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Grey Relational Analysis (GRA) of Electrode Wear Rate in Die Sinking Electric Discharge Machining

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Abstract: Electric Discharge Machining (EDM) is one of the nonconventional machining that are widely used for processing hard and difficult-to-machine materials such as stainless steel and super alloys. This study presents an experimental study of die sinking EDM process using SS316L stainless steel with copper impregnated graphite electrode to investigate the parameters affecting Electrode Wear Rate (EWR). The machining experiment was conducted in order to find the influence of five EDM parameters which are peak current, servo voltage, pulse on time, pulse off time and servo speed on electrode wear rate value. The experimental data was collected and analyzed using Grey Relational Analysis (GRA). Results from GRA indicates that peak current is the most significant parameter to the EWR value.

Key words: Electric discharge machining, stainless steel, grey relational analysis, copper, UTM

INTRODUCTION

Electric Discharge Machining (EDM) which is firstly introduced in manufacturing industries in late 1940s is one of the earlier non-conventional machining processes. EDM is well known as one of the most widely used and successfully applied machining process for the geometrically complex parts, hard materials and difficult-to-machine materials (Li *et al*., 2014; Takezawa *et al*., 2016; Zhang *et al*., 2016). EDM technology is a reliable, affordable and accurate process which is commonly used in automobile, surgical industries, molding and aerospace fields. EDM has unique feature that differs from other machining processes. The direct contact does not occurred between the research piece and electrode in EDM during the cutting process when eliminating mechanical stresses, chatter and vibration problems. EDM technology has been improved significantly and has been developed in many ideas especially in the manufacturing industries that yielded enormous benefits in economic as well as generating keen interest in research area.

Basically, the terms of electric discharge in EDM process refers to a thermal erosion process in which material is removed by the series of pulses electric discharge to cutting tool in the presence of dielectric fluid. The work piece acts as an anode while cutting tool acts as a cathode. By increasing the local temperature to >10,000°C within the discharge channel, the point of discharge takes place as the tool electrode and work piece melting. The dielectric fluid flushed away the melted material (Tang and Guao, 2014). The melting and evaporating process from the work piece material surface is completely difference with the conventional machining processes as chips are not mechanically produced (Pramanik, 2014).

There are various types of EDM such as die sinking EDM wired EDM (WEDM), powder-mixed EDM, Dry EDM and Micro-EDM (Sulaiman *et al*., 2015; Chen *et al*., 2015; Tiwary *et al*., 2015; Shabgard and Alenabi, 2015). This study focuses on die sinking EDM. In die sinking EDM, the machining process occurs by the 3D movement of an electrode with the numerical control monitors the gap conditions and synchronously controls the different axes and the pulse generator. WEDM is a cutting process that the material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by the existence of dielectric fluid. Micro-EDM is a process that is capable not only for micro-holes and micro-shafts with 5 μm in diameter but also capable for complex 3D micro-cavities. Powder-mixed EDM is basically differs from conventional EDM when a suitable material in powder form is mixed into dielectric fluid. EDM technology has been widely used to machine hard and difficult-to-machine material such as stainless steel and super alloys as they cannot be processed using conventional machining such as milling, grinding and turning. Stainless steel is one of the widely used materials in various industrial applications due to its excellent corrosion and oxidation resistance, ductility, high

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temperature strength and high strength characteristics. Stainless steel is graded based on specific characteristics. Stainless steel 316L is an austenitic chromium-nickel stainless steel which contains molybdenum that improves resistance to pitting from chloride ion solutions increases the corrosion resistance and also have high strength at elevated temperature compared with other grade such as SS304. The SS316L is an extra-low carbon version of type SS316 that minimize harmful carbide precipitation due to welding. This material is frequently used in numerous applications such as jet engine parts, furnace parts, heat exchanger, chemical equipment, pharmaceutical, etc. It is also extensively used for weldments where its immunity to carbide precipitation due to welding assures optimum corrosion resistance. Stainless steel 316L can exhibit better corrosion resistance than stainless steel 304 and also it is non-hardenable by heat treatment.

Literature review: The parameters affecting EWR has been studied by previous researchers using various types of materials and tools. Dixit *et al.* (2015) investigated the influence of pulse on time, pulse off time, peak current and fluid pressure to the EWR value on AISI D3 material. The experimental results were analyzed based on S/N ratio and it was found that EWR is mainly influenced by peak current and pulse on time. Pandey and Alam (2015) investigated EWR on EDM of stainless steel 202 with copper, brass and copper tungsten electrode. The experiment is conducted with three machining parameters which are pulse current, pulse on time and pulse off time. From the result it was found that copper gives the most minimum EWR value which is 0.0078 compared with copper tungsten and brass. The experimental investigation of copper and copper-tungsten electrode wear rate in EDM has been reported by Yu *et al.* (2014). The experiment was conducted based on three levels orthogonal array and it was found that peak current gives the most influence to the EWR value.

This study reports the experimental study of stainless steel SS316L material using copper impregnated carbide electrode to investigate the parameters affecting Electrode Wear Rate (EWR) on die sinking EDM process. Based on the review the combination of SS316L material with the copper impregnated carbide electrode to investigate the parameters affecting EWR in die sinking EDM process is still lacking.

MATERIALS AND METHODS

Experiment setup and Design of Experiment (DOE): The experiment was conducted using AG40L die sinking EDM machine as shown in Fig. 1. The material used in this experiment was stainless steel 316L as shown in Fig. 2. A

Fig. 1: AG40L model of die sinking EDM

Fig. 2: Stainless steel 316L

Table 1: Chemical composition of SS 316L

Elements	316L (wt. %)
C	0.026
Si	0.37
Mn	0.16
Cr	16.55
Cu	0.16
Ni	10.0
P	0.029
S	0.027
Mo	2.02
N	0.036
Fe	Balance

Table 2: Mechanical properties of SS 316L

Mechanical properties	Typical	Minimum
Tensile strength	600 MPa	485 MPa
Proof strength (offset 0.2%)	310 MPa	170 MPa
Elongation (Percent in 50 mm)	60	40
Hardness (Brinell)	217	-
Hardness (Rockwell)	95	-
Endurance (Fatigue limit)	240 MPa	-

cylindrical electrode with tubular section having 8mm diameter copper impregnated graphite was used as the electrode while oil was used as a dielectric fluid. The details chemical composition and mechanical properties of SS 316L are shown in Table 1 and 2, respectively. The design setting is important process that needs to be completed prior to the experimental process can be run. In

Table 3: The range value of EDM parameters

Variables	Unit	Levels 1	2
Peak current (IP)	A	5.7	10.5
Pulse on time (ON)	μs	100.0	200.0
Pulse of time (OFF)	μs	50.0	70.0
Servo Voltage (SV)	V	30.0	90.0
Servo Speed (S)	-	74.0	92.0

this study, the experiment is conducted based on two levels full factorial design of five input variables. Design of Experiment (DOE) is implemented to observe the process characteristic since it provides the best parameters of EDM to fulfil the machining objectives (Selvakumar *et al*., 2013) DOE is a systematic and powerful tool that applies principles and techniques at the data collection stage to ensure the generations of valid, defensible and supportable engineering conclusions. DOE was firstly developed in early 1920s for agriculture purpose but has been widely accepted and applied in every field in recent years. DOE can observe and identify the change that has been made from input variables. The experiment implies 2 levels of 5 input factors which consist of 32 runs (2^5). Before conducting the experiment, the range for low and high level for each factor is determined. In this study the selection of the range for EDM parameters is based on manual EDM handbook and recommendation from previous researchers. For this study, DOE consists of two level full factorial designs. All input parameters are classified into two levels, 'high' and 'low' or '1' and '2'. The design setting with all the possible high and low combinations of all the input parameters is called full factorial design in two levels. For the five input factors, A-E at two levels each, the design is 2^5 factorial design. Table 3 shows the value for low and high levels for each parameter. The machining depth is set to 2 mm and the machining time is recorded. The output which is Electrode Wear Rate (EWR) is measured.

RESULTS AND DISCUSSION

Electrode Wear Rate (EWR) can be defined as the weight difference of the electrode before and after the machining process. Electrode wear is a function of electrode properties and also a function of power supply setting (Khan *et al*., 2014). Electrode wear is measured as a percentage ratio of the amount of electrode material eroded when the machining process corresponding to the input parameters. Electrode wear rate can be calculated as (Khan *et al*., 2014; Pandey *et al*., 2014):

$$EWR = \frac{EW_b - EW_a}{t_m} (g/min) \quad (1)$$

Table 4: EWR results

Run	ON (μs)	OFF (μs)	IP(A)	SV(V)	S(s)	EWR (g/min)
1	100	70	5.7	90	92	0.0040
2	200	70	10.5	30	74	0.0014
3	100	70	5.7	30	74	0.0039
4	100	50	10.5	90	74	0.0080
5	100	70	10.5	30	92	0.0156
6	200	70	5.7	30	74	0.0018
7	100	50	10.5	90	92	0.0102
8	100	70	5.7	90	74	0.0048
9	200	50	10.5	30	92	0.0050
10	100	70	10.5	90	74	0.0076
11	100	50	5.7	90	74	0.0012
12	200	50	10.5	30	74	0.0039
13	100	70	5.7	30	92	0.0017
14	200	50	10.5	90	74	0.0005
15	100	50	10.5	30	92	0.0059
16	200	70	5.7	90	74	0.0028
17	200	50	5.7	90	92	0.0035
18	200	70	10.5	90	92	0.0026
19	200	50	10.5	90	92	0.0047
20	100	70	10.5	90	92	0.0100
21	200	50	5.7	30	92	0.0024
22	200	50	5.7	90	74	0.0017
23	100	50	5.7	30	92	0.0045
24	200	70	5.7	90	92	0.0042
25	200	50	5.7	30	74	0.0091
26	100	50	5.7	90	92	0.0367
27	100	70	10.5	30	74	0.0131
28	100	50	5.7	30	74	0.0039
29	200	70	5.7	30	92	0.0048
30	200	70	10.5	30	92	0.0057
31	100	50	10.5	30	74	0.0233
32	200	70	10.5	90	74	0.0031

Where:

EW_b = The electrode weight before machining

EW_a = The electrode weight after machining

t_m = The machining time

The value of electrode wear rate is normally depends on several EDM factors such as peak current, servo voltage, polarity, electrode and work piece material. Table 4 shows the EWR values of EDM.

The experimental result of EWR was analysed based on statistical analysis called Grey Relational Analysis (GRA). Grey relational analysis was firstly introduced by Deng Julong which is based on Grey system theory (SarIkaya and Gullu, 2015). In Grey theory, if black means no information available while white means all the information are available then the level of information for grey system is in the middle of black and white (Chang *et al*., 2013). In the other words, some information is unknown and some information is known. The correlation values of two variables or sequences can be represented using grey analysis to measure the distance of two variables discretely. For example, when in the cryptic experiment or the method of the experiment cannot be accomplish exactly then grey analysis can assists in compensate for the deficiency in statistical regression (Yadav *et al*., 2016).

Table 5: GRG value for EWR

Factors	GRG
Pulse on time (ON)	0.5558
Pulse off time (OFF)	0.5710
Peak current (IP)	0.6316*
Servo Voltage (SV)	0.5910
Servo Speed (S)	0.6058

In the grey analysis, the pre-processing data depends on the characteristic of the data sequence for the normalization of the data. Three major approaches of data are lower the better, higher the better and there is a target of the desired value. This study applies the lower the better approach as in Eq. 2:

$$x^*_i(k) = \frac{\max x_i^0(k) - x^*_i(k)}{\max x_i^0(k) - \min x^0_i(k)} \quad (2)$$

Where:

$\max x^0_i(k)$ = The maximum value of the input data
$\min x^0_i(k)$ = The minimum value of the input data
x^o = The desired value

Then, Grey Relational Coefficient (GRC) is calculated in order to shows the significance relationship between ideal and normalized data as Eq. 3:

$$\xi_i(k) = \frac{\Delta\min + \xi.\Delta\max}{\Delta_{0i}(k) + \xi.\Delta\max} \quad (3)$$

Where:

ξ = Distinguishing or identification coefficient
$\xi = [0, 1]$ and Δ_{0i} = Deviation sequence of the output sequence and the input variable sequence

The value of $\xi = 0.5$ is generally used for identification coefficient (Sallehuddin *et al*., 2010). After that, Grey Relational Grade (GRG) value is need to calculated based on Eq. 4:

$$\gamma_i = \frac{1}{n}\sum\nolimits_{k=1}^{n}\xi_i(k) \quad (4)$$

However, Equation 4 is modified since in a real application, the effect of each factors is varies. The modified grey relational grade is given in Eq. 5:

$$\gamma_i = \frac{1}{n}\sum\nolimits_{k=1}^{n} W_k.\xi_i(k) \quad \sum\nolimits_{k=1}^{n} W_k = 1 \quad (5)$$

where, w_k refers to the normalized weights. GRG is calculated to show the relationships between the sequences. Table 5 shows the GRG value for EWR.

The GRG value will be in range [0, 1]. Two sequences are identity when GRG value is 1. Usually, the parameter which has GRG value <0.6 will considered as least influential factors to the reference sequence (Sallehuddin *et al*., 2010; Deris *et al*., 2013). From the table, it can be seen that the highest GRG value is obtained by peak current which is 0.6316 followed by servo speed which is 0.6058. It shows that EWR is significantly effect by peak current and servo speed.

CONCLUSION

The effects of the five parameters on the electrode wear rate have been investigated in this study based on the EDM experiment using stainless steel SS316L and copper impregnated graphite electrode. The experiments is conducted based on the design using two levels full factorial design and the results are analysed with GRA to investigate the significance factors affecting EWR. Based on the results on Table 4 and 5 it can be conclude that:

- Peak current, servo voltage and servo speed are the most significant parameters that affects the EWR value
- Grey relational analysis shows that peak current and servo speed are having more influence to the electrode ware rate based on the GRG value which are 0.6316 and 0.6058, respectively
- The most minimum EWR is achieve when peak current and servo speed is set at a high and low level, respectively which is 0.0005
- High cutting temperature and strong adhesion between the tool and work piece material increase the tool wear

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