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Experimental Investigation of MRR, Surface Roughness and Overcut of Aisi 304 Stainless Steel in EDM

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Abstract::EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The workpiece material selected in this experiment is AISI 304 Stainless steel taking into account its wide usage in industrial applications. In today's world 304 stainless steel contributes to almost half of the world's production and consumption for industrial purposes. The input variable parameters are current, pulse on time and duty cycle. Taguchi method is applied to create an L27 orthogonal array of input variables using the Design of Experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR), Surface Roughness (SR) and Overcut (OC) is studied and investigated. The tool material is copper.

The results obtained showed that current was the most significant parameter followed by pulse on time and the least significant was the duty cycle for the entire three responses namely Material removal rate, Surface roughness and overcut. With the increase in current and duty cycle MRR increased but for pulse on time it increased only up to 100 µs and then started to decrease. SR increased significantly with the increase in current; for pulse on time it increased up to 100 µs and after that there was no significant increase; and in case of duty cycle SR increased up to 70% and then started to decrease. OC increased with the increase in current and pulse on time but in different fashion and in case of duty cycle, OC increased up to 70% and then started decreasing.

Introduction

EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The work piece material selected in this experiment is AISI 304 Stainless steel taking into account its wide usage in industrial applications. In today's world 304 stainless steel contributes to almost half of the world's production and consumption for industrial purposes. The input variable parameters are current, pulse on time and duty cycle. Taguchi method is applied to create an L27 orthogonal array of input variables using the Design of Experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR), Surface Roughness (SR) and Overcut (OC) is studied and investigated. The tool material is copper.

Electric Discharge Machining

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other

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in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles.

Effect of Input Parameters

Based on the discharge phenomena discussed above, the effect of various input parameters on material removal rate (MRR) and surface roughness (Ra) is discussed below.

Discharge Current (Id) ampere

The discharge current (Id) is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (Ra) value. Similar effect on MRR and Ra is produced when the gap voltage (Vg) is increased.

Pulse-on time (Ton) μS

Machining takes place only during the pulse-on time (Ton). When the tool electrode is at negative potential, material removal from the anode (work piece) takes place by bombardment of high energy electrons ejected from the tool surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR.

Pulse-off time (Toff) μS

A non-zero pulse off time is a necessary requirement for EDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time. The surface roughness is found to depend strongly on the spark frequency. When high frequency sparks are used lower values of Ra are observed. It is so because the energy available in a given amount of time is shared by a larger number of sparks leading to shallower discharge craters.

Selection of the work piece

AISI 304 Stainless Steel is one of the most widely used materials in all industrial applications and accounts for approximately half of the world's stainless steel production and consumption. Because of its aesthetic view in architecture, superior physical and mechanical properties, resistance against corrosion and chemicals, walkability, it has become the most preferred material over others. Many conventional and non-conventional methods for machining AISI 304 stainless steel are available.

Tool Design

The tool material used in Electro Discharge Machining can be of a variety of metals like copper, brass, aluminums alloys, silver alloys etc. The material used in this experiment is copper. The tool electrode is in the shape of a cylinder having a diameter of 21mm.

Mechanism and Evaluation of MRR

MRR is the rate at which the material is removed the workpiece. Electric sparks are produced between the tool and the workpiece during the machining process. Each spark produces a tiny crater and thus erosion of material is caused.
16 The MRR is defined as the ratio of the difference in weight of the workpiece before and after machining to the density of the material and the machining time.

$$\text{MRR (or) TWR} = \frac{\text{reduction of weight of work piece (or) electrode}}{\text{Density of work piece or electrode (g/mm^3)X machining time}}$$

Where Wi = initial weight before machining
Wf = final weight after machining
T = machining time = 15 min
ρ is the density of AISI 304 stainless steel = 8000 kg/m3

Design of Experiments Analysis

Gnocchi Taguchi developed some statistical methods to improve the qualities of manufactures goods known as Taguchi methods. This design provides a potential and efficient method for designing different products that can operate consistently over a wide range of conditions. Minitab provides both static and dynamic response experiments. The design of experiments is used to find the best combination of input variables in an orthogonal array. In this experiment the input parameters considered are current, Ton, and τ. Since three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. L27 orthogonal array waschosen for the experiments to be conducted.

Process Parameters

1. Surface roughness (R_a)
2. Metal Removal Rate (MRR)
3. Tool Rotation
4. AISI 304 SS
5. Tool wear rate (TWR)

Dielectric Medium in EDM

Functions of dielectric

Dielectric fluid plays an important role in the EDM process. Because of a high dielectric strength, the dielectric medium prevents premature discharge between the electrodes until a low discharge gap is established between them. Continuous dielectric flow in the discharge gap helps in carrying away the debris formed during the discharge and ensures a proper flushing. Also, dielectric medium cools the machining zone by carrying away excess heat from the tool electrode and the work piece.

Properties of dielectric

The most important properties of dielectric are its dielectric strength, viscosity, thermal conductivity and thermal capacity. Dielectric strength characterizes the fluid's ability to maintain high resistivity before spark discharge and the ability to recover rapidly after the discharge. High dielectric strength leads to a lower discharge gap which in turn leads to a low gap resistance. Hence, high discharge currents may flow

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leading to a higher material removal rate. Also, fluids with high dielectric strength need lower time for the recovery of dielectric strength. Thus, low pulse-off times are sufficient. This not only improves the MRR but also provides better cutting efficiency because of a reduced probability of arcing. Liquids with low viscosity generally provide better accuracies because of a better flow ability of the oil leading to improved flushing. Also, the sideward expansion of the discharge plasma channel is restricted by high viscosity fluids. This focuses the discharge energy over a small region and leads to a deeper crater which reduces the surface finish. [4]. Dielectric fluids with high thermal conductivity and thermal heat capacity can easily carry away excess heat from the discharge spot and lead to a lower thermal damage.

Types of dielectric

Selection of dielectric medium is an important consideration for EDM performance. Mineral oils are commonly used as the dielectric medium for die sinking EDM operations. Mineral oils exhibiting high dielectric strength and a low viscosity are preferred because of their higher performance. For safety reasons oils with a high flash point are usually used. Kerosene is one such oil which is used commonly for EDM. Water based dielectrics are used almost extensively for wire EDM operations. Water has a high specific heat capacity which leads to a better cooling effect required for wire cut operations. To prevent chemical reactions, Deionised water is used in such applications.

Analysis method

Taguchi's method

Taguchi's method is a well accepted methodology for experiment design. In this, signal-to-noise ratio(S/N) is used to represent a response or quality characteristics and the largest S/N ratio is required. There are three types of quality characteristics viz. nominal-the-better, larger-the-better and smaller-the-better. In this work, experimentally observed MRR value is "larger-the-better" and TWR and SR are "lower-the-better". Based on Taguchi's method, S/N ratio calculation is done as below)

Larger-the-better
S/N = -10 log (1/n$\sum_{i=1}^{n} 1/Yi$^2)

Smaller- the- better
S/N = -10 log (1/n$\sum_{i=1}^{n} Yi$^2)

Where Yi is the experimentally observed value and n is the repeated number of each experiment.

Analysis of experimental results

Material Removal Rate

The results reveal that electrode exhibited higher MRR value than electrode during production of through holes on AISi 304 SS. This is due to the fact that the electrode with lower thermal conductivity transmits the heat occurring during machining to the base material leading to higher rate of erosion a compared with -electrode.

Table 1: Properties

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Source	Degree of freedom	Sum of squares	Mean square	F-ratio	Percent contribu
Shape factor	1	10.9	10.9	7.7344	5.64
Pulse-on-time	2	12.4	6.2	4.7526	6.94
Pulse-off-time	2	123.52	61.76	47.342	69.15
Discharge current	2	0.12	0.06	0.0459	1.40
Flushing pressure	2	0.13	0.065	0.0498	0.07
Error	16	28.7	1.79375		16.06
Total	25	175.77	80.77875		100

Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes [17]. RSM is useful for the modelling and analysis of experiments in which a response of interest is influenced by several variables and the objective is to optimize this response. Consider a process where the response variable (output) y depends on the controllable (input) variables $x_1, x_2, \ldots, x_k$. The relationship is:

$$y = f(x_1, x_2, \ldots, x_k) \tag{2.8}$$

The true form of the response variable y is seldom known for a process. In RSM, the true relationship between y and the independent variables is generally approximated by the lower-order polynomial models such as: Here, the βs are the unknown parameters. These parameters are estimated by first collecting data on the system and then performing statistical model building by using regression analysis. Response surface designs are special types of experimental designs which are commonly used for the data collection phase. Polynomial models are generally linear functions of the unknown βs. Hence linear regression is used for the model building phase.

Conclusion

The present work explains the machining characteristics of EDM on AISI 304 SS. Taguchi's method has been employed as a design of experiments technique successfully for establishing the relationship between various input parameters and performance measures. MRR increases with the increase in discharge current and pulse-on-time. MRR increases initially, attains a maximum value and further decreases with increase in voltage. SR increases with the increase in discharge current and pulse-on-time. TWR increases with the increase in discharge current and flushing pressure. TWR increases initially with the increase in pulse-on-time but after certain value it decreases. ANOVA has been applied to find the level of influence of input parameters on performance measures. Discharge current is found the most influential input parameter on each performance measure. Higher discharge current increases MRR, deteriorates surface finish and leads for more tool electrode loss. Discharge current and pulse-on-time are identified as common influencing parameters for MRR, SR and TWR.

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