International Journal of Scientific and Research Publications, Volume 6, Issue 9, September 2016
ISSN 2250-3153

Analysis of EDM Parameters Influencing on Material Removal Rate and Surface Roughness of High Speed Steel

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Abstract- In present scenario, high speed steel tools are more popular because of their good toughness at high hardness, high wear resistance, and relatively high abrasion resistance properties. High speed steel is widely used to manufacture various cutting tools like tool bits, taps, milling cutters, drilling tools, planer tools and saw blades etc. So that, High Speed Steel, is selected as a workpiece material. In this paper, the behavior of an, high speed steel has been studied using electrical discharge machining (EDM). The response parameters selected are the material removal rate (MRR) and the surface roughness (SR). All of them have been studied in terms of current intensity supplied by the generator (I), voltage (V) and pulse time (Ton). To carry out the experiments, design of experiment (DOE) techniques have been used in order to obtain mathematical models to predict the most influential factors by using a small number of experiments. The experimental results confirm that positive polarity leads to higher MRR.

Index Terms- Powder mixed electrical discharge machining (PWEDM), Material removal rate (MRR), Surface roughness, Orthogonal array.

I. Introduction

High speed steel is more popular because of their good mechanical properties such as toughness at high hardness, high wear resistance, and relatively high abrasion resistance properties. High speed steel is widely used to manufacture various cutting tools like tool bits, taps, milling cutters, drilling tools, planer tools and saw blades etc. However, some characteristics such as low thermalconductivity, work hardening, and high melting temperature make it difficult to machine the alloy with traditional techniques, because of the high temperatures generated which shortens the life of the cutting tools. As a result of this, electrical discharge machining is one of the most suitable manufacturing processes to machine them. As is well known, electrical discharge machining(EDM) is a non-contact removal process in which material is removed through periodical sparks between the tool and the part in a dielectric fluid. It can machine all electrically conductive materials irrespective of their hardness, and it also allows complex shapes to be achieved with good geometric and dimensional accuracy, which by conventional processes would be very expensive or even impossible to achieve. All these advantages make it one of the non-conventional machining processes most widely used in the manufacture of molds, dies, and components for the aerospace, automotive, and surgical industries.figure 1 showing the principle of powder mixed EDM.

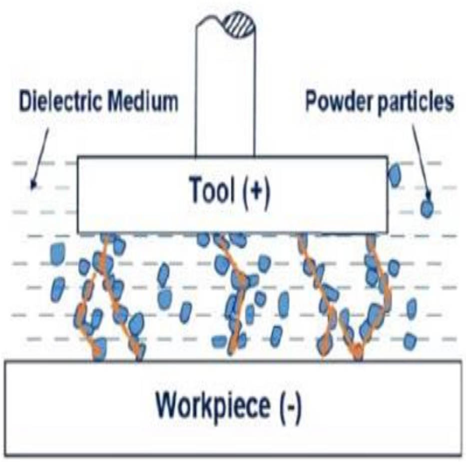

Figure 1. Principle of Powder Mixed EDM

II. EDM PARAMETER OPTIMIZATION

Over the years researchers have used various approaches to improve the performance characteristics of electric discharge machining (EDM) process.The increasing use of high speed steels and the importance which the EDM industry has nowadays have motivated numerous studies focused on determining the influence of machining parameters such as currentintensity supplied by the generator (I), voltage (V) and pulse time (Ton) on some response variables tight control of the settings of these parameters is very important to ensure the success of the process. Vemulapalli et al. (2016), optimized the process parameters of electric discharge machining using response surface methodology. AISI 52110 tool steel was used as a work piece material and copper is used as a tool material. Pulse on time, current, duty cycle and concentration of powder were the process parameters chosen for this experiment. The performance was measured in terms of material removal rate and surface roughness. The experimental design was based on central composite design (CCD) of response surface methodology. Kerosene oil mixed with silicon powder is used as a dielectric medium. Analysis of variance (ANOVA) was applied to check the effect of various process parameters on performance measures. A mathematical model was formulated to estimate the performance characteristics. Further, the process parameters were optimized by using desirability approach. It was concluded from the results that, material removal rate and surface roughness were significantly affected by the pulse on time, current, duty factor and concentration of powder. It was observed that as the pulse on time, current, duty cycle and concentration of powder increases, the material removal rate and surface finish also increase. Sundaram et al. (2016), investigated the effect of tool material on the performance characteristics of powder mixed electrical discharge machining of OHNS Die Steel. Copper with titanium carbide and copper with tungsten carbide were used a tool material. The experiments were performed on OHNS Die Steel work piece. Various parameters namely pulse on time; pulse off time, current and voltage were selected as process parameters. The performance was measured in terms of material removal rate and tool wear rate. Taguchi method was used to design the layout of experiment. Further, Analysis of variance was used to find the significant factors affecting the response characteristics. It was concluded that, copper with tungsten carbide tool provide more material removal rate and less tool wear rate as compare to copper with titanium carbide tool. Further, it was concluded that as the current and pulse on time increases, the material removal rate also increases. On the other hand, as the voltage and pulse off time increases, the material removal rate decreases. Karandeet al. (2016), studied the effect of process parameters of electrical discharge machining on tool wear rate. In this study, the authors were investigated the variation of tool wear rate with the varying process parameters. Pulse on time, pulse off time and discharge current were the process parameters selected for this experiment. Taguchi L9 orthogonal array was used to perform the experiment. The experiments were conducted on EN 31 steel using copper electrode. From results, it is observed that discharge current was the most significant parameter for tool wear rate followed by pulse on time and pulse off time. It is also concluded that, with the increase in discharge current and pulse on time, the tool wear rate also increases. On the other hand, as the pulse off time increases, the tool wear rate decreases. Younis et al.(2015),investigated the effect of tool material on surface roughness and to avoid residual stresses during electrical discharge machining. For this experiment, two types of electrode material were chosen namely, Dura graphite and Poco graphite EDMC-3. Two grades of tool steels namely DIN 1.2080 and DIN 1.2379 were chosen as a work piece material. To prepare the specimens for Electrical Discharge Machining process, the base material were machined by Electrical Discharge Machining to remove the undesired material at various machining conditions i.e. rough, medium and soft according to the pulse on time and pulse off time. The scanning of specimen was done by scanning electron microscope (SEM) to study the effect of electrode of material upon the surface roughness and cracks. After that, the X- ray diffraction technique was used to measure the residual stresses. From results, it was observed that POCO graphite EDMC-3 electrode results higher residual stresses compared with Dura graphite tool. Also the soft Electrical Discharge Machining exhibited higher residual stresses as a result of higher pulse on time.Santoki et al. (2015),studied the effect of pulse on time, pulse off time and current on overcut during electrical discharge machining process. Three electrodes as graphite, copper and silver were used to study the machining effect on SS 304 work piece material. The experimental design was based on Taguchi technique. It was observed that the copper material was more suitable for electrode material and current was the most effective parameter followed by pulse on time and pulse off time. For all the three electrodes the authors also observed that, with the increase in current and pulse on time, the overcut also increase and as the pulse off time increases then overcut decreases.Murickan et al. (2013), observed the effect of process parameters for electric discharge machining on stainless steel 316 L using copper electrode. Compressed air was used as dielectric medium. The process parameters selected were discharge current, pulse on time, spindle speed and duty cycle. The layout of design of experiment was based on central composite design (CCD). From results it was concluded that MRR was influenced by discharge current followed by pulse on time and duty factor. However, the tool wear rate was influenced by discharge current and duty factor. Kumar et al., (2012), studied the effect of tool material on the performance measures of electric discharge machining. The influence of various process parameters on MRR, TWR and SR were also studied. The experiments were performed on EN 31 steel using copper, aluminium and EN 24 electrodes. The process parameters selected were discharge current, pulse on time and flushing pressure. It was observed that, discharge current was the most effective parameter for MRR and TWR. Further, it was observed that copper electrode gave high MRR and less TWR whereas EN 24 gave less surface finish.

III. EXPERIMENTAL WORK

The experiments are performed on ELEKTRA EMS 5535 Die Sinker type of EDM machine. EDM oil mixed with silicon powder is used as a dielectric fluid with external pressure flushing. The grain size of the particles of silicon powder are 10 µm. Experiments are conducted with straight polarity i.e. electrode is connected with negative terminal of power supply system. The pulsed discharge voltage is applied in various steps. External pressure flushing is used to flush the EDM oil between the spark gap. High Speed Steel is used as a work piece material and a cylindrical shaped copper tool with 6 mm in diameter is used as an electrode. The layout of design of experiment is based on Taguchi L9 orthogonal array. In this experiment pulse off time, duty cycle, flushing pressure, spark gap and concentration of powder are kept constant 8µs, 6%, 0.3 kgf/cm2, 0.02 mm and 10g/l respectively. A constant spark gap can be maintained with the help of a servo control mechanism. Total eighteen number of experiments are performed out of which nine experiments are conducted by using EDM oil as a dielectric medium and the remaining nine experiments are conducted by using Silicon powder mixed EDM oil as dielectric medium. An electronic weighing machine is used to weigh the work piece before and after experiment for calculation of material removal rate. The capacity of weighing machine is 300 gram and accuracy is 0.001 gram.

3.1 Work material & cutting tool (Electrode)

In present study, High Speed Steel is used as a workpiece material. The work piece mounted on fixture is shown below in figure2 and a cylindrical shaped copper tool having 6 mm diameter is used. Shape of the tool produces the same cavity in the work piece. Using the cylindrical tool, circular hole is produced in the work piece surface. The pictorial view of copper electrode is shown in figure 2.

Figure 2. Copper Electrodes

Table 1. Chemical Composition of High Speed Steel

Elements	C	Mn	P	S	Si	Co	W	Cr	V	Mo
(Weight %)	0.8193	0.2701	0.018	0.0143	0.3359	0.2286	5.938	3.575	1.808	4.980

3.2 Selection of Process Parameters

Process parameters are the variables within the process that affects the performance measure. Identification of the process parameters which affects the performance is an important task for any design of experiment to achieve better results. In order to determine the process parameters that may affect the performance characteristics of Die Sinker EDM, Ishikawa cause and effect diagram is constructed as shown in Figure 3.

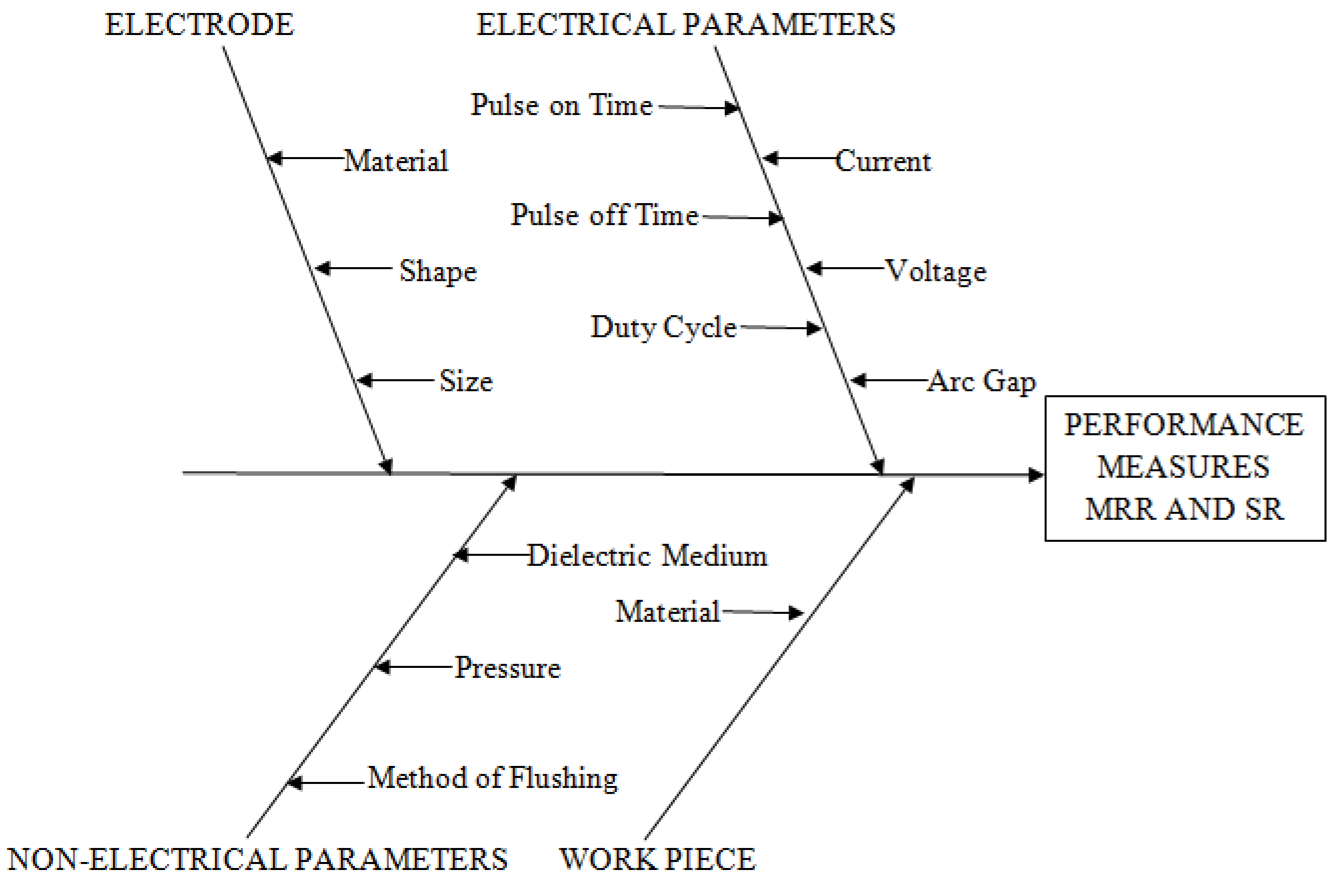

Figure 3. Ishikawa Cause and Effect Diagram

3.3 Design of experiments

For the present work, the layout of design of experiment (DOE) is based on Taguchi L9 orthogonal array. Taguchi design technique is one of the most important statistical tools for designing high quality process at low cost. Taguchi design technique uses a special design of orthogonal array to investigate the entire process parameter space with a less number of runs.Further, Analysis of Variance (ANOVA) is used to analyze the results obtained from Taguchi design technique.Minitab is statistical software used to design the experimental layout. In the present work three process parameters selected as current, pulse on time and voltage and each process parameter are varied at their three levels (see table 2).

Table 2. Process Parameters and their Levels

Machining Parameters	**Symbol**	**Unit**	**Levels**		
			Level 1	**Level 2**	**Level 3**
Current	I	Amp	4	6	8
Pulse on Time	Ton	µs	50	100	150
Voltage	V	Volt	30	35	40

The selection of orthogonal array generally depends on the three factors

1. Number of process parameters
2. Interactions between process parameters
3. Number of levels for each process parameter

For this experiment three process parameters namely current, pulse on time and voltage each at three levels have been selected. Thus the degree of freedom for each process parameter is 2 (DF = number of levels for a process parameter - 1). The sum of degree of freedom for these process parameters is 6 and L9 orthogonal array is selected. The L9 orthogonal array for these process parameters is shown in table 3.

Table 3. L9 Orthogonal Array design matrix

Column	C1	C2	C3	Response Data		S/N Ratio	
Run	**I**	**Ton**	**V**	**MRR**	**SR**	**MRR**	**SR**
1	4	50	30				
2	4	100	35				
3	4	150	40				
4	6	50	35				
5	6	100	40				
6	6	150	30				
7	8	50	40				
8	8	100	30				
9	8	150	35				

Where, I = Current, Ton = Pulse on Time, V = Voltage, MRR = Material Removal Rate, SR = Surface Roughness and S/N Ratio = Signal to Noise Ratio

4. EXPERIMENTATION

Experiments were conducted using an Electric Discharge Machine; model ELEKTRA EMS 5535 as per L_9 OA combinations for getting reliable database i.e.9×2 total 18 experiments conducted.For this work, a bit of HSS having 140mm in length and 10mm in width is used as a work piece and cylindrical shaped copper tool with 6mm in diameter is used as a tool. The complete work is done by an Electric Discharge Machine, model ELEKTRA EMS 5535. Figure 4 shows the experimental setup for present study.

Figure 4.Experimental Setup

4.1 Experimental results and analysis for MRR

In order to see the effect of process parameters on the MRR, experiments were conducted using L9 OA.Performance characteristics chosen for present investigation was material removal rate and surface roughness.The value for all 18 specimenswith silicon powder and without silicon powder was measuredand corresponding data is displayed in Table.The average values of material removal rate (Ra) for each parameter at levels 1, 2 and 3 for raw data and S/N data are displayed in Table 4.The S/N ratios for MRR are calculated as given in Equation (4.1). Taguchi method is used to analyze the result of response of process parameter for higher the better (HB) criteria.

$$SN_i = -10log\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y^2}\text{.......................................}(4.1)$$

Where, i= Experiment number, u= Trial number

Ni= Number of trials for experiment i, y= Response

Table 4.Signal to Noise Ratio for MRR

Run	I	Ton	V	S/N Ratio For MRR	
				EDM Oil	PMEDM Oil
1	4	50	30	-52.7278	-50.1448
2	4	100	35	-48.9710	-47.4322
3	4	150	40	-45.4818	-43.9172
4	6	50	35	-43.6619	-42.1804
5	6	100	40	-41.9927	-40.8670
6	6	150	30	-39.6928	-38.4745
7	8	50	40	-38.9924	-37.8017
8	8	100	30	-36.1097	-35.5249
9	8	150	35	-34.5492	-34.1327

From the observation table, it is clears that the EDM oil mixed with silicon powder as a dielectric medium gives more material removal rate as compared to EDM oil without silicon powder mixed in it. This is due to the fact that, the powder particles form a chain with the effect of electric forces at different places in the sparking zone. The formation of chain helpsin bridging the gap between the tool and work piece. Due to this, the strength of dielectric medium decreases and an easy short circuit takes place, which causes early explosion in the spark gap and results a series of spark under the tool zone. As a result the process became more stable, thereby improving material removal rate. The comparison of material removal rate with and without mixing silicon powder in EDM oil is shown in Figure5.

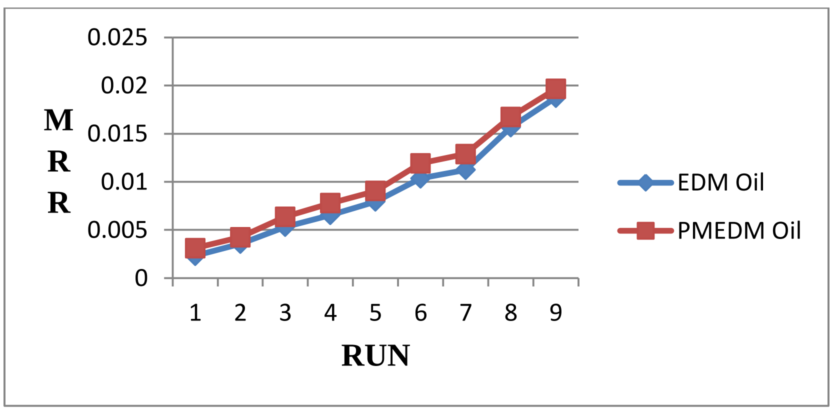

Figure 5.MRR with and without Powder Mixed in EDM Oil

4.2 Results and analysis of SR

The S/N ratios for SR are calculated as given in Equation (2). Taguchi Design approach is used to analyze the result of response of machining parameter for smaller the better (SB) criteria.

$$SN_i = -10log\sum_{u=1}^{N_i}\frac{y^2}{N_i}\text{.......................................}(4.2)$$

Table 5. S/N Ratio for SR

Run	I	Ton	V	S/N Ratio For SR	
				EDM Oil	PMEDM Oil
1	4	50	30	-7.8187	-6.2773
2	4	100	35	-10.5009	-9.3964
3	4	150	40	-12.8096	-12.0629
4	6	50	35	-13.8569	-12.9281
5	6	100	40	-15.2985	-14.5833
6	6	150	30	-16.8771	-15.9868
7	8	50	40	-17.9855	-17.4081
8	8	100	30	-19.0462	-18.5679
9	8	150	35	-19.9127	-19.4255

From the observation table, it is clears that the EDM oil mixed with silicon powder as a dielectric medium gives better surface finish as compared to EDM oil without silicon powder mixed in it. The comparison of surface roughness with and without mixing silicon powder in EDM oil is shown in Figure 5.

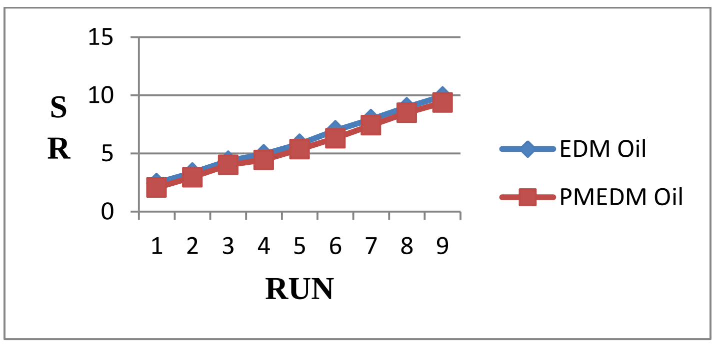

Figure 5.SR with and without Powder Mixed in EDM Oil

IV. CONCLUSIONS

The main objective of this work is to investigate the effect of dielectric medium (silicon powder mixed with EDM oil) on MRR and SR and further is to find out the most significant values of different process parameters like current, pulse on time and voltage to maximize the MRR and to minimize the SR. For this work, a bit of HSS having 140mm in length and 10mm in width is used as a work piece and cylindrical shaped copper tool with 6mm in diameter is used as a tool. The complete work is done by an Electric Discharge Machine, model ELEKTRA EMS 5535. The layout of experiment is based on Taguchi L9 orthogonal array. The following conclusions have been made from this experiment:-

1. Silicon powder mixed EDM oil as a dielectric medium gives more MRR and better surface finish as compare to EDM oil without silicon powder.
2. Voltage is not important for influencing material removal rate and the value of current and pulse on time is most effected the material removal rate.
3. From results clearly definite that current is the most effective factor for material removal rate followed by pulse on time and last is the voltage.As the value of current and pulse on time increases, the MRR also increase.
4. In case of MRR, the most significant parameter is current followed during pulse time and voltage.
5. The value of current and pulse on time is most affected the surface roughness and the voltage is not important for influencing the surface roughness
6. In case of SR, current and pulse on time are the most significant parameters. As the current and pulse on time increases, the surface finish decreases.

V. SCOPE FOR FUTURE WORK

The scope of traditional optimization techniques is very limited due to their complexity since they require large number of experiments. Due to this fact, these optimization techniques have very limited areas of application. On the other hand, Taguchi Design approach requires less number of experiments to optimize performance parameters. This design approach is best suited to optimize the performance parameters individually and hence it can also be applied to optimize other performance parameters like tool wear rate (TWR), overcut and surface integrity aspects like white layer thickness andheat affected zone (HAZ) etc. and to minimize the costing and environmental effects outcome of dry EDM is a better option to explore.

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