THE INFLUENCE OF EDM PARAMETERS WHEN MICRO-HOLE DRILLING OF TUNGSTEN CARBIDE

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ABSTRACT

Tungsten carbide is one of the essential materials used in carbide dies, cutting tools and components under erosion. Although Electrical Discharge Machining (EDM) is suitable for handling this material, it is not ideal for micro-hole machining due to its hardness property. The purpose of this study is to describe the characteristics of EDM micro-hole tungsten carbide using Sodick 3-axis die sinking machine with 0.5mm diameter copper as an electrode. In the current study, the effectiveness of the EDM process was evaluated in terms of material removal rate (MRR), electrode wear rate (EWR) and diameter overcut. Design of Experiment (DOE) method has been adopted and findings on the influence of the process parameters, namely peak current (I_p), pulse on time (t_i) and polarity (*ve*) over MRR, EWR and diameter overcut is presented in this paper. The process employs different range of peak current (1.5, 3.0(A)), pulse on time (3.2, 6.4 (μs)) and polarity ((+ve), (-ve)). Experimental results indicate that the MRR increased when the peak current with negative polarity is kept at high level whilst the EWR minimised when the negative polarity with low level of peak current setting is employed. In the case of diameter overcut, it has been found that the use of positive polarity associated with low level pulse on time setting will minimise the diameter overcut and produce a constant micro-hole shape.

Keyword: tungsten carbide; micro-hole drilling; EDM; DOE.

INTRODUCTION

Electrical discharge machining process is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and the workpiece. There are no physical cutting forces generated between the tool and workpiece.

Recent developments in the field of EDM have progressed due to the growing application of EDM process and the challenges being faced by the modern manufacturing industries, from the development of new materials that are hard and difficult to machine such as tool steels, composites, ceramics, super alloys, hastalloy, waspalloy, nemonics, carbides, stainless steels, heat resistant steel, etc. being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries. Review of the research work reveals that much work has been done on various aspects of electro-discharge machining on low carbon steels, carbides and few die-steels. There are little investigation have been reported on electric discharge machining onto composite material such as tungsten carbide. Therefore, this paper presented the electrical discharge machining of a tungsten carbide with a copper electrode. Subsequently, an analysis on the influence of pulse duration, peak current, and changing polarity over technological variables namely electrode wear rate (EWR), material removal rate (MRR), and dimensional accuracy of micro-hole had been performed.

M.G. Her and F.T. Weng (2001) studied the hole machining of copper using the EDM process with a tungsten carbide electrode compared with a copper electrode. A series of experiments were performed on an EDM machine to investigate the effects of electrode material polarity setting and of a rotating electrode in respect of electrode wear, removal rate of electrode and surface roughness. Results have shown that electrode wear and hole are both smaller, and a better profile of a hole can be obtained when positive polarity machining is selected; whereas electrode wear is larger when negative polarity machining is selected.

B.H. Yan (1999) studied carbide hole machining by EDM. The effects of various machining parameters on the qualities of the hole machining of carbide have been reported. In this study, a die-sinking EDM machine and a tri-axial work table were used. The tri-axial work table was controlled by a stepping motor, and the tool electrode was placed horizontally and controlled by the Z-axis drive of the EDM machine for servo motion. This study investigates the effects of: (1) polarity; (2) the diameter of the straight tool electrode; and (3) the rotational speed of the straight tool electrode. Present experimental results show that during machining holes in carbide with copper electrode, positive polarity machining must be used. As for the rotational speed of the electrode, it is shown that a higher rotational speed electrode can minimize the expansion and improve the debris discharge, but it has no great effect on the tool electrode wear rate.

Puertas *et al* (2004) studied the electrical discharge machining (EDM) of conductive ceramics. This study has been done only for the finishing stages and the selection of the conductive ceramics was motivated by their wide range of application: machining and mining for WC-Co, thermal-neutron absorber and nozzle for B_4C and wear parts and heat exchangers for SiSiC, among others. The comparative study has been carried out on the influence of the design factors of intensity (I), pulse time (t_i) and duty cycle (η) over response variables such as surface roughness (evaluated through the R_a parameter), volumetric electrode wear (EW) and material removal rate (MRR). This was accomplished through the technique of design of experiments (DOE), along with multiple linear regressions, which allowed us to carry out the analysis with only a small number of experiments.

Lee *et al* (2001) studied the effect of machining parameter on the machining characteristics in electrical discharge machining of tungsten carbide. The effectiveness of the EDM process with tungsten carbide is evaluated in terms of the relative tool wear ratio and surface finish. A series of experiments on EDM of tungsten carbide was conducted on a Roboform 40 electrical discharge machine to examine the effects of input parameters such as the gap voltage, electrode polarity and current. The electrodes used are copper and graphite. The results of experiment show that the tool wear ratio decreases when the current is lower for graphite electrode, but increase for copper electrode. Copper exhibits the best performance with regards to surface finish while graphite shows the poorer.

EXPERIMENTAL PROCEDURE

In this study, a series of experiments on EDM of tungsten carbide were carried out on a Sodick electrical discharge machine to examine the effects of pulse duration, peak current and changing polarity on the process performance. The electrodes used were made of brass tube with external diameter of 0.5mm and the workpiece was a rectangular block of a tungsten carbide cut to 70mm x 25mm x 5mm size. The surface of the workpiece was grinded to ensure the 5 mm thickness is achieved for consistency in machining time. The dielectric fluid used was kerosene.

The DOE module in the MINITAB 14 software was used to design the experiments, model, and analyse the results. The design factors selected were peak current, pulse duration and polarity. A summary of the levels selected for the factors is shown in Table 1. For the appropriate Orthogonal Array (OA), the 2^k full factorial design was selected to construct the Orthogonal Array table. The design of experiments chosen for this experimental work is a factorial design 2^3, subsequently carrying out a total of 8 experiments.

The tool wear and material removal rate were determined by computing the weight difference (Δm) of the tool and workpiece before and after the machining operation divided by machining time. The diameter overcut was determined by calculating the difference between the size of the electrode and the size of the machined micro-hole. The diameter of the electrodes and micro-hole were measured using tool maker measuring microscope. The experiments were executed according to the experimental conditions in Table 2.

TABLE 1: Factors and levels selected for the experiments

Factors	**Level**	
	High (+1)	**Low (-1)**
Changing polarity	Positive	Negative
Peak current (I_p)	3.0	1.5
Pulse on-time (t_i)	6.4	3.2

TABLE 2: The setting of EDM parameters

EDM parameters	**Setting conditions**
Dielectric fluid	Kerosene
Electrode material	copper
Work material	Tungsten carbide
Peak Current (I_p)	1.5 , 3 A
Pulse on-time (t_i)	3.2 , 6.4 (µs)
Polarity	(+ ve) and (- ve) interchangeably

RESULT AND DISCUSSION

This section presents the effects of process variables (peak current, pulse duration and polarity) over machining characteristics of: (1) material removal rate; (2) electrode wear rate; and (3) diameter overcut.

(1) *Effects of process variables on material removal rate (MRR)*

Figure 1 shows the Pareto chart of the effects corresponding to the MRR parameter. As can be seen clearly, all bars in the diagram which go beyond the reference line (0.00000705) are statistically significant at 95 % of confidence level. Therefore, there are three significant effects which were in the ascending order of contribution, namely peak current (A), polarity (C) and interaction between peak current (A) and polarity (C). The graph indicates clearly that the interaction factors of AB, ABC, BC and B brought less impact on the material removal rate for the tungsten carbide workpiece. Figure 2 shows the interaction plot for the MRR. It can be observed that there is a strong interaction between peak current and polarity (due to non-parallel lines). The MRR is minimised when the peak current with positive polarity is kept at high level (3.0A). The maximum MRR is obtained when the peak current with negative polarity is set at high level. It can also be seen that there is an interaction between pulse duration and polarity but they were not significantly effect the MRR due to the line pattern is almost parallel.

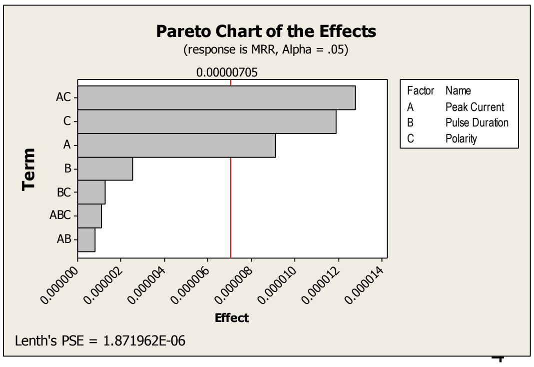

Figure 1: Pareto chart of the effects to MRR

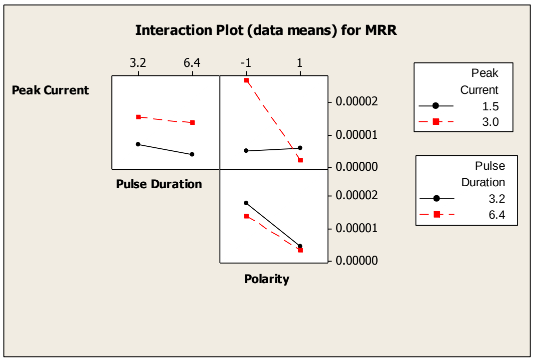

Figure 2: Interaction plot for MRR

From the result, it can be observed that the most significant factor influence material removal rate is interaction between peak current and polarity, followed by polarity and peak current individually.

In the case of polarity, the MRR increases significantly when the negative electrode polarity is used. According to Lee and Li (2001), this is more desirable because the material removal rate is high, and the relative wear ratio is lower than using a positive electrode. The negative polarity also yields a better surface finish. In EDM of tungsten carbide, better machining performance is obtained with the tools as cathode and the workpiece as anode.

Besides that, the material removal rate also tends to increase with the factor of peak current. This tendency has been expected to occur as such this phenomenon ever been reported in the previous work for the other types of materials. The reason of MRR increased with the increase of peak current is due to the fact that the spark discharge energy is increased to facilitate the action of melting and vaporisation, and advancing the large impulsive force in the spark gap, thereby increasing the MRR as reported by Shankar et. al, 2004.

Moreover, the material removal rate decreases when the pulse on-time increased, although its influence is not significant. This is because the more non-sparking time means the less efficient cutting. According to Lee and Li (2001), the material removal rate is thus a function of the pulse duration.

(2) *Effects of process variables on electrode wear rate (EWR)*

Figure 3 shows the Pareto chart of the effects corresponding to the EWR parameter. There are two significant effects can be seen from the chart (at 95% level of confidence). The peak current (A) and interaction between peak current (A) and polarity (C) were dominant factors affecting the electrode wear. The graph indicates clearly that the rest of the effects or interaction effects contribute a less impact on electrode wear. Figure 4 shows the interaction plot for the electrode wear rate. From the figure, it can be seen clearly that there is a strong interaction between peak current and polarity whilst pulse duration and polarity also depict the similar non-parallel lines pattern. It is obviously can be seen that the polarity at different levels of peak current cause a different effect. The EWR is minimised when the peak current is kept at low level (1.5A) associated with the use of negative polarity.

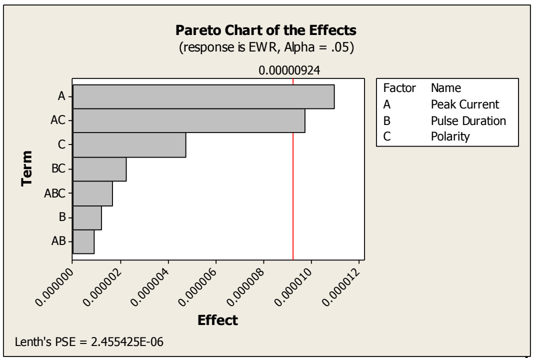

Figure 3: Pareto chart of the effects to EWR

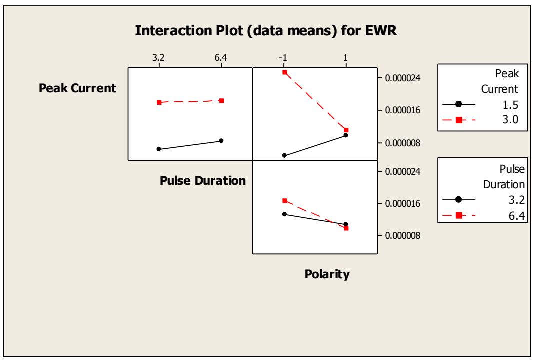

Figure 4: Interaction plot for EWR

From the results, the most significant factor influence the electrode wear is peak current, followed by interaction between peak current and polarity.

From the analysis, the results indicate that the relative wear ratio upwardly increases with increasing of current for the copper electrode. Lee and Li (2001) found that if the energy input is increased (peak current), the amount of debris in the gap can become too great. The particles can then form an electrically conducting path between the electrode and workpiece, causing unwanted discharges which become arcs, with consequential damage to both the electrode and workpiece. This will lead to the decreasing of material removal rate whilst the relative wear ratio is increased.

Besides that, with the increase of pulse on-time the electrode wear will be increased, even though the factor of pulse on-time, as noticed earlier, not being significant at 95% of confidence level. The reason for higher wear values with higher pulse duration setting can be explained by the generation of large craters due to large amounts of energy (Lee and Li, 2001). Findings by Puertas *et al* (2004) showed similar result where the value of electrode wear tends to increase when pulse on-time factor is increased.

In the case of polarity, the negative polarity produces a fairly constant relative wear ratio, whereas positive gives a generally decreasing trend. According to Lee and Li (2001), at high current settings, the value of the relative wear ratio for both negative and positive polarity electrodes converge and are quite close. This is more desirable because the material removal rate is high, and the relative wear ratio is lower than using a positive electrode. The use of negative polarity also produces a better surface finish.

(3) *Effects of process variables on diameter overcut*

Pareto chart as seen in figure 5 shows the significant factors affecting the diameter overcut. As can be seen clearly, there was only one significant effect on the diameter overcut which is polarity, (C). It is quite obvious from the graph that the other effects or interaction effects contribute a minor impact on the diameter overcut of tungsten carbide. The interaction plot for the diameter overcut is shown in figure 6. From the figure, it can be seen that the interaction between pulse duration and polarity is significant (due to non-parallel lines). The diameter overcut is minimised when the pulse on time is kept at low level (3.2µs) and the polarity is set at high level (positive polarity). Maximum overcut is obtained at negative polarity when the pulse on time is kept set at high level.

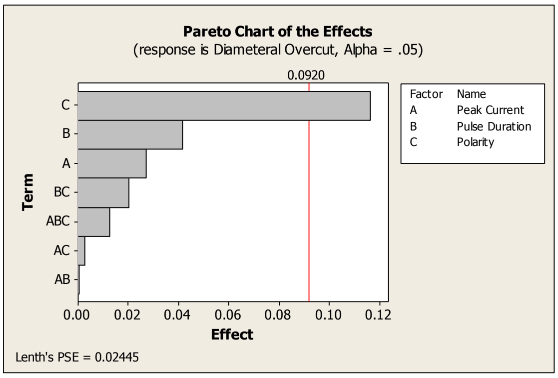

Figure 5: Pareto chart of the effects for diameter overcut

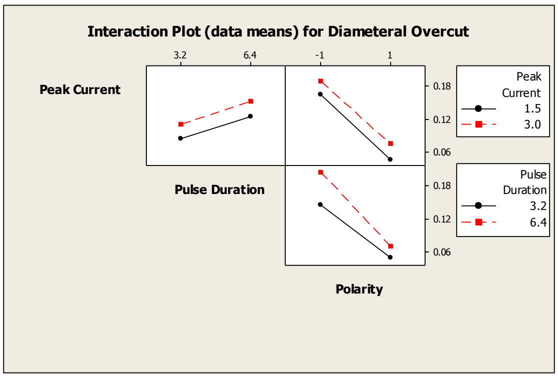

Figure 6: Interaction plot for diameter overcut

Jeswani (2004) noted that, the diameteral overcut is low due to the fact that at low current, erosion is less. As spark energy is low at low current, the crater formed on the work material is small in depth and hence results in good dimensional accuracy. From the above results, the most significant factor influence the overcut is polarity. The results show that in machining of tungsten carbide, the use of positive electrode polarity is more desirable.

From the analysis, it was observed that the value of overcut is decreased with decreasing current for electrodes. It is because less energy will be dissipated through the electrode. This means that the overcut will also decrease proportionally. Prolong pulse-on duration will significantly increase overcut due to the extension of the plasma channel and it appears to be more severe at areas surrounding the micro tool.

Lee *et al.,* (2004) noted that the electric spark occurs more readily at the bottom of the electrode. The value of the overcut is initially determined by the area affected by the electric spark. Increasing the current extends the affected area of the electric spark bombardment of the workpiece, and this result in an increased overcut value.

CONCLUSION

As a conclusion, the Design of Experiment (DOE) approach enabled the identification of significant factors and prediction of the variables at their best level. Based on the analysed results, it was observed that the most significant factors which will influence on material removal rate is interaction between peak current and polarity, polarity individually and followed by peak current whilst the pulse on-time factor was not significant at the considered confidence level. In order to obtain high amount of material removal rate for the case of tungsten carbide, high value of the peak current (3.0A) and negative electrode polarity should be used. In addition, the most significant factor that influences the electrode wear was peak current, followed by interaction between peak current and polarity, whilst the factor of pulse duration was less significant. The electrode wear can be reduced with the use of low value of peak current (1.5A) associated with employment of positive electrode polarity. In the case of diameter overcut, the most influential factor was polarity. The high precision of drilled micro-hole can be obtained when EDM of the tungsten carbide with low pulse on-time (3.2μs) and peak current (1.5A) setting associated with the use of positive polarity electrode.

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