24P

ونيۏرسيتي تيكنولوݢي مارا
UNIVERSITI TEKNOLOGI MARA

University Publication Centre (UPENA)

Journal of Mechanical Engineering

An International Journal

Volume 7 No. 1 July 2010 ISSN 1823-5514

JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Journal of Mechanical Engineering (ISSN 1823-5514) is jointly published by the Faculty of Mechanical Engineering (FKM) and University Publication Centre (UPENA), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

Journal of Mechanical Engineering

An International Journal

Volume 7 No. 1 **July 2010** **ISSN 1823-5514**

Journal of Mechanical Engineering *Vol. 7, No. 1, 81-90, 2010*

Effect of Discharge Current and Electrode Size on Material Removal Rate and Wear Ratio in Electrical Discharge Machining

Ahsan Ali Khan
*Mohammad Yeakub Ali**
Md. Mohafizul Haque
Department of Manufacturing and Materials Engineering
Faculty of Engineering
International Islamic University Malaysia
Kuala Lumpur, Malaysia
**Corresponding author / email: mmyali@iiu.edu.my*

ABSTRACT

In the present study the effect of electrode size and discharge current on material removal rate (MRR) and wear ratio (WR) during electrical discharge machining has been investigated. The work and electrode materials were mild steel and copper respectively. The diameters of the cylindrical electrodes were 9, 15, 20 and 30 mm. Experiments were conducted for three current values of 2.5, 3.5, and 6.5 A. MRR and WR were analyzed with respect to current density. Both MRR and WR were found to increase with the increase of current density. The trend lines are also expressed by two degree parabolic plots and equations. The models were found to be significant with the R-squared and p-values of 0.95 and 0.0001 respectively. Higher current density produces sparks of higher thermal energy which increases MRR and WR. For a constant current, an electrode of smaller diameter exhibited a higher MRR as well as WR.

Keywords: *EDM, Material removal rate, MRR, Electrode wear rate, EWR, Wear ratio, WR, Electrode diameter, Current density*

ISSN 1823-5514

Nomenclature:	
A	Current (A)
EDM	Electrical discharged machining
EWR	Electrode wear rate
J	Current density (A mm^{-2})
MRR	Material removal rate ($mm^3 min^{-1}$)
WR	Wear ratio

Introduction

In electrical discharge machining (EDM) material is removed by a series of electrical sparks between the electrode and the workpiece that develops a temperature 8000-12000°C. The unique feature of using thermal energy to machine electrically conductive parts regardless of their hardness has been the distinctive advantage of EDM in the manufacture of mold, die, and other automotive, aerospace and surgical components. The performance of EDM is usually evaluated by the output parameters such as material removal rate (MRR), electrode wear rate (EWR), wear ratio (WR) and machined surface roughness, etc. [1]-[3]. The definitions of MRR, EWR, and WR used in this research are expressed by Eqn. (1, 2, 3) respectively. It is desirable to obtain higher MRR with lower WR. With the electrical sparks, more material is removed from the work material because of its positive polarity. This material removal is measured as MRR. However, due to high temperature of the sparks, the electrode material is also melted and vaporized, which is expressed by EWR [4]. Due to this wear, electrodes loose their dimensions resulting inaccuracy of the formed cavities [2]. It is found that electrode wear along the length of the electrode is less compared to the same on the cross-section of the tool [5]. The later can be

$$MRR = \begin{array}{l} \textit{volume of work material removed per} \\ \textit{unit time per unit cross - sectioal area of electrode} \end{array} \tag{1}$$

$$EWR = \begin{array}{l} \textit{volume of electrode material removed per} \\ \textit{unit time per unit cross - sectioal area of electrode} \end{array} \tag{2}$$

$$WR = \frac{EWR}{MRR} \tag{3}$$

compensated by additional vertical feed of the electrode, but the wear along the length cannot be compensated and results inaccuracy of the machined cavity. Electrodes are made of wide varieties of materials. The common electrode materials are graphite, brass, copper and copper-tungsten alloys, etc. [6], [7]. Manufacturing of electrodes of special composition is expensive and requires many experiments to confirm their effectiveness. The electrode wear can be reduced by strengthening the surface of the electrode with high wear resistance coating [8]. A metal matrix composite ZrB_2-Cu was developed by adding different amount of Cu to get an optimum combination of wear resistance, electrical and thermal conductivity. It was reported that this composite with 40 wt% of copper shows high MRR with low WR [7]. Conductive diamond electrode was used at high current density (~10 $A.mm^{-2}$) to achieve very high MRR (~0.11 $mm^3.min^{-1}$) with insignificant electrode wear [9], [10]. Sensing the electrode wear and providing in-*situ* compensation is an alternative way of achieving high machining accuracy [11]. Multi-electrode discharging system was also reported to optimize MRR and WR substantially [12]. However, these processes are complex and expensive especially for the case of shape compensation [13]. Empirical and mathematical relationships of MRR, EWR, WR with EDM parameters such as current, voltage and pulse duration have been reported for different combination of work materials and electrodes [14]-[19]. However, most of these reports deal with EDM process parameters such as pulse-on time and pulse-off time. The present experimental research investigates the influence of electrode diameter and discharge current on MRR and WR for mild steel work material and copper electrode.

Experimental Details

In the present study of EDM die sinking, the work and electrode materials were mild steel and copper respectively. The general properties of these two materials are shown in Table 1. In order to investigate the influence of diameter of the electrode on the EDM performance, copper electrodes were made with diameters of 9, 15, 20, and 30 mm. The length of all electrodes was cut to 80 mm for convenience. For the ease of analysis, the discharge current was normalized by dividing the current values with the cross-sectional area of the electrodes.

Table 1: Properties of Mild Steel and Cooper

Property	Mild Steel	Copper
Composition (wt %)	C: 0.14-0.2, Mn: 0.6-0.9, P: 0.04, S: 0.05, Fe: balance	Cu: 99.7, Ag, Mg, P: balance
Specific gravity ($g.cm^{-3}$)	7.8	8.96
Melting point (^0C)	1523	1083
Thermal conductivity ($W.m^{-1}.K^{-1}$)	51.9	391
Specific heat capacity ($J.g^{-1}.C^{-1}$)	0.472	0.385
Electrical resistivity ($\mu\Omega.cm$)	1.74	1.96
Hardness (HRB)	143	80
Tensile strength (MPa)	475	220
Yield strength (MPa)	275	70

A CNC die sinking EDM (FX-K 4.1, Mitsubishi, Japan) was used to machine 2 mm deep cylindrical cavities for investigation of MRR and WR. The experiments were conducted for different values of discharge current and electrode diameters. The gap voltage, spark on-time and duty cycle were kept constant. The details of the machining conditions are listed in Table 2. The machining time for each of the cavity was recorded. Using an electric balance (B204-S Mettler Toledo,

Table 2: Die Sinking EDM Conditions

Control Factor	Values/description
Current (A)	2.5, 3.5, and 6.5
Electrode diameter (mm)	9, 15, 20, and 30
Fixed parameters	
Tool electrode material	Cooper
Work material	Mild steel
Spark on-time (μs)	5.5
Spark off-time (μs)	5.5
Gap voltage (V)	10
Duty cycle (%)	50
Polarity	Workpiece positive
Dielectric fluid	Kerosene
Machined cavity depth (mm)	2

Table 3: Measured MRR and WR for Different Current Densities

Experiment	Discharge current (*A*) (A)	*Current density (*J*) ($A.mm^{-2}$)	*MRR* ($mm^3.min^{-1}$)	*WR*
1	2.5	0.039	0.081	0.016
2		0.014	0.029	0.014
3		0.008	0.018	0.012
4		0.004	0.009	0.011
5	3.5	0.055	0.129	0.026
6		0.020	0.047	0.013
7		0.011	0.027	0.011
8		0.005	0.012	0.010
9	6.5	0.102	0.434	0.230
10		0.037	0.162	0.130
11		0.021	0.092	0.120
12		0.009	0.042	0.110

*Current density is the discharge current divided by the cross-sectional area of the electrode of diameter 9, 15, 20, 30 mm.

Switzerland), the workpiece and the electrode were weighed before and after each of the 12 experiments as listed in Table 3. Then using Eqn. (1-3), the MRR and WR were calculated and listed in Table 3.

Results and Discussions

Two responses namely MRR and WR were analyzed for the different level of discharge current density. Instead of handling two input variable such as electrode diameter and discharge current, the single input variable current density (discharge current divided by the cross-sectional area of the electrode) was analyzed. The trend lines and models for MRR and WR were established for the variation of current density as discussed in the following sub-sections.

Material Removal Rate (MRR)

The values of MRR were plotted against current density and categorized according to the input current 2.5 A, 3.5 A, and 6.5 A as shown in Figure 1. It can be seen that the MRR increases with the increase of current density. However, the level of MRR was higher and the trend was steeper for higher values of discharge current. Again, all of the MRR values were plotted together against the discharge

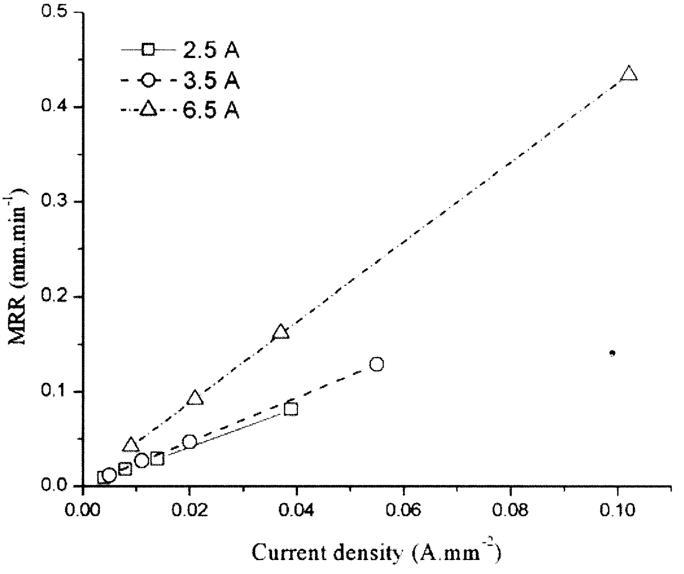

Figure 1: Plot of MRR vs. Current Density for Three Current Values of 2.5 A, 3.5 A, and 6.5 A

current density for the ease of analysis. Using computer software Origin (Microcal Inc.) a second order polynomial fit curve was drawn by regression as shown in Figure 2. The R-squared value and standard deviation of the fit curve were 0.948 and 0.03 respectively. The model for MRR, as expressed by Eqn. (4), was found to be 99.99% significant with its 0.0001 p value. The fit polynomial shows that the MRR increases sharply with the increase of discharge current density. In other words, the MRR increases with the decrease of electrode diameter. Therefore, for the simultaneous increase of discharge current and decrease of electrode diameter, the MRR increases very sharply.

$$MRR = 0.01282 + 1.485 * J + 25.22 * J^2 \tag{4}$$

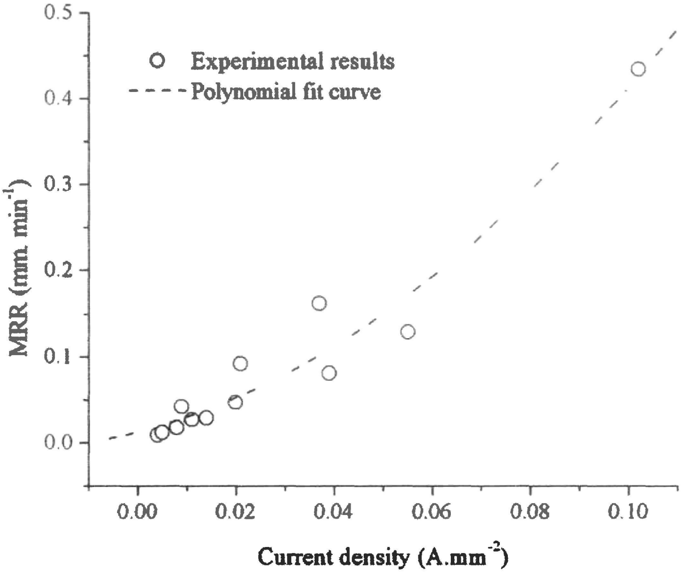

Figure 2: Plot of MRR vs. Current Density and Polynomial Fit Curve for All Current Values

Wear Ratio (WR)

Similar to MRR, the WR and current density (Table 3) were plotted as shown in Figure 3. WR increases with the increase of current density but the trend is less steep (Figure 3) compared to that of MRR (Figure 2). However, there are two different levels of WR with the similar trend. For the higher current the EWR was high and hence the WR was also very high. Polynomial fit curves for both set of the scattered points were drawn (Figure 3). The models for the estimations of WR for both low and high level of discharge current were also developed as

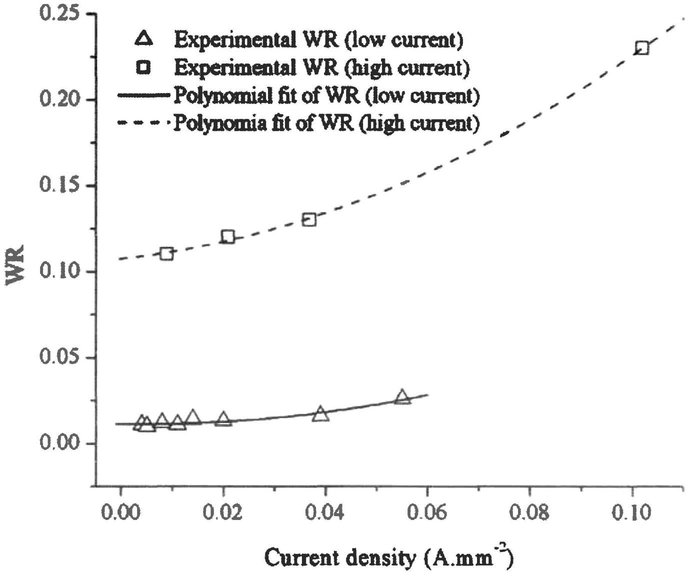

Figure 3: Plots of WR (Table 3) vs. Current Density for Low Current (2.5 A and 3.5 A) and High Current (6.5 A) with Their Polynomial Fit

expressed by Eqn. (5) and Eqn. (6) respectively. The R-squared values of these two models are 0.9394 (standard deviation 0.0015) and 0.9993 (standard deviation 0.00253). The two WR models, Eqn. (5) and (6), were found to be 99.99% and 97.4% significant with their 0.001 and 0.02624 p value respectively.

$$WR_{J\,low} = 0.0114 - 0.051 * J + 5.5 * J^2 \quad (5)$$
$$WR_{J\,high} = 0.1074 + 0.3194 * J + 8.64 * J^2 \quad (6)$$

Conclusions

In this research the influence of electrode size and discharge current on MRR and WR was investigated. The discharge current was normalized by diving with the cross-sectional area of the electrode which is called current density. This normalization was done for the ease of analysis with single input variable. The values of current and four electrode diameter were used for the calculation of current density to eliminate any influence of a single value of current and single electrode diameter. From this present work, the following conclusions can be made.

1. MRR increases with the increase of current density. Both higher discharge current and or smaller electrode diameter resulted into high current density.

This high current density causes quick material removal and increases the MRR.

2. Under the same machining conditions, the WR of smaller diameter electrode is higher than that of an electrode of larger diameter. The heat concentration for an electrode of smaller diameter is higher than that of a larger diameter that results more EWR and hence WR.
3. The empirical models, Eqn. (4-6), showed that both MRR and WR decrease with the increase in diameter of the electrode. It indicates that an electrode of smaller diameter undergoes more wear compared to the electrode of larger diameter.
4. High MRR and very low EWR are expected for industrial applications of EDM such as for mold and die making. As current density increases both MRR and EWR, lower current density is to be selected for higher accuracy and shape geometries of mold and die.

Acknowledgement

This research was funded by Research Management Centre of International Islamic University Malaysia under the grant EDWB 0701-13.

References

[1] Marafona, J. and Wykes, C.A. (2000). 'New Method of Optimizing Material Removal Rate using EDM with Copper-tungsten Electrodes', *International Journal of Machine Tools and Manufacture*, Vol. 40, No. 2, 153-164.

[2] Ho, K.H. and Newman, S.T. (2003). 'State of Art Electrical Discharge Machining (EDM)', *International Journal of Machine Tools and Manufacture*, Vol. 43, No. 13, 1287-1300.

[3] Dhanik, S., Joshi, S.S., Ramakrishnan, N. and Apte, P.R. (2005). 'Evolution of EDM process modelling and development towards modelling of the micro-EDM process', *International Journal of Manufacturing Technology and Management*, Vol. 7, No. 2/3/4, 157-180.

[4] Khan, A.A. and Mridha, S. (2007). 'Performance of Copper and Aluminum Electrodes during EDM of Stainless Steel and Carbide', *The International Journal for Manufacturing Science and Production*, Vol. 7, No. 1, 1-7.

[5] Khan, A.A. (2008). 'Electrode Wear and material Removal Rate during EDM of Aluminum and Brass Electrodes', *International Journal of Advanced Manufacturing Technology*, Vol. 39, No. 5-6, 482-487.

[6] Haron, C.C.H., Ghani, J.A., Burhanuddin, Y., Seong, Y.K. and Swee, C.Y. (2008). 'Copper and graphite electrodes performance in electrical-discharge machining of XW42 tool steel', *Journal of Materials Processing Technology*, Vol. 201, No. 1-3, 570-573.

[7] Khanra, A.K., Sarker, B.R., Bhattacharya, B., Pathak, L.C. and Godkhindi, M.M. (2007). 'Performance of ZrB2–Cu Composite as an EDM electrode', *Journal of Materials Processing Technology*, Vol. 183, No. 1, 122-126.

[8] Guo, D.M., Zhang, M., Jin, Z.J. and Zuo, B.X. (2008). 'Particle strengthening of the surface of copper electrode for electrical discharge machining', *International Journal of Materials and Product Technology*, Vol. 31, No. 1, 81- 87.

[9] Suzuki, K., Iwai, M., Sharma, A., Sano, S. and Uematsu, T. (2006). 'Low-wear diamond electrode for micro-EDM of die-steel', *International Journal of Manufacturing Technology and Management*, Vol. 9, No. 1/2, 94-108.

[10] Suzuki, K., Sharma, A., Iwai, M., Uematsu, T., Shoda, K. and Kunieda, M. (2004). 'Electrical discharge machining of using electrically conductive CVD diamond as an electrode', *New Diamond and Frontier Carbon Technology*, Vol. 14, No. 1, NDFCT 443.

[11] Bleys, P., Kruth, J.P. and Lauwers, B. (2004). 'Sensing and compensation of tool wear in milling EDM', *Journal of Materials Processing Technology*, Vol. 149, No. 1-3, 139-146.

[12] Kunieda, M. and Muto, H. (2000). 'Development of multi-spark EDM', *Annals of CIRP*, Vol. 49, No. 1, 119-122.

[13] Yu, Z., Jun, T. and Kunieda, M. (2004). 'Dry electrical discharge machining of cemented carbide', *Journal of Materials Processing Technology*, Vol. 149, 353-357.

[14] Iuliano, L., Violante, M.G., Gatto, A. and Bassoli, E. (2008). 'Study of the EDM process effects on aluminium alloys', *International Journal of Manufacturing Technology and Management*, Vol. 14, No. 3/4, 326-341.

[15] Kang, S.H. and Kim, D.E. (2003). 'Investigation of EDM characteristics of nickel-based heat resistant alloy', *Journal of Mechanical Science and Technology*, Vol. 17, No. 10, 1475-1484.

[16] Kansal, H.K., Singh, S. and Kumar, P. (2005). 'Application of Taguchi method for optimisation of powder mixed electrical discharge machining', *International Journal of Manufacturing Technology and Management*, Vol. 7, No. 2/3/4, 329-341.

[17] Kunieda, M. and Kobayashi, T. (2004). 'Clarifying mechanism of determining too electrode wear ratio in EDM using spectroscopic measurement of vapor density', *Journal of Materials Processing Technology*, Vol. 149, 284-288.

[18] Ramasawmy, H. and Blunt, L. (2001). '3D Surface characterization of electropolished EDMed surface and quantitative assessment of process variables using Taguchi methodology', *International Journal of Machine Tools and Manufacture*, Vol. 42, No. 10, 1129-1133.

[19] Puertas, I., Luis, C.J. and Alvarez, L. (2004). 'Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co' *Journal of Materials Processing Technology*, Vol. 153-154, 1026-1032.

[15] Kang, S.H. and Kim, D.E. (2003). 'Investigation of EDM characteristics of nickel-based heat resistant alloy', *Journal of Mechanical Science and Technology*, Vol. 17, No. 10, 1475-1484.

[16] Kansal, H.K., Singh, S. and Kumar, P. (2005). 'Application of Taguchi method for optimisation of powder mixed electrical discharge machining', *International Journal of Manufacturing Technology and Management*, Vol. 7, No. 2/3/4, 329-341.

[17] Kunieda, M. and Kobayashi, T. (2004). 'Clarifying mechanism of determining too electrode wear ratio in EDM using spectroscopic measurement of vapor density', *Journal of Materials Processing Technology*, Vol. 149, 284-288.

[18] Ramasawmy, H. and Blunt, L. (2001). '3D Surface characterization of electropolished EDMed surface and quantitative assessment of process variables using Taguchi methodology', *International Journal of Machine Tools and Manufacture*, Vol. 42, No. 10, 1129-1133.

[19] Puertas, I., Luis, C.J. and Alvarez, L. (2004). 'Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co' *Journal of Materials Processing Technology*, Vol. 153-154, 1026-1032.