behavior of MRR.

Table 4: ANOVA for MRR

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8.689E-005	4	2.172E-005	39.35	0.0063	significant
A-CURRENT	5.250E-005	1	5.250E-005	95.11	0.0023	
B-ON TIME	2.949E-005	1	2.949E-005	53.43	0.0053	
C-OFF TIME	4.432E-006	1	4.432E-006	8.03	0.0660	
AB	5.598E-006	1	5.598E-006	10.14	0.0499	
Residual	1.656E-006	3	5.520E-007			
Cor Total	8.855E-005	7				

Table 5: ANOVA for TWR

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.701E-003	4	2.425E-003	98.95	0.0016	significant
A-CURRENT	8.269E-003	1	8.269E-003	337.39	0.0004	
B-ON TIME	7.106E-004	1	7.106E-004	29.00	0.0125	
C-OFF TIME	4.324E-004	1	4.324E-004	17.65	0.0246	
AC	9.113E-005	1	9.113E-005	3.72	0.1494	
Residual	7.352E-005	3	2.451E-005			
Cor Total	9.774E-003	7				

Table 5 shows the ANOVA for selected factorial model of TWR. The model F-value of 98.95 indicates that it is significant. It is found that the model terms A, B and C yield “Prob>F” less than 0.0500, implying that they are the significant model terms. It should be noted that there is no interaction effect between any of the three parameters for this output.

3.2. Effect of the Parameters on machining performance

The 3-D surface plots of the output responses based on the models involving current, on-time and off-time are presented in Figures 2 and 3. For the MRR, Figure 2a indicates that a combination of both the current and pulse on-time influences the amount of material that can be obtained from the electrode. Both of the factors have direct proportional effect on the MRR. It is observed that increasing one or both leads to corresponding increase in MRR and vice versa. This is in agreement with the normal feature of metallic electrodes. Khan [16] also noted that at low current or low pulse on-time led to low MRR in investigation. He also observed that with increase in current, the MRR increase sharply. At such a low current, small quantity of heat is generated, with substantial portion absorbed by the surroundings and the machine components. The rest is then utilized in melting and vaporizing of the work material. But increased current leads stronger sparks with higher energy production. Thus, more heat is generated and substantial quantity of it is utilized to facilitate the melting and vaporization action on the workpiece.

The MRR increases with the increase of on-time. This is due to the fact that increasing on-time gives room for more time to be spent in cutting. This allows the same heat temperature to use for longer time. With higher heat intensity more evaporation takes place and this lead to removal of higher volume of the molten metal [13]. In Figure 2b, off-time is observed to nearly constant while the current varied over the range of the investigation. The implies that the duty factor of the machine setting is nearly constant because it is of short ranged. However, the range is acceptable since the machining stability was attained with this range. During the off time no energy is applied to the workpiece surface and this small time lag is needed for the stability of the process.

Figure 3 illustrates the 3-D surface plots for the tool wear rate based on the corresponding models which evolved from the ANOVA of Table 5. The charcteristic behaviour of TWR for the electrode with the electrical parameters follows similar trend with the MRR as can be observed from Figure 3a. Increasing on-time and current increases the TWR because of the increased heat intensity which can easily influence more erosion of the less dense electrode. Reduced off-time also leads to higher tool wear (Figure 3b). This is because more time is spent on cutting as opposed to less idle time. From these trends however, low electrode wear can be achieved at lower current and on-time, but at higher off-time. Khan (2007) emphasize that a higher current will produce a stronger sparks which would erode more material from the electrode.

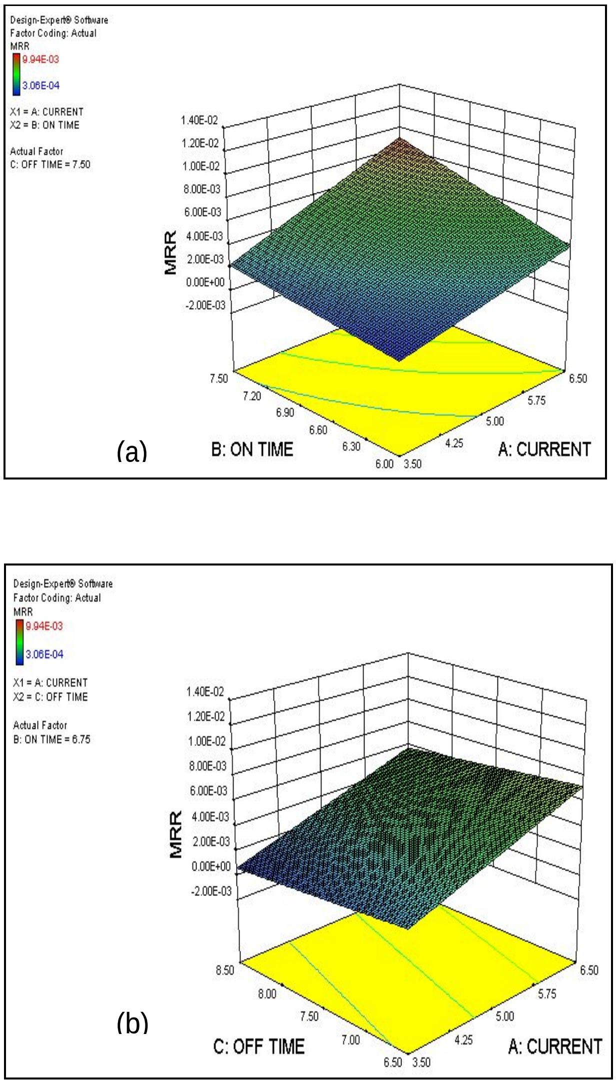


Fig. 2: 3-D surface plot of MRR: (a) current and on-time; (b) current and off-time

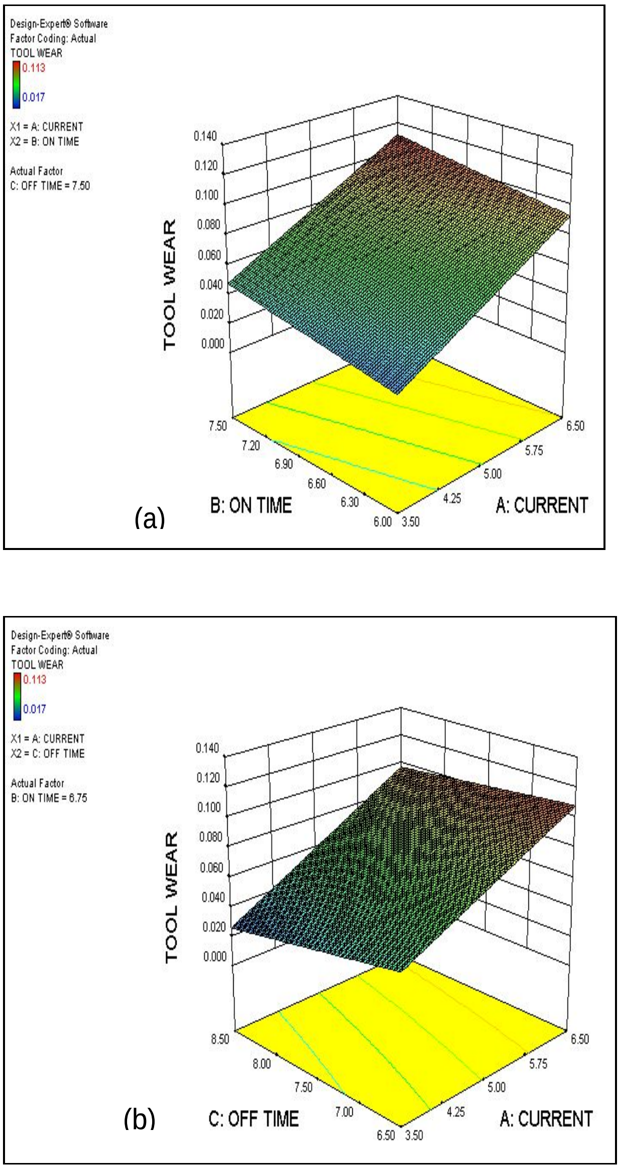


Fig. 3: 3-D surface plot of TWR: (a) current and on-time; (b) current and off-time

4. CONCLUSIONS

The influence of machining parameters on the performance characteristics in the EDM process with Cu-TiC mixed ceramic compact electrode was investigated using material removal rate and tool wear rate as the basic criteria. The following conclusions are drawn from the results.

1. The analysis show that the material removal rate is significantly affected by the EDM discharge current and the pulse on-time in addition to the interaction effect between the two. On the other hand, all the three factors have statistical significant effect on the tool wear rate during the EDM of mild steel with Cu-TiC compact electrode.
2. Both the current and pulse on-time have direct relationship on the MRR and TWR. Thus, the outputs increase with increasing current and on-time. The highest MRR obtained with the PM electrode is 9.93mg/min with the current of 6.5A and pulse duration of 7.5 µs. The rate of tool wear is higher compared to the material removal from the workpiece. The highest TWR is 11.30 mg/min which also higher than the highest MRR at the same machining conditions.

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