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EFFECT OF DIFFERENT ELECTRODE SHAPE VARIATION ON SURFACE ROUGHNESS OF MILD STEEL DURING EDM

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Abstract: EDM machining process that removes metals by electric spark erosion is widely used in automotive and aerospace industries. Such industries demand parts that follow very stringent tolerances for dimensions and topology. Many research involving state-of-the-art methods (numerical, computational, or experimental etc.) have been carried out to predict and compare surface roughness variation. This research has been conducted to compare the variation of surface roughness produced in EDM of mild steel specimens using two different type of electrode shape of circular and rectangular copper electrode. Machining was performed on a CNC JS EDM machine, commonly used for industrial production of dies and molds. Three machining parameters: Pulse on (T_{on}), Pulse off (T_{off}), and Gap Voltage (V) were used to investigate the effect of process parameter on surface roughness for two different shape electrodes. Surface roughness values (R_a) were measured using surface Profilometer and a novel Digital Image Processing (DIP) technique, previously developed by the authors. The surface roughness produced in both the cases was then compared and it was observed that better surface finish was attained in the case of the round electrode.

Keywords: EDM, Surface Roughness, Machining Parameters, Digital Image Processing, Electrode Shape

INTRODUCTION

Electrical-Discharge Machining is one of the oldest and most widely used unconventional machining processes. The usefulness of this method stems from the fact that no contact between the work-piece and tool is necessary for the machining to occur [1]. Thus, no mechanical cutting forces are necessary to remove unwanted material. This has led to the use of EDM in a manifold of industrial applications such as: machining of dies and tools, aerospace and automotive components, mirror finishing, and machining involving transient and tough alloys [2]. Since, material is removed by fusion and vaporization, by plasma discharges through the dielectric, miniature crater formation at the machining site is unavoidable. Such rough surface, if unchecked, can lead to sliding friction between moving surfaces and ultimately to heat generation, wear, and failure. These phenomena are also a source of energy loss and additional head costs at industries [3]. Many research works carried out for the prediction and optimization of the surface roughness in different machining processes [4]. Alauddin et al. [5] used Response Surface Methodology (RSM) and ANOVA to predict the surface finish in end-milling of Inconel 718. In this study Design Expert Software (DOE) has been used to conduct 13 experiments in order to build a statistical model for surface roughness. Suresh et al. [6] developed statistical models for milling operations. They were able to achieve valuable insight into the interaction of various machining parameters on machining response. Alam et al. [7] used RSM to model surface roughness produced in high speed end milling of Ti-6Al-4V alloy and subsequently predicted the minimum roughness attainable using DF. There maximum desirability was 95.63%, which was experimentally verified using a 3 factors and 3 levels full factorial CCD model in DOE. The prediction and subsequent comparison of the resultant surface

roughness, is therefore, a crucial and important research area. Anayet U Patwari et al. [8] used a well known approach for the predicting surface roughness in End milling of medium carbon steel with Titanium Carbide Inserts. Their method was the utilization of Response Surface Methodology (RSM) and specifically a small Central Composite Design (CCD) for surface roughness model generation. The authors of this paper had previously used a similar 3 factors: T_{on} (On Time), T_{off} (Off Time), and V (Gap Voltage); and 5 level (-1.414, -1, 0, 1, 1.414) rotatable CCD model in RSM, to develop the mathematical model for predicting surface roughness, ' R_a ' produced using circular electrodes in machining mild steel specimens in EDM [9]. The DOE software, in this case, suggested a quadratic model based on insignificant lack of fit and a confidence level of 95% by ANOVA analysis. The predictions of the developed model was verified using both a surface Profilometer and a digital image processing technique developed by Anayet U Patwari et al. [10]. This research has been conducted to compare the variation of surface roughness produced in EDM of mild steel specimens using two different type of electrode shape of circular and rectangular copper electrode. Machining was performed on a CNC JS EDM machine, commonly used for industrial production of dies and molds. Three machining parameters: Pulse on (T_{on}), Pulse off (T_{off}), and Gap Voltage (V) were used to investigate the variation effect on surface profile. Surface roughness values (R_a) were measured using surface Profilometer and a novel Digital Image Processing (DIP) technique.

EXPERIMENTAL SETUP

EDM machine: For the EDM process, JS EB 600L CNC EDM, in the IUT machining laboratory was utilized. The advantage of this machine is that it has a built in computer terminal and software. Figure 1 is a photograph of the EDM machine used. For performing the

experiments the work piece, electrode and the dielectric fluid of the EDM machine was chosen very carefully after extensive literature review and commercial availability. In this study used kerosene as the preferred dielectric because it is cheap, available, and commonly used in industries.

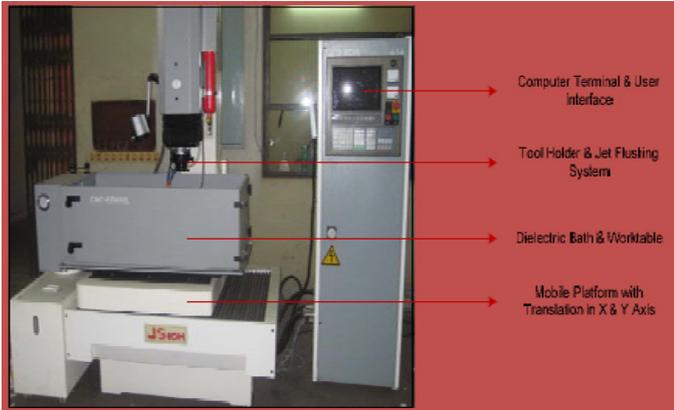


Figure 1: Photograph of the CNC EDM machine used.

EDM is mostly used to machine steel dies and tools. Thus, for this investigation and research purpose, mild steel was used as the work-piece material. A coarse mild steel plate was taken and it was grinded and polished accordingly to investigate the effects on electrode shape on surface roughness very carefully. The shape of the work piece dimensions is shown in figure 2.

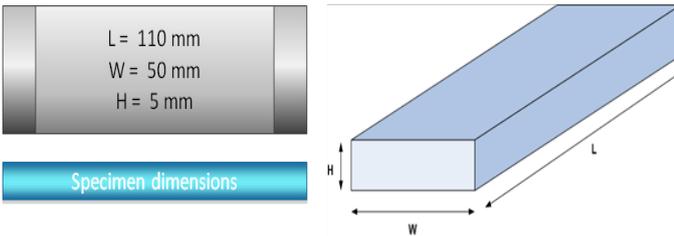


Figure 2: Work-piece specimen's dimensions

Electrode and Process parameter: The most common electrode materials for EDM are graphite and copper. Though graphite gives lesser electrode wear and good machinability compared to copper, copper electrode is used in this research as it gives greater material removal rate and is less costly. Two electrodes with the same cross-sectional area but different geometric shapes, circular and rectangular, were used. Figure 3 is a schematic of the electrodes' dimensions.

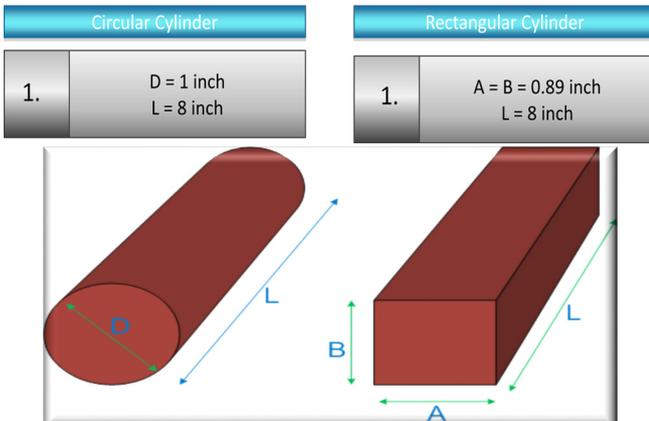


Figure 3: Schematics of the electrodes with dimensions

The different process parameters to investigate the effect of size of electrode on surface roughness are shown in Table 1.

Table 1: Different process parameters used in experimentation

No	Process parameters	Lowest	Low	Center	High	Highest
1	On T, T _{on}	80	120	300	700	1000
2	Off T, T _{off}	5	6	10	16	20
3	Gap Voltage, V (volts)	50	55	70	90	100

SURFACE ROUGHNESS MEASUREMENTS

The surface roughness of the machined mild steel specimens was measured using two different techniques: surface Profilometer and DIP. The DIP process, previously developed by the authors, was used as it greatly automated the measurement process and aided in visualization. The measurements of the surface Profilometer, a well established surface topography tool, were used as the benchmark for the DIP process. The Mitutovo SURFTEST was used, which is a contact Profilometer. It can measure small surface variations in vertical stylus displacement as a function of position. It can typically measure small vertical features ranging in height from 10 nanometers to 1 millimeter. The disadvantage of the profilometer is that it only samples a small linear section of the specimen. The surface roughness, in both cases, was measured using digital image processing [10]. Figure 4 illustrates the logic sequence for the DIP measurements.

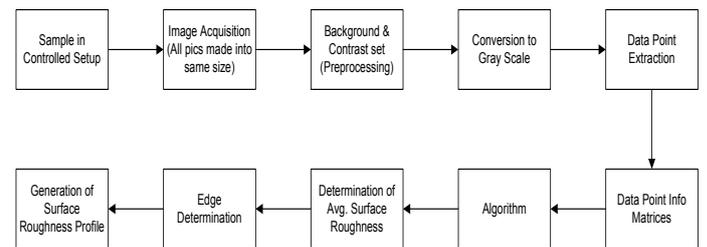


Figure 4: Flow diagram of the digital image processing [10] Image acquisition was done in a controlled setup and using a metallurgical microscope MMB 2300. Figure 5 shows the photograph of the microscope.



Figure 5: Photograph of the metallurgical microscope

On/off and brightness control
Digital image processing involves the application of computer logic and algorithm to analyze images. For the analysis, image processing toolbox efficiently processes the samples' images represented as n by m 2-D matrix form. The acquired RGB images were resized,

keeping their aspect ratios intact, to standardize the comparison. Grey scale and binary conversions were performed. The peaks and valleys of the surface roughness showed up as bright and dark regions in the grey scale images and stored each resized image as a 2-D matrix, where each column corresponded to a 'strip' of the image and contained pixel intensity values. The output matrices were then used to plot surface roughness profiles, surface contour maps, and 3-D contour surfaces. Figure 6 illustrate the typical graphical outputs for the purpose of visualization in DIP [10].

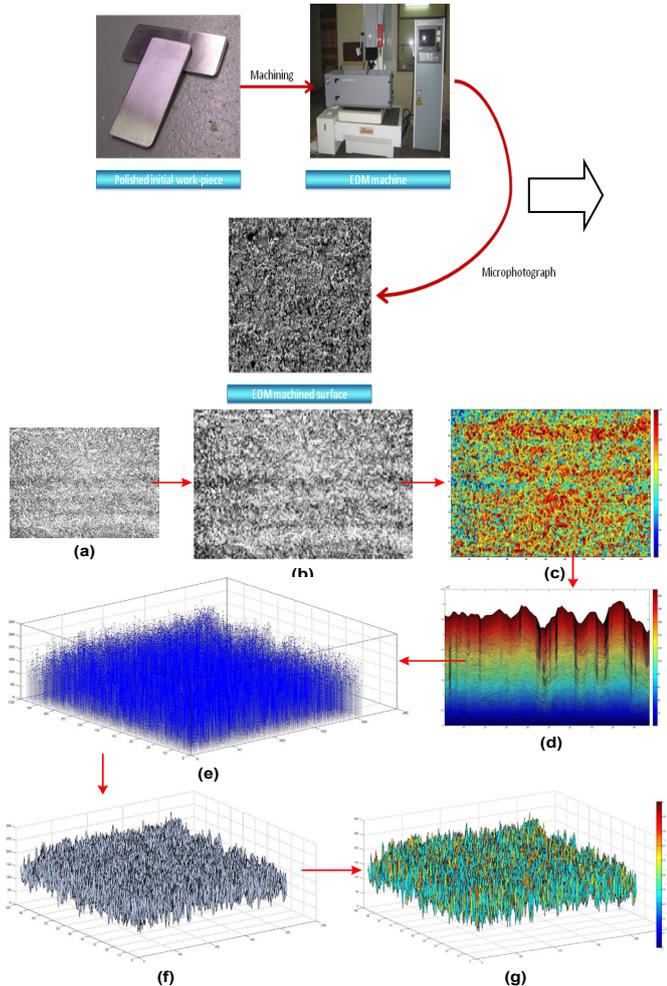


Figure 6: DIP results (a) microphotograph, (b) resized grayscale, (c) 2-D colored contour plot, (d) 2-D profile plot, (e) 3-D plot of datum points, (f) 3-D contour plot, and (g) 3-D colored contour plot

Surface Roughness Obtained:

Twelve experiments with different experimental conditions for circular and rectangular copper electrode has been conducted and the surface roughness measured using DIP and surface Profilometer are presented in Table 2.

Effect of Pulse on time:

Obtained Surface roughness (measured by DIP) at different Pulse On Time for the two electrode shapes are shown in figure 7. It was observed from that the pattern of surface roughness variation was similar for the two electrode shapes. In both cases the roughness decreased to a minimum and then increased as the Pulse on Time duration was increased.

Table: 2 Surface roughness obtained at different conditions

Process parameter			Circular Electrode		Rectangular Electrode	
On Time T_{on} (s)	Off Time T_{off} (s)	Gap Voltage V (volts)	R_a (μm) by DIP	R_s (μm) Profilometer	R_a (μm) by DIP	R_s (μm) Profilometer
700	16	55	0.86936	0.93	0.8985	0.9378
700	6	90	1.75418	1.713	2.467	2.3996
120	16	90	1.85893	1.8054	2.5521	2.5020
120	6	55	0.7882	0.842	0.8082	0.8510
300	10	70	1.03149	1.0021	1.0408	1.0012
300	10	70	1.03149	1.0021	1.0408	1.0021
80	10	70	1.62322	1.5452	2.026	1.9789
1000	10	70	1.40124	1.37	1.7051	1.6534
300	5	70	0.69486	0.7412	0.7488	0.7898
300	20	70	0.77588	0.8245	0.8267	0.8612
300	10	50	1.20866	1.165	1.2311	1.1878
300	10	100	1.60369	1.51	1.8813	1.8210

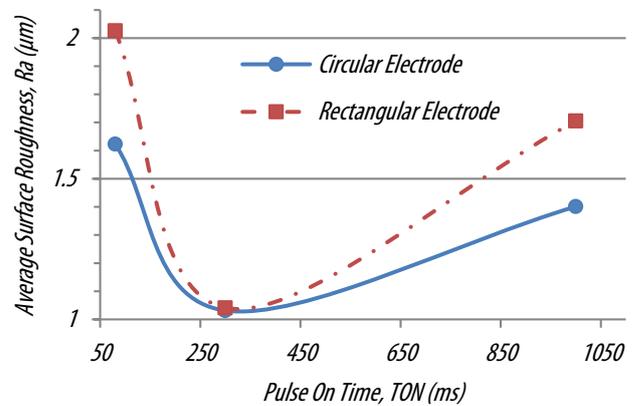


Figure 7: Average Surface Roughness, 'Ra' vs. Pulse On Time, 'TON' Plots for Circular and Rectangular Electrodes

It was also apparent that the resultant surface roughness was higher when rectangular electrode was used. To standardize the comparison and to study the influence of only T_{ON} on R_a the other two machining parameters' values (T_{OFF} and V) were set to constant.

Effect of Pulse off time:

Obtained average surface roughness (measured by DIP) is plotted against different Pulse Off Time for the two electrode shapes are displayed in figure 8.

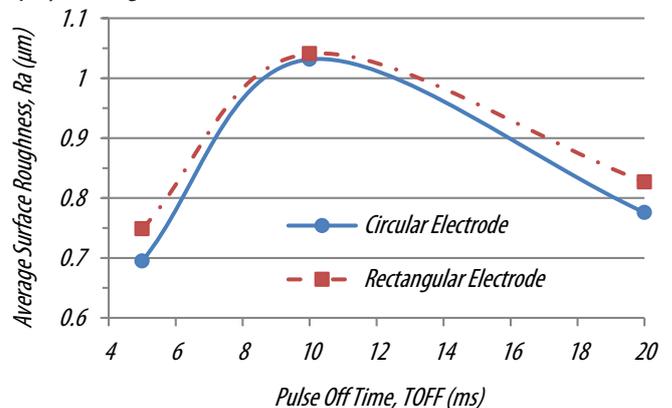


Figure 8: Average Surface Roughness, 'Ra' vs. Pulse Off Time, 'TOFF' Plots for Circular and Rectangular Electrodes

It was observed from the above graph that the pattern of surface roughness variation was similar for the two electrode shapes. In both cases the roughness increased to a maximum and then decreased as the Pulse Off Time duration was increased. It was also apparent that the resultant surface roughness was higher when rectangular electrode was used. To standardize the comparison and to study the influence of only T_{OFF} on R_a the other two machining parameters' values (T_{ON} and V) were set to Constant.

Effect of Gap voltage:

The one factor plots of resultant surface roughness (measured by DIP) vs. Gap Voltage for the two electrode shapes are displayed in figure 9 below: This time, it was observed in the graph, below, that the pattern of surface roughness variation was again similar for the two electrode shapes. In both cases the roughness decreased to a minimum and then increased as the Gap Voltage was increased. It was also apparent that the resultant surface roughness was higher when rectangular electrode was used. To standardize the comparison and to study the influence of only V on R_a the other two machining parameters' values (T_{ON} and T_{OFF}) were set to Constant.

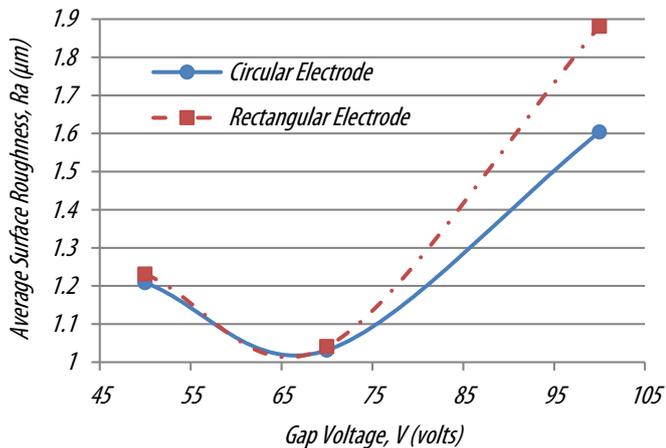


Figure 9: Average Surface Roughness, 'Ra' vs. Gap Voltage, 'V' (One Factor) Plots for Circular and Rectangular Electrodes

It has been observed from the surface roughness plots for the two electrode shapes, that roughness was usually higher in the case of the rectangular electrode but the trends of the two graphs were similar.

CONCLUSIONS

The findings, of this research, suggest that the average surface roughness is greater when the rectangular electrode is used. This could be due to the concentration of electric field at the sharp edges of the rectangular electrode. The similarity of shape of the two electrodes, however, implies that the effect of the three machining parameters, investigated, is similar in case of both electrode shapes.

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