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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF PROCESS PARAMETERS ON THE CHARACTERISTICS OF SQUARE HOLES

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ABSTRACT
Electrical Discharge Machining (EDM) is a non-traditional machining method in which material removal occurs through melting and vaporization of small amounts of metal due to the instantaneous high temperature generated during pulsed electric discharge. It has unique advantages such as non contact processing, no limitations on material strength and hardness, and high machining precision. As a result, EDM is increasingly used for high precision machining of difficult-to-cut materials in the aerospace, and mold manufacturing industries. From the literature, the material removal in deep holes slows down due to debris entrapment since it is a blind hole there is not much effective flushing as there is only a narrow gap to escape. Consequently, machining time increases with depth. In this study, an attempt has been made to improve the machining efficiency by varying input parameters such as Pulse on time and Current while maintaining a constant depth of 20 mm. The experiments were designed and conducted based on a full factorial design of experiments. Results indicate that as Pulse on Time increases, the Material removal rate decreases, Surface Roughness increases and Squareness slightly deviates. In contrast, increasing the discharge current leads to a higher MRR, reduction in surface roughness,and an initial decrease followed by an improvement in Squareness accuracy.

Keywords:
Blind hole,Current,Electrical Discharge Machining,Squareness,Surface Roughness

1. Introduction

Nowadays most of the products manufactured by machining processes which include material removing processes like milling, turning, boring, drilling, broaching, sawing, shaping, planing, reaming and taping are performed on machine tools. In material removing mechanism, the temperature and force generated play critical role in deciding tool life which leads to quality of product. Quality of a product characterizes as surface roughness, shape and size of product, tolerance limit and aesthetic features. Quality of a product decides life of product such as surface roughness play critical role in fatigue of product. So while machining of difficult to cut material like Maraging
Steel large amount of temperature and force generated which leads to premature failure of tool.

2. Literature

A significant amount of work has been focused on ways of yielding optimal EDM performance measures of high metal removal rate (MRR), low tool wear rate (TWR) and satisfactory surface roughness (SR). **Ohdar et al. [1]** proposed a optimization model to investigate the effects of peak current, pulse on time, pulse off time and flashing pressure in Electrical Discharge Machining (EDM). In this experiment, Material Removal Rate (MRR) and Tool Wear Rate (TWR) in machining of mild steel utilizing copper as electrode with negative polarity have been calculated. Based on the experiments and using Taguchi's design of experiments response Tables and graphs are made. For high MRR, the most significant factor is pulse on time and for low TWR, the most significant factor is found to be peak current. We got the optimum result at peak current amp, pulse on time 5µs, and pulse off time µs and flushing pressure. kg/cm2, where the material removal rate (MRR) becomes high and at peak current 14amp, pulse on time 5µs, pulse off time 7µs and flushing pressure 0.3 kg/cm2 the tool wear rate (TWR) reduces significantly.**Basha et al.[2]** investigated on Hastelloy C276 the most versatile corrosion resistant nickel based super alloy which is used for industrial applications is considered for doing the experiments. The high nickel and molybdenum content provides better corrosion resistance at extreme environments. In this report, the experiments are performed by using Taguchi L18 technique and their results are used for performance of each process parameters on their output responses. The process parameters considered for experimentation are discharge current, pulse-on-time, type of electrode and pulse off time for the output responses of material removal rate and surface roughness. Eco-friendly (drinking water) is used as a dielectric fluid. The experiments are designed and conducted using Taguchi L18 technique and analyze the influence of each process parameters on machining performance characteristics. Further, mathematical equations were developed using the statistical software MINITAB17. 0. ANOVA is used for analyzing the experimental results obtained. It was observed from the response Table that the average values of MRR and SR for pulse on time, discharge current, electrode are identified as important process parameters.**Jeykrishnan et al. [3]** investigated to analyze the optimum machining parameter, to curtail the machining time with respect to high material removal rate (MRR) and low tool wear rate (TWR) by varying the parameters like current, pulse on time (T on) and pulse off time (T off). By conducting several dry runs using Taguchi technique of L 9 orthogonal array (OA), optimized parameters were found using analysis of variance (ANOVA) and the error percentage can be validated and parameter contribution for MRR and TWR were found.**Vikas and Kumar [4]** studied on the effect of various parameters on the material removal rate of EN41 material using Die Sinking Electrical Discharge Machining (EDM). Here, various parameters like Pulse ON time, Pulse OFF time, discharge current and gap voltage are considered as the input parameters and based on these input parameters, calculation for the MRR for EN41materialis done. The various combinations of these inputs were considered using the Taguchi s method, and the MRR for the EN41 material was calculated. The level of importance of the machining parameters on MRR was determined by using analysis of variance (ANOVA). The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. The analysis shows that discharge current has the most significant effect on MRR followed by pulse off time and gap voltage. The pulse on time has no or negligible effect on the studied output. The study also compares the theoretical and the experimental value of MRR. The values are almost identical. The methodology described here is expected to be highly beneficial to automotive components manufacturing industries.**Lin, J. L et al. [5]** proposed the application of the Taguchi method with fuzzy logic for optimizing the electrical discharge machining process with multiple performance characteristics. A multi-response performance index is used to solve the electrical discharge machining process with multiple performance characteristics. The machining parameters (the work piece polarity, pulse-on time, duty factor, open discharge voltage, discharge current and dielectric fluid) are optimized with considerations of the multiple performance characteristics (electrode wear ratio and material removal rate). Experimental results are presented to demonstrate the effectiveness of this approach.**Sugeno, M [6]** reviewed the studies on fuzzy control by referring to most of the papers ever written on fuzzy control. As an introduction, the paper picks up key points in applying fuzzy control and shows very recent results in industrial applications. The paper also points out some interesting and important problems to be solved.**Choudhary et al.[7]** studied that the electric discharge machine provides an effective solution for machining hard conductive materials and reproducing complex shapes. EDM involves the phenomena such as: spark initiation, dielectric breakdown, and thermo-mechanical erosion of metals. High cost of non conventional machine tools, compared to conventional machining, Optimization is one of the techniques used in manufacturing process area to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. In this paper various optimization technique such as Taguchi method, artificial neural network (ANN), Genetic Algorithms (GA), grey relational analysis (GRA), Response Surface Methodology (RSM) used in the field of electric discharge machining process. **Andromeda et al. [8]** predicted Material Removal Rate (MRR) in Electrical Discharge Machining (EDM) using Artificial Neural Network (ANN). Experimental data were gathered from Die sinking EDM process for copper-electrode and steel-workpiece. It is aimed to develop a behavioral model using input-output pattern of raw data from EDM process experiment. The behavioral model is used to predict MRR and than the predicted MRR is compared to actual MRR value. The results show good agreement of predicting MRR between them.**Jung et al. [9]** applied the Taguchi method to optimize EDM conditions but extended it using Grey relational analysis to handle multiple performance characteristics. The study aimed to achieve a minimum micro-hole diameter with a maximum aspect ratio. Key factors affecting hole diameter were electrode wear and entrance/exit clearances. Grey relational analysis identified input voltage and capacitance as the most significant parameters. The optimal machining conditions were 60 V input voltage, 680 pF capacitance, 500 Ω resistance, 1.5 µm/s feed rate, and 1500 rpm spindle speed. Under these conditions, a 40µm diameter micro-hole with a 10 aspect ratio was achieved.**Kansal et al.[10]** optimized the process parameters of powder mixed electrical discharge machining (PMEDM). Response surface methodology has been used to plan and analyze the experiments. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM were chosen as variables to study the process performance in terms of material removal rate and surface roughness. Experiments are performed on a newly designed experimental setup developed in the laboratory. The results identified the most important parameters to maximize material removal rate and minimize surface roughness. The recommended optimal process conditions have been verified by conducting confirmation experiments.

From the literature, there is a significant effect of various process parameters in EDM machining of MDN 250. In this study, an attempt has been made to improve the machining efficiency by varying input parameters such as Pulse on time and Current while maintaining a constant depth of 20 mm. The experiments were designed and conducted based on a full factorial design of experiments.

3. Experimental Work

A set of 9 experiments were conducted using full factorial design of experiments on spark EDM (Model: Sparkonix).The schematic diagram of the experimental setup is shown in fig.1 with workpiece material and copper tool. The workpiece is predrilled with circular holes of ø 4.8 mm with Electrical Discharge Drilling machine. The square copper electrodes used in this set of experiments are fabricated using milling machine and grinded to smoother surface using Tool end cutter to a dimension of 4.8 x 4.8 mm. The sample of the workpiece machined with square holes is shown in fig.2. After machining, the size of the square hole obtained is measured using Co-ordinate Measuring Machine in x and y direction as shown in fig.3. The process parameters and their levels are given in Table 1.The Table 2 gives the experimental values with results.

Table 1: Matrix of Parameters and their levels

factors	levels		
Process parameters	1	2	3
Pulse On Time (Ton) µs	6	7	8
Current (I) A	12	15	18

Table 2: Experimental results

	Experimental values		**Experimental results**		
run	Pulse on time(µs)	Current(A)	MRR (mm3 /min)	SR (Ra) µm	Squareness(°)
1	6	12	13.09	4.025	0.999
2	6	15	15.29	4.065	1.001
3	6	18	17.95	5.751	0.998
4	7	12	10.74	7.097	0.995
5	7	15	12.00	7.496	0.985

6	7	18	13.09	7.820	1.004
7	8	12	8.00	8.002	1.002
8	8	15	8.96	8.399	0.991
9	8	18	10.76	8.609	0.992

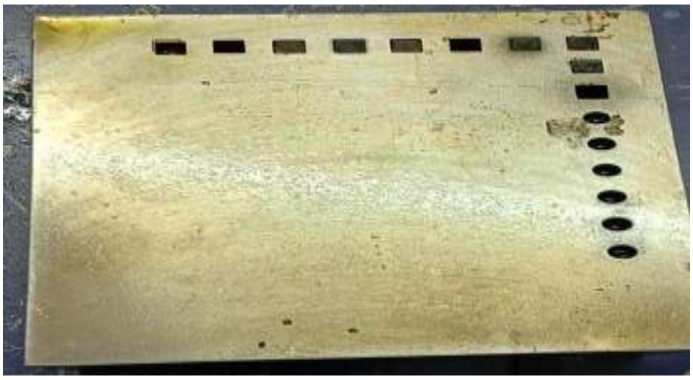

Fig 1: Work piece machined with square holes

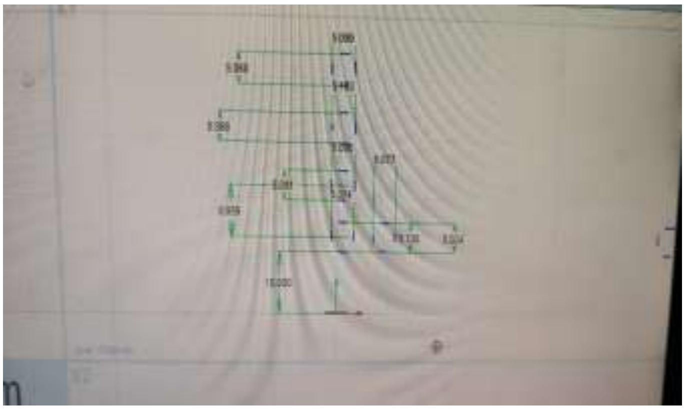

Fig.2: Sample data measuring the size of square hole using CMM

The workpiece sample is then sectioned for measuring the various performance parameters. The sectioning of the sample was done using Wire-cut EDM machine. The cross-section of the sample is as shown in fig.3.

Fig.3 Workpiece sample after wire cut

The performance measurements like Surface Roughness and Taperness are measured on the sectioned sample using Talysurf equipment and CMM respectively.

The Material removal rate was calculated using the volumetric method. The machined depths were measured and then multiplied by the surface area to get volume of the material removed. The Material removal rate (mm^3/min) was obtained by simple mathematical calculation i.e. dividing the volume of the material removed by the machining time.The tool wear is calculated by the difference between the weight of the electrodes before and after machining.

4. Results And Discussion

4.1 Effect of Pulse on Time on MRR,Surface roughness and Squareness

The fig.4 shows the relationship between the Pulse on time and Material removal rate.At 20 mm of hole depth ,as the pulse on time increases, the material removal rate is decreased.As there is accumulation of debris in the deeper holes due to improper flushing in the blind hole, even though the pulse on time is increased,the material removal rate is decreased.

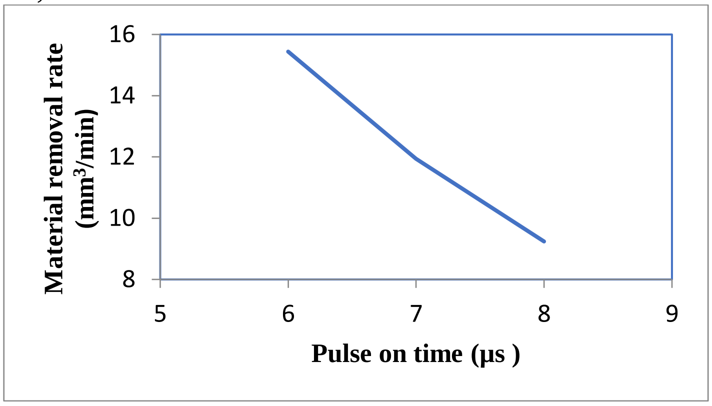

Fig.4: Effect of Pulse on time on MRR

As the pulse on time increases more heat and molten material can cause increased surface roughness due to irregular material removal.At a higher pulse on time,improved flushing and stable plasma conditions may lead to a smoother surface and thus lower surface roughness is achieved as shown in fig.5.

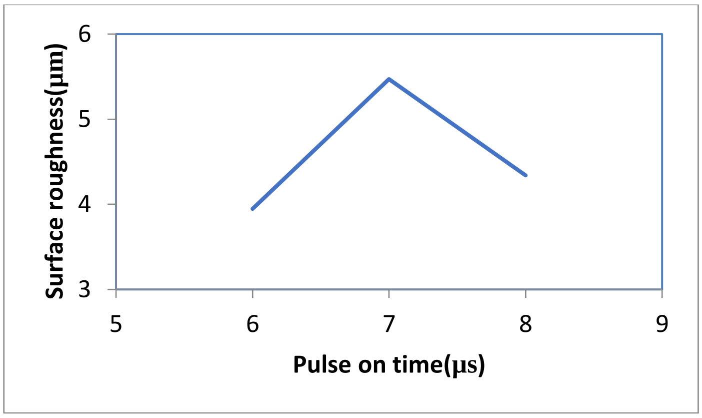

Fig.5: Effect of Pulse on time on Surface Roughness

Squareness decreases as pulse on increases from 6 to 7 µs.After reaching the lowest value at 7 µs,squareness slightly improves. As Pulse on time increases, excessive discharge energy could lead to overcutting or uneven material removal causing deviations in squareness.

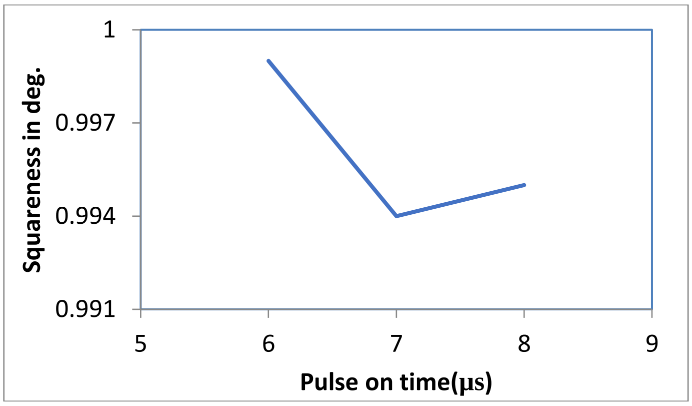

Fig.6: Effect of Pulse on time on Squareness

4.2 Effect of Current on MRR, Surface roughness and Squareness

The effect of current on Material removal rate is shown in fig.7 As the current increases,the material removal rate also increases from 10.5 mm^3/min at 12 A to 14.5 mm^3/min at 18 A.In EDM, higher current leads to higher discharge energy, increasing the rate at which material is removed from the workpiece.

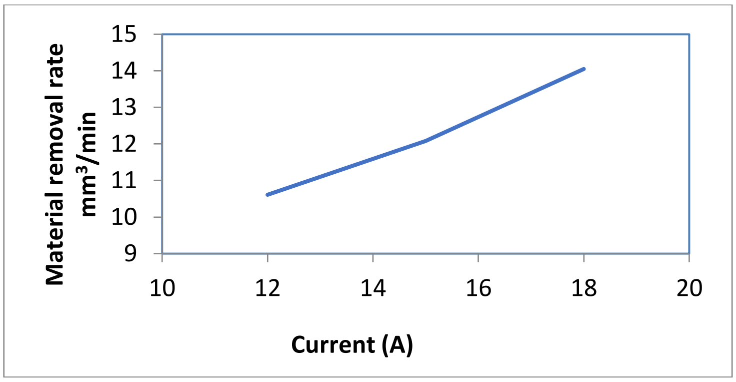

Fig.7: Effect of Current on MRR

Higher currents lead to higher discharge energy, which increases material removal efficiency and often improves surface finish. At lower currents, incomplete material melting and resolidification can lead to a higher surface roughness. At higher currents, better flushing and uniform discharge conditions can result in a smoother surface. However, very high currents might cause thermal damage, micro-cracking or excessive tool wear potentially worsening the surface finish.

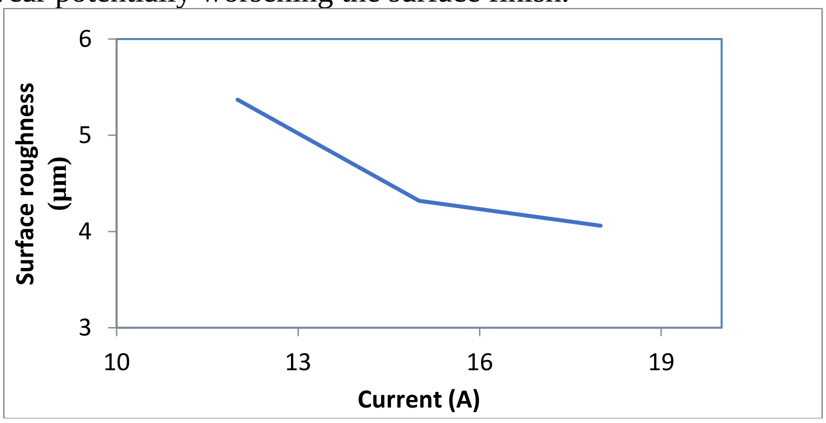

Fig.8: Effect of Current on Surface roughness

The squareness values decreases as current increases upto 15 A, reaching a minimum as shown in Fig.9.. After 15 A, the squareness increases as current continues to increase. At lower currents, the material removal is more controlled leading to a higher squareness accuracy. As current increases, excessive discharge energy can cause overcutting, uneven erosion and poor squareness,resulting in a drop in squareness accuracy.

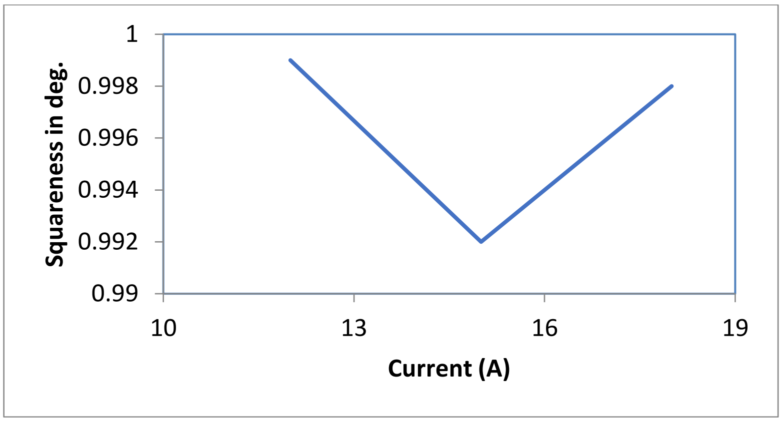

Fig.9: Effect of Current on Squareness

5. Conclusion

1. As the Pulse on Time was increased,the Material removal rate decreased with increase in surface roughness and the squareness is decreased with slight deviations.
2. The material removal rate is increased with increase in the current with decrease in surface roughness and the squareness is initially decreased and then increased with increase in discharge current.

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