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A STUDY OF ELECTRODE SHAPE CONFIGURATION ON THE PERFORMANCE OF DIE SINKING EDM

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ABSTRACT

This paper discusses the performance of die sinking EDM due to the shape configuration of the electrode. The effect of electrode shape on material removal rate (*MRR*), electrode wear rate (*EWR*), wear ratio (*WR*), and average surface roughness (R_a) has been investigated for mild steel work material and copper electrode. The shapes of the electrodes were round, square, triangular, and diamond of constant cross-sectional area of 64 mm^2. Experiments were repeated for three current values of 2.5, 3.5, and 6.5 A. The highest *MRR* was found for round electrodes followed by square, triangular and diamond shaped electrodes. However, the highest *EWR* and *WR* were found for the diamond shaped electrodes. The minimum surface roughness was found for the round electrodes followed by square, triangular and diamond shaped electrodes. However, the influence of the shape of the electrodes on surface roughness was found to be insignificant.

***Keywords*:** EDM, Material removal rate, Electrode wear, Electrode shape configuration, Surface roughness

NOMENCLATURE

A	Current (A)
EDM	Electrical discharged machining
EWR	Electrode wear rate (mm^3.min^{-1})
MRR	Material removal rate (mm^3.min^{-1})
R_a	Average surface roughness (µm)
WR	Wear ratio (*EWR* ÷ *MRR*)

1. INTRODUCTION

Die sinking electrical discharge machining (EDM) is one of the most widely used techniques for the fabrication of die and mold cavities which are finally used for mass production of metals and polymer products by replication such as die casting, injection molding, etc. In any replication process, it is expected that the quality mold will faithfully duplicate its shape and surface texture. Inaccurate duplications cause problems in assemblies, operations as well as lower the aesthetic view. In die sinking EDM the electrode produces exactly its opposite shape on the work material. For the case of complex shaped mold cavities, the machining effectiveness or performance of die sinking is not uniform all over the machining area. The machining performance for the intricate areas such as sharp or pointed corner, flat or pointed areas of electrode, is obviously different because of different concentration of heat and current density. The performance of EDM is usually evaluated by the output parameters namely material removal rate (*MRR*), electrode wear rate (*EWR*), wear ratio (*WR*), machined surface roughness, etc. [1-3]. The usual definition of *MRR*, *EWR*, *WR* and R_a are used in this research and expressed in nomenclature. It is always desirable to obtain higher *MRR* with lower *EWR*, *WR*, and R_a. With the electrical sparks, more material is removed from the work material because of its positive polarity. 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 electrode [5]. The former can be compensated by additional vertical feed, but the wear along the cross-section cannot be compensated and it results inaccuracy of the machined cavity. Electrodes are made of wide varieties of materials. The common electrode materials are graphite, brass, copper, copper-tungsten alloys, etc. [6]. 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 [7]. 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 showed high *MRR* with low *WR*. 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 [8]. Sensing the electrode wear and providing compensation is an alternative way of achieving high machining accuracy. Use of multi-electrode discharging system can also optimize *MRR* and *EWR* substantially [9]. However, these processes are complex and expensive especially for the case of shape compensation [10]. Empirical and mathematical relationships of *MRR*, *EWR*, *WR* with EDM parameters such as current, voltage, pulse duration, etc. have been reported for different combination of work materials and electrodes [10-13]. However, most of these reports deal with EDM process parameters. The present experimental research investigates the influence of electrode shape configuration under a constant current density on *MRR*, *EWR*, and R_a for mild steel work material.

2. EXPERIMENTAL DETAILS

In the present study of EDM die sinking, the work and electrode materials were mild steel and copper respectively. The properties of these two materials are shown in Table 1. In order to investigate the influence of shape configuration of the electrode on the EDM performance, electrodes were made with circular, square, triangular, and diamond shape as shown in Figure 1. The cross-sectional areas of the electrodes were kept constant to 64 mm^2 for all shapes. The length of all electrodes was cut to 80 mm for convenience. Consequently, the peripheral length of the round, square, triangular and diamond shapes were 28.27 mm, 32 mm, 36.47 mm and 45.25 mm respectively. The details of the machining conditions are listed in Table 2. A CNC die sinking EDM (FX-K 4.1, Mitsubishi, Japan) was used to machine 2 mm deep cavities for investigation of four response parameters as listed in Table 3. The experiments were conducted for different electrode shapes of constant cross-sectional area. For the constant gap voltage, spark on-time and duty cycle, the experiments were repeated for three different values of discharge current. The machining time for each of the cavity was recorded. Using an electric balance (B204-S Mettler Toledo, Switzerland), the workpiece and the electrode were weighed before and after each of the 12 experiments. Then the *MRR*, *EWR* and *WR* were calculated and listed in Table 3. The surface roughness of the machined area was measured by using a surface profiler (Surftest SV-500, Mitutoyo, Japan) as recorded in Table 3. The corner wear of the electrodes along the length and cross-section was measured using scanning electron microscope (SEM) (JSM 56000, JEOL, Japan).

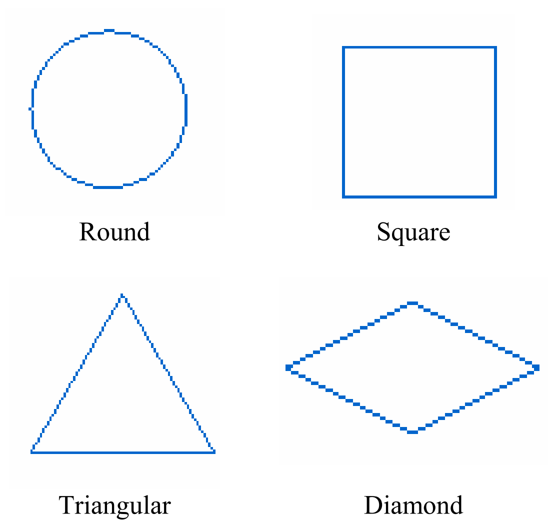

Figure 1. Selected shape configurations of electrode for die sinking EDM.

Table 1. Properties of Mild steel work material and cooper electrode.

Property	Mild Steel	Copper
Composition (wt%)	C: 0.14-0.2, Mn: 0.6-0.9, P: 0.04, S: 0.05, Fe: balance	Ag, Mg, P: 0.2-0.3 Cu: 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 (μΩ.cm)	1.74	1.96
Hardness (HRB)	143	80
Tensile strength (MPa)	475	220
Yield strength (MPa)	275	70

Table 2. Die sinking EDM conditions.

Control Factor	**Values/description**
Current (A)	2.5, 3.5, and 6.5
Electrode shape (peripheral length in mm)	Round (28.27), square (32), Triangular (36.47), and diamond (45.25)
Electrode cross-sectional area (mm^2)	64
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

3. RESULTS AND DISCUSSIONS

Four responses *MRR*, *EWR*, *WR*, and R_a were analyzed for the different shapes of electrodes and three different levels of discharge current. The trends of these responses are discussed in the following sub-sections.

3.1. Material Removal Rate

MRR with electrodes of different shapes at different currents are shown in Fig.2. It is obvious that *MRR* increased significantly with the increase of current. A higher current will produce a stronger spark with higher thermal energy that results more *MRR*. However, for the shape configuration, the highest *MRR* was found for round electrodes followed by square, triangular and diamond shaped electrodes. Diamond shaped electrodes had the largest peripheral area that allowed faster heat loss to the surroundings. As a result, less heat is available for material removal compared to the other electrodes.

3.2. Electrode Wear Rate

EWR results inaccuracy of the shape and size of the cavity machined by EDM. It was found that electrode wear along the cross-section of the tool is more compared to the same along the length of the electrode [Khan, 2008]. The later can be compensated by additional vertical feed of the electrode, but the wear along the cross-section cannot be compensated and results inaccuracy of the machined cavity. EWR of different shaped electrodes is shown in Figure 3. The maximum wear was observed for diamond shaped electrodes followed by triangular, square and round shaped electrodes. Sharp corner angles of diamond shaped electrodes causes high heat concentration resulting more electrode melting and vaporization. An intensive corner wear of diamond shaped electrodes compared to the round shaped one can be observed from Figure 4.

3.3. Wear Ratio

The values of *MRR* and *EWR*, *WR* were calculated. Then the influence of the shape of electrodes on *WR* is plotted against discharge current as shown in Figure 5. For any machining parameter the highest *WR* was found for the diamond shaped electrode followed by the triangular, square and the round shaped electrodes. The similar trend is observed for all three discharge current values. For the discharge current of 6.5 A, the *WR* of a diamond shaped electrode is found to be 1.7 times to that of a round shaped electrode. For the lower current, the influence of shape on *WR* is less significant. Violent sparks at high discharge current damage the sharp corner.

3.4. Surface Roughness

The measured R_a surface roughness values produced by electrodes of different shape configurations are shown in Figure 6. It can be seen that the R_a sharply increases with the increase of current. A higher current produces stronger spark that makes a crater of higher depth. Consequently, the surface becomes rougher. The highest surface roughness was found to be produced by the diamond shaped electrode followed by the triangular, square and round shaped electrodes. Temperature distribution along the cross-section of a round shaped electrode is more uniform than electrodes of other shapes. This causes more uniform sparks and results smoother surface. However, the influence of electrode shape on surface roughness is not significant.

Table 3. Measured *MRR*, *EWR*, *WR*, and R_a.

Input			Response			
Ex. No	Shape *	Current (A)	*MRR*	*EWR*	*WR*	R_a (µm)
1	○	2.5	7.14	0.114	0.016	0.16
2	□		6.35	0.152	0.024	0.19
3	Δ		5.36	0.177	0.033	0.21
4	◊		5.12	0.266	0.052	0.22
5	○	3.5	10.4	0.271	0.026	1.24
6	□		9.5	0.323	0.034	1.27
7	Δ		8.92	0.410	0.046	1.27
8	◊		8.23	0.502	0.061	1.36
9	○	6.5	29.1	6.700	0.230	2.45
10	□		28.9	7.798	0.270	2.66
11	Δ		28.1	8.155	0.290	2.87
12	◊		27.6	10.76	0.390	3.23

* Cross-sectional area (mm^2): 64 (for all shape)

Peripheral length (mm): 28.27 (round), 32 (square), 36.47 (triangular) and 45.25 (diamond), Unit of MRR, EWR: $mm^3.min^{-1}$

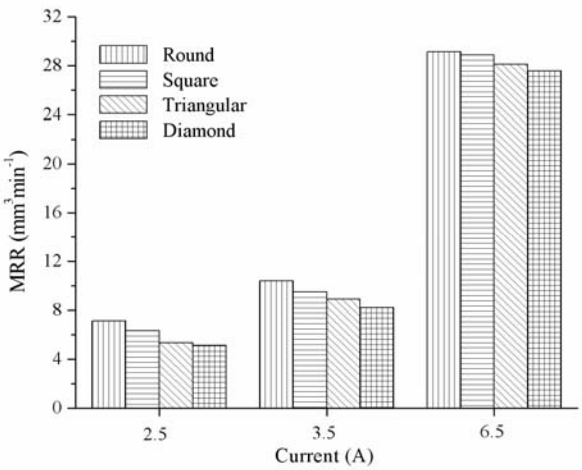

Figure 2. Comparison of MRR in die sinking EDM with different electrode shape configurations.

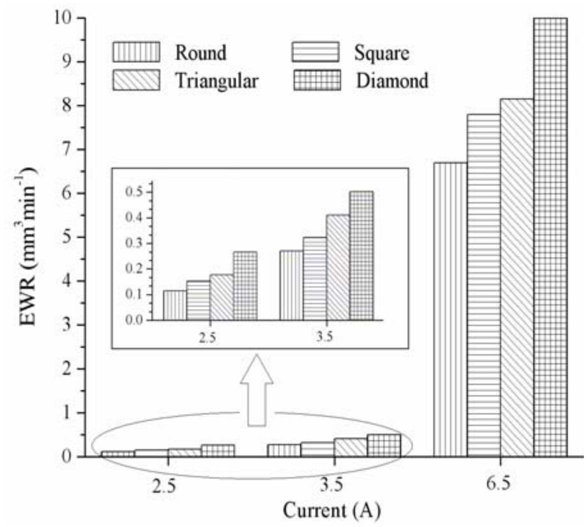

Figure 3. Comparison of EWR in die sinking EDM with different electrode shape configurations.

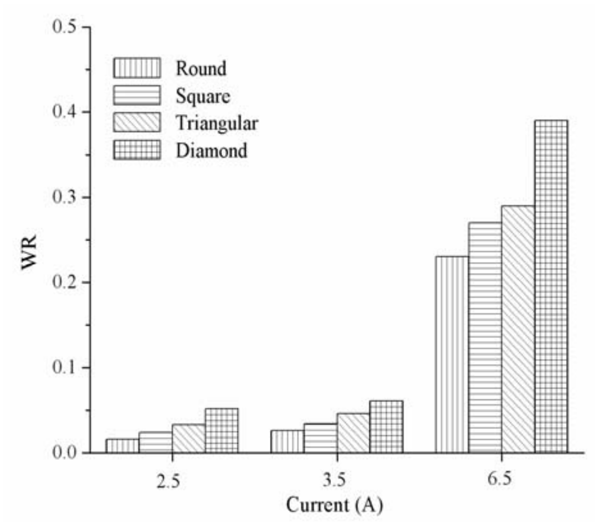

Figure 5. Comparison of WR in die sinking EDM with different electrode shape configurations.

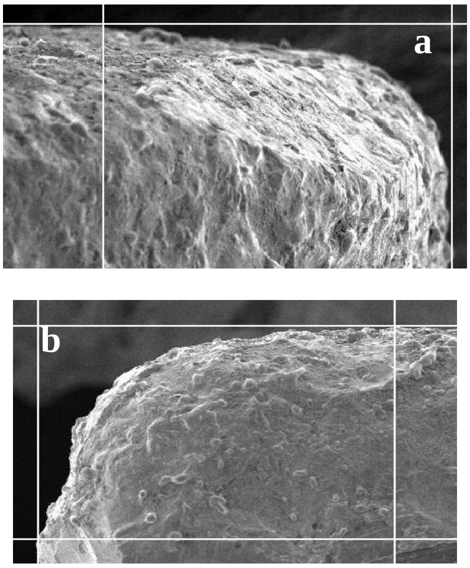

Figure 4. SEM micrographs of electrode wear due to die sinking EDM with 2.5 A current for (a) round and (b) diamond shape configurations.

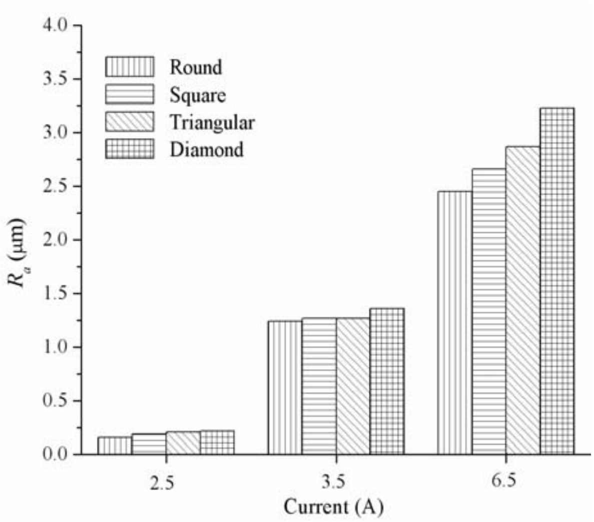

Figure 6. Comparison of R_a surface roughness due to die sinking EDM with different electrode shape configurations.

4. CONCLUSIONS

In this research the influence of electrode shape and discharge current on *MRR* and *WR* was investigated. Electrodes of four different shapes of constant cross-sectional area were used for experiment with different discharge current. The *MRR*, *EWR*, *WR*, and surface roughness were measured and analyzed. The following conclusions can be made from this experimental research.

1. For round shaped electrodes *MRR* was the maximum followed by the square, triangular and the diamond shaped electrodes. Diamond shaped electrode has the largest peripheral length compared to the other electrodes which results more heat loss to the surrounding and finally causes low *MRR*.
2. A round shaped electrode undergoes less wear followed by the square, triangular and the diamond shaped electrodes. It is because of no vulnerable sharp corner at the sparking tip.
3. *WR* was the highest for the diamond shaped electrode followed by the triangular, square and the round shaped electrodes.
4. The influence of the shape of electrodes on surface roughness is found to be insignificant. However, a round shape electrode produces a smoother surface followed by the square, triangular and the diamond shaped electrodes.
5. Cavities made by EDM die sinking may have intricate shapes and it is difficult to achieve high accuracy at the sharp corner of the cavities. The

single irregular electrode contains several geometries such as flat, round, square surface, pointed tip, etc. which removes materials with different effectiveness. The present paper proposes to carefully select the EDM parameters for machining cavities with multiple and intricate shaped electrodes.

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