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Parametric Optimization of PMEDM Process with Nickel Micro Powder Suspended Dielectric and Varying Triangular Shapes Electrodes on EN-19 Steel

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Abstract: In this study, parametric optimization for Material Removal Rate (MRR) and Tool Wear Rate (TWR) study on the Powder Mixed Electrical Discharge Machining (PMEDM) of EN-19 (AISI-4140) steel has been carried out. Response Surface Methodology (RSM) has been used to plan and analyze the experiments. Peak current, duty cycle, angle of triangular electrode and concentration of micro-nickel powder added into dielectric fluid of EDM were chosen as process parameters to study the PMEDM performance in terms of MRR and TWR. Experiments have been performed on newly designed experimental setup, developed in laboratory. Most important parameters affecting selected performance measures have been identified and effects of their variations have been observed.

Key words: PMEDM, MRR, Electrode, parameters, micro-mickel, RSM, India

INTRODUCTION

Electrical discharge machining is an important manufacturing process for tool mould and die industries. This process is finding an increasing application for because of its ability to produce geometrically complex shapes and its ability to machine materials irrespective to their hardness. However, poor surface finish and low machining efficiency limits its further applications. Powder Mixed Electrical Discharge Machining (PMEDM) is a relatively new material removal process applied to improve the machining efficiency and surface finish in presence of powder mixed dielectric fluid (Luo, 1997; Narumiya *et al*., 1989; Mohri *et al*., 1985; Furutani *et al*., 2001; Tzeng and Chen, 2003; Kunieda and Yanatori, 1997; Erden and Bilgin, 1980; Jeswani, 1981; Kansal *et al*., 2003).

Researchers have explained the working principle of powder mixed electrical discharge machining process (Kansal *et al*., 2005). When a voltage is applied between the electrode and the work piece facing each other with a gap an electric field in the range of 10^5-10^7 V m^{-1} is created. The powder particles in the spark gap get energized. These charged particles are accelerated by the developed electric field and act as conductors.

The conductive particles promote breakdown in the gap and also increase the spark gap between tool and the workpiece. Under the sparking area, the particles come closer and arrange themselves in chain like structures between both the electrodes. The interlocking between the different powder particles takes place in the direction of current flow. This chain formation helps in bridging the discharge gap between electrodes and also results in decreasing the insulating strength of the dielectric fluid. The easy short circuit takes place, causing early explosion in the gap resulting in series discharges under the electrode area.

The faster sparking within a discharge occur causing faster erosion from the workpiece surface and hence the Material Removal Rate (MRR) increases. At the same time, the added powder also modifies the plasma channel making it enlarged and widened. The sparking is uniformly distributed among the powder particles hence, electric density of the spark decreases. Due to uniform distribution of sparking among the powder particles, shallow craters are produced on the workpiece surface resulting in improvement in surface finish.

Literature review: Erden and Bilgin (1980) has investigated the effect of abrasive powder mixed into the dielectric fluid and proposed that the machining rate increased with an increase of the powder concentration due to decreasing the time lag. Jeswani (1981) have investigated the effect of addition of graphite powder to kerosene and proposed that the material removal rate was improved around 60% and electrode wear ratio was reduced about 15% by using the kerosene oil mixed with 4 g L^{-1} graphite powder. Mohri *et al*. (1985, 1988, 1991) have investigated the influence of silicon powder addition

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on machining rate and surface roughness in EDM. Furutani *et al*. (2001) have proposed that the machined surface properties, including hardness, wear resistance and corrosion resistance could be significantly improved by using the PMEDM process. Wu have discussed the improvement of the machined surface by adding aluminum powder and surfactant into dielectric fluid. Narumiya *et al*. (1989) concluded that Al and Si powders, yield better surface finish under specific work conditions. Kobayashi *et al*. (1992) investigated the effects of suspended powder in dielectric fluid on MRR and SR of SKD-61 material. Uno have studied the effect of nickel powder mixed working fluid modifies the surface of aluminum bronze components.

Okada *et al*. (2000) have proposed a new method for forming hard layer containing titanium carbide by EDM with carbon powder mixed fluid using titanium electrode. Chow *et al*. (2000) have studied the EDM process by adding SiC and aluminum powders into kerosene for the micro-slit machining of titanium alloy. Wang have investigated the effect of Al and Cr powder mixture in kerosene. Tzeng and Lee have reported the effect of various powder characteristics on EDM of SKD-11 material.

Furutani and Shiraki (2002) have proposed a deposition method of lubricant layer during finishing EDM process to produce parts for ultra high vacuum. Simao *et al*. (2003) have explored the role of PMEDM in modifying the surface properties of the workpiece by application of Taguchi method. Pecas and Henriques (2003) have investigated the influence of silicon powder mixed dielectric on conventional EDM.

The relationship between the roughness and pulse energy was roughly investigated under a few sets of the conditions in the removal process. However, the effect of the energy was not systematically analyzed. Kansal *et al*. (2005) researched to optimize the process parameters of PMEDM by using the response surface methodology. Cogun *et al*. (2006) have made an experimental investigation on the effect of powder mixed dielectric on machining performance. Kansal *et al*. (2007) have studied the effect of Silicon powder mixed EDM on machining rate of AISI D2 Die steel. Pecas and Henriques (2008a, b) have investigated the effect of the electrode area in the surface roughness and topography. Prihandana *et al*. (2009) have investigated the effect of micro-powder suspension and ultrasonic vibration of dielectric fluid in micro-EDM processes by a pplying the Taguchi a pproach. Furutani *et al*. (2009) have investigated the influence of electrical conditions on performance of electrical discharge machining with powder suspended in working oil for titanium carbide deposition process. Kung *et al*. (2009) have studied the influence of MRR and electrode wear ratio in the PMEDM of cobalt-bonded tungsten carbide. Kuldeep Ojha *et al*. (2011) have investigated the effect of nickel micro powder suspended dielectric on EDM performance measures of EN-19 steel.

Elaborate scrutiny of the literature reveals that material removal mechanism of PMEDM process is very complex and theoretical modeling of the process is very difficult. Regarding empirical results, much research work is required with more work-tool-powder-parametric combinations to make the process commercially applicable. Also, most of the research work is with Al, Si and graphite powders. Much investigation is needed regarding other types of powder like Cr, Ni, Mo, etc. Also, there is a literature gap regarding investigation of influence of electrode profile parameters on PMEDM performance measures (Ojha *et al*., 2010).

In present research, different parametric combinations of peak current, duty cycle, electrode angles and powder concentration of micro-Ni powder in dielectric has been explored for EN-19 steel. Literature review reveals that this combination has not been explored yet. EN-19 steel finds wide applications in industry in making components of mediums and large cross section, requiring high tensile strength and toughness for automatic engineering and gear and engine construction such as crane shafts steering, connecting rods. Investigation of EN-19 steel with promising emerging area of PMEDM is useful in research field.

MATERIALS AND METHODS

Selection of design factors: The status of nickel powder particles mixed into the dielectric fluid has a significant role in determining and evaluating the EDM characteristics of a product. There are many design factors to be considered concerning the effects of nickel powder particles but in this study concentration of suspended powder particles has been taken as variable. In addition, the discharge current (I_P, A) and duty cycle (%) were only taken into account as design factors out of many factors. The reason why these two factors have been chosen is that they are the most general and frequently used among EDM researchers (Pecas and Henriques, 2008a). Electrode angle has also been selected as design factor as electrode shape parameter.

Selection of response variable: The response variables selected in this study were MRR and TWR. Both MRR and TWR refer to the machining efficiency of the PMEDM process and the wear of copper electrode, respectively and are defined as follows:

$$\text{MRR mm}^3\ \text{min}^{-1} = \frac{\text{Wear weight of work piece}}{\text{Time of machining} \times \text{Density of work piece material}}$$

$$\text{TWR mm}^3\ \text{min}^{-1} = \frac{\text{Wear weight of tool electrode}}{\text{Time of machining} \times \text{Density of electrode material}}$$

The work piece and electrode were weighed before and after each experiment using an electric balance with a resolution of 0.001 mg to determine the value of MRR and TWR. For efficient evaluation of the PMEDM process, the larger MRR and the smaller TWR are regarded as the best machining performance. Therefore, the MRR is considered as a the larger-the-better characteristic and the TWR is considered as the smaller-the-better characteristic in this experimentation.

Experimental design: Response Surface Methodology (RSM) is used in design matrix formation which is an empirical modeling approach using polynomials as the local approximations to obtain true input/output relationships (Montgomery, 1997). The experimental plans were designed on the basis of the Central Composite Design (CCD) technique of RSM. The factorial portion of CCD is a full factorial design with all combinations of the factors at two levels (high, +1 and low, -1) and composed of the eight star points and six central points (coded level 0). Central points are the midpoint between the high and low levels. The star points are at the face of the cube portion on the design that corresponds to an alpha value of 1 and this type of design is commonly called the face-centered CCD.

In this study, the experimental plan was conducted using the stipulated conditions according to the face-centered CCD and involved a total of thirty experimental observations at four independent input variables. The machining time for each experimental specimen is 15 min. This was set up before the operation of the machine reached the stable state. The levels of design factors have been selected in accordance with literature consulted as well as by personal experience. The design factors selected for study with their low and high levels are shown in Table 1. Design expert 8.0.4 software was used for design of experiments and regression and graphical analysis of data obtained. The optimum conditions have been obtained by solving the regression equations and by analyzing response surface contours.

Table 1: Process parameters and their levels

	Notation			Range and levels		
Parameters	Natural	Coded	Unit	-1	0	1
Current	I	X1	Amp.	4	6	8
Duty cycle (%)	D (%)	X2	%	54	63	2
Powder concentration	C	X3	g L^{-1}	2	4	6
Angle	A	X4	Degree	8	12	6

RESULTS AND DISCUSSION

Thirty experimental runs have been conducted and values of MRR and TWR along with design matrix are shown in Table 2. Parametric optimization is done for each single response for higher MRR and lower TWR. Figure 1a, b shows perturbation curves for both the response variables. For variation of one paremeter, others are kept constant at center point. From Fig. 1a, b, it is evident that current is the most dominant factor affecting

Table 2: Experimental design matrix and collected data

Coded values				Natural values				Responses	
X1	X2	X3	X4	I (A)	D (%)	C (g L^{-1})	D (mm)	MRR (mm^3 min^{-1})	TWR (mm^3 min^{-1})
0	0	0	0	6	63	4	90	6.29	0.034
+1	0	0	0	8	63	4	90	7.54	0.049
0	0	0	+1	6	63	4	130	5.78	0.038
-1	-1	-1	-1	4	54	2	50	2.19	0.025
0	0	0	0	6	63	4	90	7.52	0.033
0	0	-1	0	6	63	2	90	3.25	0.030
-1	0	0	0	4	63	4	90	4.35	0.023
+1	+1	-1	+1	8	72	2	130	6.95	0.036
+1	+1	-1	-1	8	72	2	50	4.55	0.045
0	0	0	0	6	63	4	90	7.85	0.037
+1	+1	+1	+1	8	72	6	130	4.95	0.034
+1	-1	-1	+1	8	54	2	130	8.52	0.036
-1	-1	+1	+1	4	54	6	130	3.53	0.025
-1	-1	-1	+1	4	54	2	130	2.99	0.029
+1	-1	-1	-1	8	54	2	50	5.34	0.034
+1	+1	+1	-1	8	72	6	50	6.58	0.035
0	0	0	0	6	63	4	90	8.13	0.038
+1	-1	+1	-1	8	54	6	50	5.85	0.037
+1	-1	+1	+1	8	54	6	130	4.76	0.035
0	-1	-1	0	6	54	4	90	6.36	0.039
0	+1	-1	0	6	72	4	90	4.18	0.031
-1	+1	-1	-1	4	72	2	50	1.85	0.020
-1	+1	+1	+1	4	72	6	130	2.98	0.018
0	0	+1	+1	6	63	6	90	4.65	0.029
-1	+1	+1	-1	4	72	6	50	4.35	0.015
0	0	0	0	6	63	4	90	5.52	0.038
-1	-1	+1	-1	4	54	6	50	2.39	0.021
0	0	0	0	6	63	4	90	6.59	0.038
0	0	0	-1	6	63	4	50	4.53	0.033
-1	+1	-1	+1	4	72	2	130	2.67	0.018

Table 3: Constraints in design space

Constraints						
Names	Goal	Limit	Limit	Weight	Weight	Importance
A	In range	4.000	8.000	1	1	3
B	In range	54.000	72.000	1	1	3
C	In range	2.000	6.000	1	1	3
D	In range	50.000	130.000	1	1	3
MRR	Maximize	1.850	8.520	1	1	3
TWR	Minimize	0.015	0.049	1	1	3

Table 4: Optimum value in design space

Items	Values
Current	4.34
Duty cycle (%)	72
Powder concentration	3.60
Tool angle	130
MRR	5.28107
TWR	0.0256093
Desirability	0.595

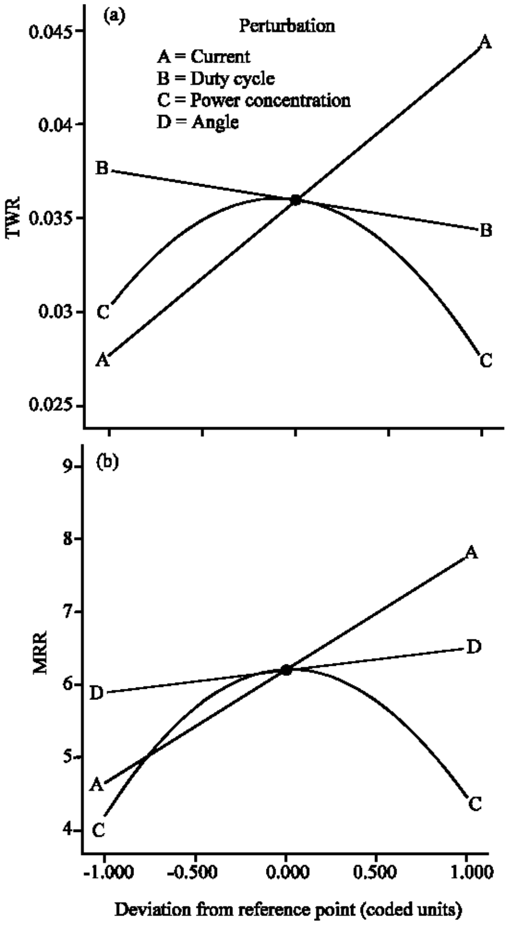

Fig. 1: Perturbation curves for a) MRR; b) TWR

the performance measures. Optimization of parameters with the help of software suggest the following results. Following constraints on the design space has been applied as shown in Table 3 and 4. Following solution has been suggested by software for optimum parameter settings.

CONCLUSION

In this study, quantitative analysis of machinability of EN-19 steel in PMEDM process has been carried out. Micro nickel powder particles are mixed in EDM dielectric fluid. RSM has been applied for analysis. Optimum results has been found as suggested by software.

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