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Optimization of control parameters for SR in EDM injection flushing type on stainless steel 304 workpiece

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Abstract. The operating control parameters of injection flushing type of electrical discharge machining process on stainless steel 304 workpiece with copper tools are being optimized according to its individual machining characteristic i.e. surface roughness (SR). Higher SR during EDM machining process results for poor surface integrity of the workpiece. Hence, the quality characteristic for SR is set to lower-the-better to achieve the optimum surface integrity. Taguchi method has been used for the construction, layout and analysis of the experiment for each of the machining characteristic for the SR. The use of Taguchi method in the experiment saves a lot of time and cost of machining the experiment samples. Therefore, an L18 Orthogonal array which was the fundamental component in the statistical design of experiments has been used to plan the experiments and Analysis of Variance (ANOVA) is used to determine the optimum machining parameters for this machining characteristic. The control parameters selected for this optimization experiments are polarity, pulse on duration, discharge current, discharge voltage, machining depth, machining diameter and dielectric liquid pressure. The result had shown that the lower the machining diameter, the lower will be the SR.

Keyword—ANOVA, EDM, Injection Flushing, L18 Orthogonal Array, SR, Stainless Steel 304

1. Introduction

Electrical discharge machining, commonly known as EDM is a non-traditional machining technique that is used to remove metal through the erosive action of an electrical discharge of short duration and high current density between the tool and the workpiece in an immersed dielectric fluid. This dielectric fluid is used to continuously flush the eroded particles (mainly in the form of hollow spheres) from the machining gap besides performs as a coolant and reduces the extremely high temperatures in the arc gap. Improper flushing such as wrong selection of flushing method during EDM machining, insufficient flushing pressure during machining would contribute to erratic cutting, poor machining rate [1] and occurrence of short-circuits [2]. Hence, a proper flushing method is critical to achieve good machining condition such as low surface roughness (SR) of the machined workpiece.

There a many types of flushing method exist in EDM machining and one of it is side flushing. Side flushing is the least effective or inefficient method of removing suspended particles from the spark gap. This is because the pressurized dielectric would not effectively being flushed away especially when the tool electrode is cycled down in negative Z-axis; it only pushes out the contaminated oil without the pressurized side flushing goes between the machining gap. Hence, injection flushing is the proper method to be used to help the dielectric being flushed away effectively [3]. Injection flushing is the method where dielectric fluid is forced down through a flushing hole in the electrode. Great advantage of injection flushing is the operator can visually see the amount of oil that is being used for flushing and with pressure gauge this method is ease and simple to used [2, 4].

In electrical discharge machining (EDM), it is important to select machining parameters for achieving optimal machining performance with the proper flushing method used. Usually, the desired machining parameters are determined based on experience or on handbook values. However, this does not ensure that the selected machining parameters may results in optimal or near optimal machining performance such as surface roughness (SR) for that particular electrical discharge machine and environment. Minimizing the surface roughness to obtained a good surface finish of the workpiece with optimizing the input parameters will affect the machining performance [5]. The Taguchi Method using L18 orthogonal array is used in carrying out experiments for solving the optimization process. [6]. Before the use of Taguchi method in the Design of Experiment, experiments were selected with a full combination of factors that the total number of factors is so large. The effect of this, the number of experiments increases rapidly. Hence, by using Taguchi Method fewer experiments is done compared to the use of full combinations of factors [7].

2. Experimental Setup

Design of Experiments Using L18 Orthogonal Array

By using Taguchi method, the control factors table is used as a reference guide to start and execute the experiment. This table will be used with L18 Orthogonal Array table where different levels of factors will be selected for each experiment. L18 Orthogonal Array is used because among of all the control factors, one of it has one-2 level control factors and others has six-3-level of control factors [8]. Table 1 shows the control factors table.

Table 1: Control Factors

Factor	Description	L1	L 2	L 3	Units
A	Polarity	W/P(+) Tool (-)	W/P (-) Tool (+)	-	Positive (+) Negative (-)
B	Pulse-on time	4	6	8	Microsecond
C	Discharge Current	57	66	75	Ampere
D	Discharge Voltage	60	90	120	Voltage
E	Machining Depth	1.5	2.0	2.5	mm
F	Machining Diameter	9.5	11.0	12.5	mm
G	Dielectric Liquid Pressure	1.0	1.5	2.0	bar

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Description of Factors

i) Polarity – refers to the direction of current flow in relation to the electrode. The polarity can be either positive or negative. Usually positive terminal of workpiece determines positive polarity and negative terminal of workpiece determines negative polarity.
ii) Pulse on duration – The amount of time current runs into the gap before it is turned off.
iii) Discharge current – Electrical discharge known as plasma sustained by a direct current (DC) through an ionized medium.
iv) Discharge voltage – Discharge voltage is referred as electrical pressure, force or electromotive force (EMF). It is the pressure that makes amperes flow in the form of a spark. Besides that, it is normally known as the potential difference between the electrode and the workpiece.
v) Machining Depth – The hole depth of cut in EDM machining
vi) Machining Diameter – The hole diameter of cut in EDM machining
vii) Dielectric Liquid Pressure – The pressurized dielectric liquid flow through the electrode.

Workpiece Material

Stainless Steel 304 was used as the workpiece in the experiment. It is being selected as it is often used in producing springs, nuts, bolts and screws. Table 2 shows the physical properties of stainless steel 304.

Table 2: Physical Properties of Stainless Steel 304

Physical properties	**Stainless Steel 304**
Density [g/cm^3]	8.03
Electrical conductivity [x 10^5 / Ω cm]	11.6
Thermal conductivity [W/(cm K)]	0.162
Melting point [K]	1644
Boiling point [K]	1672

Tool Material and Shape

A pipe copper tool is being selected for the machining because it is a highly conductive tool, low cost, low wear ratio, good machinability and finishing. The initial cubic cylindrical copper tool is being drilled to produce a pipe copper tool. It is mainly for the purpose of the dielectric could be flow through and being injected to the workpiece during the machining and it is called injection flushing machining. Table 3 shows the copper pipe tool electrode properties.

Table 3: Properties of copper pipe tool electrode

Properties	**Copper**
Density [g/cm^3]	8.96
Electrical conductivity [x 10^5 / Ω cm]	5.88
Thermal conductivity [W/(cm K)]	3.98
Melting point [K]	1356

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Machining Characteristic Calculation

A profilometer measured the machined surface roughness. The centre-line average surface roughness R_a is measured to quantitatively evaluate how EDM parameters affect the surface finish. 2 measurements were taken per workpiece after experiment. Figure 1 shows the respective machine used for this purpose.

Figure 1: Surface Roughness Measuring Machine

Optimum Condition and Verification

The optimum condition for surface roughness is determined using response graph where the quality characteristics should be known to select which point exhibits the relation with the quality characteristics. In this case, for SR quality characteristic is lower-the-better, where minimum points are chosen from the response graph.

Verification of the optimum condition is done where confirmation result for machining characteristics (after determine the optimum condition) is not less than 90% difference with the predicted values to proof that the optimum condition obtained is acceptable.

Significant Factor Analysis using Analysis of Variance (ANOVA)

The significant factors that contributed to the optimized machining characteristic (SR) is determined by using Analysis of Variance (ANOVA). ANOVA is a method of calculating the statistical significant of factors in the experimentation and it represents the relationship between the machining parameters with overall process performance.

Results and Discussions

Figure 2 shows the response graph for SR machining characteristic.

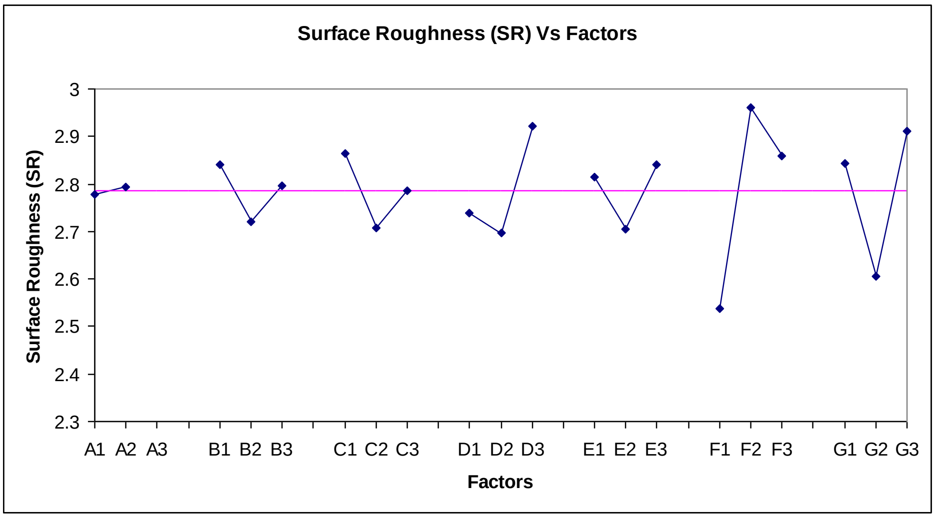

Figure 2: Response Graph for SR

According to lower-the-better quality characteristic for SR, the optimum condition for each factor indicated is A1 (positive polarity), B2 (6μs), C2 (66A), D2 (90V), E2 (2.0 mm), F1 (9.5 mm), G2 (1.5 bar). Consequently, based from confirmation experiment, only 8.08% difference from predicted value, PV that still below the maximum allowance percentage for quality which is 10%.

The significant factors from the above graph were calculated using ANOVA equation and the result is shown on the following table 4.

Table 4: ANOVA for SR

Factor	Description	F-ratio	% contribution ratio, ρ
A	Polarity, P	0.04650	1.125
B	Pulse-on-duration, τ_{on}	0.88890	0.261
C	Discharge Current, I_d	1.4423	1.047
D	Discharge Voltage, V_d	3.4219	5.718
E	Machining Depth, l_i	1.2301	0.543
F	Machining Diameter, d	11.718**	25.30
G	Dielectric Liquid Pressure, P_l	6.131*	12.11

The highest F-ratio contributes to be the most significant factor which is machining diameter, d followed with 2nd highest F-ratio to be the significant factor which is dielectric liquid pressure, P_l.

SR Most Significant Factor – Machining Diameter

Machining diameter is the most significant factor that affects surface roughness for this research. From the review of the previous research papers, there was no direct research made due to effects of machining diameter on surface roughness. However, there was one paper reported by Lee H.T. [5], he reported that surface roughness is caused by surface cracks. In their reports said reducing the electrode diameter can prevent the formation of surface cracks as well as surface roughness. Electrical discharge machining uses erosion process by means of recurring electrical discharge to remove material. Effect to this process, it will produce heat energy on a unit surface area affected that the temperature on the surface and the body is different. Surface cracks may happen due to the internal stress occur between this two body differences in temperature phenomenon. According to the basic heat conduction formula which local heat flux, q is equal to the product of thermal conductivity, k, and the negative local temperature gradient, ΔT. The heat flux density is the amount of energy that flows through a unit area per unit time. By relating with this formula, the surface crack may be eliminated or reduced if the workpiece heat flux density is increased by means of increasing the temperature gradient, ΔT with fixed unit area for energy to flow. Hence, this is why the electrical discharge should be set higher than the minimum setting (referred to the response graph for current) to increase the workpiece heat flux. This agrees the paper reported by Lee H. T. [5].

SR Significant Factor – Dielectric Liquid Pressure

Dielectric liquid pressure is the significant factor that affects surface roughness for this research. As agreed by Wang C.C. [9], surface roughness will decrease slightly if flushing pressure is not applied. Flushing is the removal of the metal particles generated in the spark gap. If there is no flushing pressure to flow through the machining gap, then it would increase dielectric liquid temperature to a very high temperature. This phenomenon will affect more crack formation especially on the machined surface that soon will increase the surface roughness. As previously explained, surface crack formation is related to the surface roughness and it was being affected by the heat energy supplied during EDM machining. Increasing of temperature gradient, ΔT may contributes to the decrease of machined workpiece surface roughness where dielectric liquid may decrease the workpiece temperature during machining along with the initial high temperature obtained from the electrical discharge phenomenon . Hence, increasing the heat flux, q may improve the surface roughness and this was proved by the confirmation experiment made.

3. Conclusions

This research has investigated the optimization of control parameters in injection flushing type of electrical discharge machining on stainless workpiece with copper tools. The main conclusions of this research are as follows:-

1. Machining performance in the EDM process can be improved effectively by using optimum factors that had been determined for SR machining characteristic and it has been proved by the confirmation experiment made.
2. Machining diameter and flushing pressure are most significant and significant factors that affect SR.
3. Optimum condition for SR are being set at positive polarity (workpiece positive and tool negative), 6 microseconds of pulse on duration, 66 Ampere of discharge current, 90 volts of discharge voltage, 2.0 mm of machining depth, 9.5 mm of machining diameter and 1.5 bar of dielectric liquid pressure.
4. For future research work, other single objective performance characteristic material removal rate (MRR), and electrode wear ratio (EWR) could be made using the same method.

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