Influence of electrical discharge machining parameters by additives Nano [AL2O3] on surface roughness and material removal rate in machining of AISI 304

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Abstract: Experimental investigation and optimization of machining parameters in electrical discharge machining (EDM) in terms adding particles Nano-reinforced among the various mechanical processes, the process of manufacturing in electrical discharge machines is one of the most effective and cost-efficient manufacturing processes in the manufacture of stainless steel. It has been dealt with in this article investigate each of operating parameters such as peak current (Ip), pulse on time (Pon) and pulse off time(Poff), insulating liquid with Nano powder (AL₂O₃) in EDM compounds AISI 304. In the present research work, the influences of certain process parameters on surface roughness(Ra) and material removal rate(MRR) were investigated on stainless steel carried out with powder mixture with particles size average of [5 nm]. Operating parameters are taking into consideration three factors based on the Taguchi method. The results from this work will be useful for manufacturing engineers to select appropriate set of process parameters to machine stainless steel.

Keywords: Taguchi method, surface roughness, additives Nano, MRR, Al₂O₃

1. Introduction

In recent years, Stainless steel possesses manufacturing flexibility, high strength, high hardness, durability, low maintenance, and resistance to corrosion. These alloy steels are widely used in various engineering applications. Some conventional processing techniques lose the original properties of SS work materials and make them behave like normal materials within the machined surface. Stainless steel is more difficult to manufacture due to its high alloy content [1]. Seem run on Nano powder alumina at with suitable operating environment so it was mixed Nano powder in works to improve the materials flow capacity on the surface during machining, thus enhancing the corrosion resistance in the composite microstructure [2] with an increase in the percentage of booster size. Certain properties such as the softness and strength of the nano compost effect are maintained lone until the adding of 2.0% volume of...
the above Nano powder which greatly decreases the value due to the excessive aggregation of the Nano powders [3]. The heterogeneity of compounds is due to uncontrolled aggregation of Nano powders due to the forces of van der val. By doing some other practical ways, such as spray mining and deposition, Heat has a practical role in moving and is an economically feasible and flexible process reduced production cast and higher manufacturing rate [4]. Ultrasound is an effective and applicable process in dispersing nanotubes widely used in the magnesium matrix [5]. It is difficult to operate the machines through docking methods due to high rigidity and strength of reinforcement. These compounds can be easily formed by unconventional methods such as manufacturing jet water machine, but this method may be limited to linear cutting only. Thus, EDM becomes an appropriate operation for cutting difficult and complex shapes in these types the composite materials [6]. The basic diagram of the EDM setup is observed in Figure 1.

![Figure1. Schematic diagram of EDM](image)

The results showed that the Poff along the Pon was the most important process parameter that influenced on the MRR and Ra [7]. It was observed experimentally that the peak current and pulse time were the more influencing factors that affected on machining time and electrode wear rate [8]. Current density was the term more relevant to variances in material removal rate. It was increased with current and Pon [9,10]. The surface finish and microstructure of the surface are better found with the Cu-Sic electrode [11]. MRR increases greatly when the peak current increased due to the high temperature of the material. The electrode wears decrease with increase in Pon. The value of Ra is greater at high current density and high pulse time. [12]. Ra is used to evaluate the quality of mechanical parts that primarily affect their production costs [13,14]. Therefore, the analysis of effect of different process parameters on AISI 304 steel is very essential. Quadratic models of the response surface have been developed and improved using a desire-based approach [15]. The influences of certain process parameters on (Ra) and (MRR) were investigated on stainless steel carried out with powder mixture (Al2O3) with particles size average of (5 nm). Operating parameters are taking into consideration four factors based on the Taguchi method.

2. Experimental work

The effects of stainless steel 304 alloy have been studied with an insulating liquid mixed with particles Nano Al2O3 with an average particle size of 5nm. The ultrasonic cavity arrangement used in the synthesis and the preheating chamber is made up of powder. Nano powders are heated with the insulating
liquid at about 80°C for one hour in the pre-powder chamber to improve the ability to mix. Uses deionized water mixed with powder Nano AL2O3 as a dielectric and electrode tool made from copper with a diameter of 20 mm, the chemical composition of tool which were the test in central organization for standardization and quality control Table 1. The stainless steel 304 were selected as the workpiece with dimension (40x30x10mm). The chemical structure ratio of the work material is presented in Table 2.

Table 1. Composition of copper tool

| Element  | Zn%  | P%   | Pb%  | Sn%  | As%  | Si%  | S%   | Cd%  | Ag%  | Bi%  | Sb%  | Cu%  |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|
| Weight   | 0.003| 0.005| 0.004| 0.010| 0.008| 0.013| 0.004| 0.001| 0.002| 0.006| 0.009| remain|

Table 2. Chemical properties for workpiece material

| Element                | C%   | Si%  | Mn%  | Cr%  | P%   | Mo%  | S%   | AL%  | Ni%  | Fe%  |
|------------------------|------|------|------|------|------|------|------|------|------|------|
| Stainless steel 304    | 0.06 | 0.33 | 1.30 | 17.26| 0.04 | 0.018| 0.02 | 0.003| 8.6  | remain|

Product quality obtained by the EDM is always affected by the machining parameters like Pon, Poff and, Ip. Proper selection of the machining parameters can cause lower surface roughness and higher material removal rate. Taguchi method was used to design of experiments (DOE) and determine the optimal control factors for minimum Ra and maximum MRR in EDM. It is, a good method for design of experimental (DOE) with performance characteristics, was used based on L9. From Taguchi design concept, a L9(3^3) Table of orthogonal array (OA), the input factors namely (Pon), (Poff), and (Ip) with three levels for each factor is present in Table 2.

Table 3. Control Factors and their Levels

| The Parameter            | Symbol | Level1 | Level2 | Level3 |
|--------------------------|--------|--------|--------|--------|
| Pulse on time (μsec)     | Pon    | 100    | 110    | 120    |
| Pulse off time (μsec)    | Poff   | 20     | 30     | 40     |
| Peak current (A)         | Ip     | 10     | 15     | 20     |
2.1 Experimental procedure

Al experiments on cutting machine EDM CNC (CHEMER CM 323C), as shown in Figure (2).

![EDM machining](image)

Figure 2. EDM machining

The Ra of the workpiece was measured by a surface roughness tester (The Pocket Surf gauge) with 0.8 mm cut off length and stylus radius of 0.0025mm. The MRR (g/min) was calculated with the help of equation 1[16):

$$MRR = \frac{W_{bm} - W_{am}}{M_t}$$  \hspace{1cm} (1)

Where: $W_{bm}$ is Weight before machining in (g), $W_{am}$ is Weight after machining in (g), and $M_t$ represent Machining time. The value of Ra was selected from average readings taken at 9 locations in each sample perpendicular to the layer orientation. Essentially, surface roughness is the lowest of the best performance characteristics while the (MRR) is largest of the best characteristics for Taguchi method in EDM.

2.2. Methodology

The experimental data analysis was done using the Taguchi method and analysis of variance (ANOVA) to find out influence and contribution of input parameters

2.2.1. Taguchi

It is widely used in all applications as a powerful software for analyzing parameters of processes [17]. A specially designed orthogonal array from Taguchi was used in this work to investigate the effects of processing parameters through a small number of experiments and takes less time for experimental investigations.
2.2.2 Signal-to-Noise (S/N) ratio characteristics

Signal to noise ratio was used to measure the variations of experimental design. The word signal says the desirable value and the word noise says the undesirable value [18]. The equation used for calculating S/N ratio for obtaining the smallest Ra is:

\[
S/N = -10 \log \left[ \frac{1}{n} \sum_{i=1}^{n} (y_i^2) \right]
\]

(2)

The quality characteristic for MRR is of the-higher-the-better type. The equation used for calculating S/N ratio for obtaining the largest MRR is [19]:

\[
S/N = -10 \log \left[ \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right]
\]

(3)

Where n: number of replications.

yi: observed response value

3. Results and discussion

According to (DOE) by Taguchi method the results of the experimental work for (Ra) and (MRR) are shown in Table 3. Analysis of variance (ANOVA) was utilized to examine and analysis the effect of input factors on the Ra and MRR. The results of ANOVA are exhibited in Tables 4 and 5.

| No. | Pulse on time (μsec) | Pulse off time (μsec) | Peak current (A) | Surface roughness (μm) | S/N ratio for Ra | Material removal rate (mm3/min) | S/N ratio for MRR |
|-----|---------------------|---------------------|------------------|------------------------|-----------------|---------------------------------|------------------|
| 1   | 100                 | 8                   | 10               | 1.79                   | -5.05706        | 23.62                           | 27.4656          |
| 2   | 100                 | 16                  | 20               | 1.77                   | -4.95947        | 42.17                           | 32.5001          |
| 3   | 100                 | 24                  | 30               | 1.78                   | -5.00840        | 57.11                           | 35.1342          |
| 4   | 150                 | 8                   | 20               | 1.93                   | -5.71115        | 45.36                           | 33.1335          |
| 5   | 150                 | 16                  | 30               | 1.91                   | -5.62067        | 63.22                           | 36.0171          |
| 6   | 150                 | 24                  | 10               | 1.83                   | -5.24902        | 31.42                           | 29.9441          |
| 7   | 200                 | 8                   | 30               | 2.05                   | -6.23508        | 68.82                           | 36.7543          |
| 8   | 200                 | 16                  | 10               | 2.02                   | -6.10703        | 37.65                           | 31.5153          |
| 9   | 200                 | 24                  | 20               | 1.99                   | -5.97706        | 53.71                           | 34.6011          |
3.1 Surface roughness

The OA based on the results of (Ra) and its corresponding signal-to-noise (S/N) ratio as shown Table 3. The corresponding of ANOVA results is lists in Table 4, where the contribution of each parameters was calculated. Signal to noise ratio response in Fig. 3 indicate that the Ra increase upon increasing the pulse on time (Pon), and peak current (Ip). Experiments have shown that Nano powders affect improving surface roughness, which reduces surface roughness. The use of stainless steel increases in voltage frees the surface of the workpiece further, therefore can be attributed to the improvement of the cutting speed in the EDM. The depth of the drilling surface of the EDM increase with an increase in peak current, resulting in larger value of Ra. It can be said that Pon and Ip have great effects on Ra of stainless steel 304 in EDM. These two parameters influence the power input and arguably less power input improves the surface finish.

| Source   | DF | Seq SS   | Adj SS   | Adj MS   | F       | P       |
|----------|----|----------|----------|----------|---------|---------|
| Pon      | 2  | 1.81052  | 1.81052  | 0.90526  | 73.79   | 0.013   |
| Poff     | 2  | 0.09954  | 0.09954  | 0.04977  | 4.06    | 0.198   |
| Pi       | 2  | 0.03392  | 0.03392  | 0.01696  | 1.38    | 0.420   |
| Residual Error | 2 | 0.02454 | 0.02454 | 0.01227 |         |         |
| Total    | 8  | 1.96852  |          |          |         |         |

**Table 5.** Analysis of variance for signal to noise surface roughness

The contour plots in Fig. 4 indicates that the influence of the Pon, Poff, and Ip on the surface roughness. The piecemeal rise in the surface roughness for the incremented Pon and simple change in the Ra for the raised Poff was illustrated from Fig. 4(a). Drastic change in the surface roughness for the increased pulse on time and peak current, which enhances the thermal energy generated during the manufacturing operation. When the thermal energy is distributed around the electrode, it melts the material larger. The increase in the spark gap set voltage isn’t allowed the electrode of EDM to disseminate the thermal energy to an inclusive area around it towards the alloy cross-section. The energy is also disseminated with the successive layers of the stainless steel workpiece with an increased pulse on time and current. The shortage of time for the heat disseminate into the alloy will be decreasing the surface roughness, formed during the experimental operation which was observed in Fig. 4(b). The effect of pulse on time with spark voltage on the surface roughness is increases gradually was observed in Fig.4(c).
3.2 Material removal rate

MRR with the S/N ratio and the ANOVA results are shown in Table 3 and 5, respectively. By showing the contribution of each given factor in the table, it was found that the Pon dominated the performance properties of the MRR, with the contribution being approximately 88.68% followed by the spark gap voltage of 9.51%. The graph of the signal to noise response in Fig. 5. The MRR increases with increasing pulse time, and peak current .. As the pulse duration increases, more energy is provided to the cutting process due to the increased cutting speed. Increasing the current causes an increase in the Pon, which in turn can improve the cutting rate further. In clear sense, higher pulse on time is the main factor in obtaining a higher removal rate in the process of the stainless steel operation. Poff and Ip can be considered as less important factors since their percentage contributions are smaller than those of Pon .

| Source      | DF  | Seq SS  | Adj SS  | Adj MS  | F      | P     |
|-------------|-----|---------|---------|---------|--------|-------|
| Pon         | 2   | 10.0668 | 10.0668 | 5.0334  | 20.26  | 0.047 |
| Poff        | 2   | 1.4126  | 1.4126  | 0.7063  | 2.84   | 0.260 |
| Pi          | 2   | 60.7794 | 60.7794 | 30.3897 | 122.33 | 0.008 |
| Residual Error | 2   | 0.4968 | 0.4968 | 0.2484 |        |       |
| Total       | 8   | 72.7557 |         |         |        |       |
The effect of machine parameters on MRR as shown in Figure 6. The gradual increase in the MRR for the increased Pon and Poff was observed from Fig. 6(a). Increasing in MRR for the increased Pon and Ip, because the heat energy generated on the workpiece surface therefore melting and removed the particles of metal which was shown in Fig.6(b). The increase in Pon leads to spread the thermal energy to a large area around it it towards the alloy cross-section. Moreover, the presence of a solid Al2O3 particle is not completely dissolved during the experimental process. The effect of Pon on the MRR is increases drastic change which exhibited in Fig.6(c).
4. Conclusion

In this paper the effects of machining conditions are conducted on the Ra and MRR in EDM for AISI 304 with additives Nano powders (AL2O3) was determined by using Taguchi method in Minitab 17 software. Analysis of variance (ANOVA) was using to determine the significant of the machining conditions on Ra and MRR, the most significant parameters on Ra were found to be pulse on time, where peak current was less effective factor, while were found the peak current and pulse on time is most significant parameters on MRR. With increased current the molten metal is removed due to the increase in discharge power and heat energy. when the pulse on time increases and the surface roughness increases, peak current also has a role in reducing surface hardness to the surface. A rigorous examination of the component surface revealed to the surface roughest was due primarily to the high value of Pon and current. The cooling fluid mixed with the Nano powders has an effective role in improving the roughness of the surface and increasing the cutting speed.

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