Influences and Optimization of Electrical Discharge Machining of AISI 2205

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Abstract. The effective implementation of any machining process relies on its ability to machine the component with high efficiency and with excellent surface finish. Electrical discharge machining is a non-conventional method of machining which is well developed and is used for the manufacture of components which have geometrically complex shapes and intricate profiles. In the present research an attempt has been made to determine the optimized process parameters of electrical discharge machining of duplex stainless steel (DSS) AISI 2205. Process parameters are optimized and selected based on resulted material removal rate (MRR) and tool wear rate (TWR). Taguchi method is used for design of experiments and their analyses to determine best suitable parameters for AISI 2205 machining.

Keyword: EDM; MRR; TWR; Taguchi Method; AISI 2205;

1. Introduction

Materials plays key role in deciding the properties structure which to be build[1-5]. Urbanization and global modernization are increasing rapidly which are the main reasons for the growth and demand of the stainless steel’s in industries and market [6]. The growth in the automotive industry will likely maintain the demand for stainless steel in the near future[7]. Duplex 2205 is the most widely used duplex stainless-steel grade and it is characterized by high yield strength and also good fatigue strength. The major application of duplex stainless steel 2205 are in ship containers, shipbuilding, heavy duty vehicle, pressure vessels, petrochemical industries, food processing industries, heat exchangers etc. The chemical content of chromium and sulphur in high and low level respectively, make it as corrosion resistance, high toughness and good hot working ability. Demand of DSS in various applications require its processing in terms of machining and fabrication. It is well known that the duplex stainless-steel exhibits body centered (α) ferrite phase which shows resistance to pitting and corrosion (Crevice) whereas, second Face centered Y’ austenite structure which give it better strength ,toughness and hot workability [8]. This is foreseen to continue as recent development specifies evolving applications of such duplex stainless steels in structural design [9]. Stainless steel put an extra challenge during machining operation due to its high affinity to work hardening [10]. Among the family of stainless steel, duplex stainless steel has difficulties during machining due to its high strength and low carbon content [11]. It is reported in literature that duplex stainless steel during machining shows built up edge formation due to material adherences to tool and hence low cutting speed. High tool wear is reported
due to low cutting speed and hence low dimensional tolerance /finish [12]. Investigation of the material response during machining process is generally strategy of understanding the machinability of any material. There are some studies to investigate machinability and established a correlation between the pitting resistance equivalent and the machinability for duplex alloys [13, 14]. Nomani et al. [3] have investigated machinability of duplex alloys such as SAF2507, SAF 2205 and found the duplex alloys experience higher incidences of built-up edge formation as compare to austenitic stainless steel which increase tool wear and poor finish using conventional machining. Thus, these complexities limit the use of conventional machining duplex stainless steel. Electrical discharge machining is one kind of non-traditional machining process [15-17]. EDM is a commonly used non-conventional method which is economical to remove material by vaporizing through high temperature sparks [18]. The effect of process parameters on duplex stainless steel during wire electrical discharge machining were studied by many researchers [19, 20]. It is observed that increase pulse on time results in increase in surface roughness at low pulse off time whereas MRR increase with increase in pulse on time. It is because in higher pulse on time results higher energy to vaporization which results higher MRR [12]. Thus, it is clear from the literature that more study related EDM process parameters needed to get best performance of the process. In the present work an attempt has been made to investigate accuracy of EDM process during machining of DSS at different machining condition by the help of Taguchi experimental design. Surely, this study adds some literature to scientific community to understand the virtue of EDM to optimizing the process parameters.

2. Experimentation

In present work a plate of DSS 2205 is machined on a die-sink EDM machine (Make Sparkonix) as shown in Fig.1(a). The chemical composition of base metal DSS 2205 is presented in Table 1. The proper selection of EDM machining parameters is important in order to achieve successful machining process. It is found from the literature that there are four important process parameters of machining using EDM, which significantly influences the characteristics of the machining. In present work peak current, pulse on time (Ton), duty cycle, gap voltage process parameters are selected for the study.

Table 1: Chemical Composition of DSS

| Element in DSS | Carbon | Silicon | P | Mn | Cr | Mo | Cu | S | N |
|----------------|--------|---------|---|----|----|----|----|---|---|
| Weight %       | 0.026  | 0.47    | 0.023 | 1.37 | 22.27 | 3.10 | 0.15 | 0.001 | 0.15 |
| Ni             | Fe     | Bal     | 5.46 |

The machining is performed in fine finish setting mode. Pure copper electrode is used to carry out the experiment as shown in Figure 1(b). Transformer oil is utilized as a dielectric fluid and other details related machining are presented in Table 2.

Table 2: EDM Details of electrode and dielectric fluid

| Electrode Description | Specification       |
|-----------------------|---------------------|
| Electrode material    | Pure copper         |
| Electrode diameter    | 8mm                 |
| Dielectric fluid      | Transformer oil     |

Based on the selected machining parameters, L9 orthogonal array is used to design the experiments. The selected parameters and their levels are presented in Table 3. The selected machining parameters and their levels were selected based on the available information in the literature of EDM.
Table 3. Machining parameters and their respective level

| Input Parameter | Symbol | Level-1 | Level-2 | Level-3 |
|-----------------|--------|--------|--------|--------|
| Current         | Ip (A) | 2      | 4      | 6      |
| Pulse on time   | Ton (µs) | 40    | 100    | 160    |
| Duty cycle      | D      | 0.30   | 0.60   | 0.90   |
| Gap between     | Vgap   | 20     | 50     | 80     |

Experimental design based on L9 orthogonal array is presented in Table 4. The present orthogonal array is capable to examine the effect of varying process parameters. Machined sample using EDM is shown in Figure 1(c).

Table 4: Experimental design and response as per orthogonal L9 array

| Experiment | Ip  | Ton  | D   | Vgap |
|------------|-----|------|-----|------|
| 1          | 2   | 40   | 0.30| 20   |
| 2          | 2   | 100  | 0.60| 50   |
| 3          | 2   | 160  | 0.90| 80   |
| 4          | 4   | 40   | 0.60| 80   |
| 5          | 4   | 100  | 0.90| 20   |
| 6          | 4   | 160  | 0.30| 50   |
| 7          | 6   | 40   | 0.90| 50   |
| 8          | 6   | 100  | 0.30| 80   |
| 9          | 6   | 160  | 0.60| 20   |
3. Results and discussion

Experiments were conducted based on the Taguchi experimental design L9. Responses in terms of MRR and TWR are measured as presented in Table 5. In Taguchi based experimental design and process optimization, signal-to-noise (S/N) ratio calculation plays important role in quantitative evaluation of responses. S/N ratio is mainly used to estimate the deviation of response values (MRR and TWR in the present work) from the desired target. In order to achieve the best possible machine parameters, the deviation from desired target must be minimum. Higher value of material removal rate (MRR) shows favorable machining condition, thereby the characteristics of algorithm is called as Larger the better. Whereas, the characteristics where lower value of response is favorable machining condition such as TWR is known as smaller the better.

Table 5: Experimental design and responses as per orthogonal L9 array

| Experiment | Ip | Ton | D   | Vgap | MRR (gm/min) | TWR (gm/min) |
|------------|----|-----|-----|------|--------------|--------------|
| 1          | 2  | 40  | 0.30| 20   | 0.00444      | 0.00012      |
| 2          | 2  | 100 | 0.60| 50   | 0.00702      | 0.00011      |
The measured MRR and TWR for respective experimental condition is given in Table 5. The calculated S/N ratio based on the characteristics of response are presented in Fig 2 and Fig 4. The parameter contribution or significance is determined based on calculated rank of the parameters.

3.1. Influence of Process Parameters on material removal rate
Material removal rate is important characteristics in machining [17]. In order to calculate the MRR, the weight of the workpiece before and after machining is recorded. With these records, MRR is calculated using Equation 1. It is well established that more MRR shows the better performance of the machine.

\[
MRR = \frac{Initial \ weight \ of \ workpiece \ (w_i) - Final \ weight \ of \ workpiece \ (w_f)}{total \ machining \ time (t)} \quad (1)
\]

The signal to noise ratio for MRR is calculated considering the higher the better characteristics, which is given in Equation 2.

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

In Eq. 2, the value of n is number of experiments performed. Figure 2, shows respective S/N ratio, for all experimental condition.
Figure 2: Signal to noise ratio graph for MRR with larger is better characteristics

It is found from the Figure 2 that the value of S/N ratio is higher with parameters 6A peak current, Ton time 160 micro second, Duty cycle 80 % and gap voltage 80V. It is obvious that high peak results in high density flow of electron between the electrode and work piece which results in higher material loss or removal. Analysis of variance (ANOVA) is also used to determine the contribution of all influential parameters. It is observed from the results that peak current (Ip) has first rank, whereas, gap voltage is least rank among all influential parameters.
Figure 3: Generated contour plot for MRR a) peak current Ip Vs current on time Ton b) peak current Ip vs duty cycle D c) peak current Ip vs gap voltage Vgap

Figure 3 represents the different contour plots for MRR to understand the interaction effects of two parameters. It is clear from the Figure 3(a) that maximum MRR i.e. 0.020-0.025 gm/min is achieved at 6A with 150 micro seconds. In Figure 3(b), interaction effect of peak current (Ip) and duty cycle (D) is presented. It is found from the Figure 3(b), optimal results of MRR is obtained at 6A peak current (Ip) and 65% duty cycle. Whereas, optimal results in terms of MRR is obtained at low gap voltage (Vgap) as shown in Figure 3(c).

3.2. Influence of Process Parameters on tool wear rate

The effect of parameters on tool wear rate (TWR) is evaluated. The weight of tool before and after machining is recorded and rate of loss of tool is calculated using Equation 1.

\[
TWR = \frac{\text{Initial weight of electrode/tool (wt) - Final weight of electrode/tool (wt_0)}}{\text{total machining time (t)}}
\]  

(3)

In order to find the optimal process parameters, the value of S/N ratio is determined using Eq. 4, which has the lower the better characteristics.

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

(4)

where n represents the total number of experiments performed.

Figure 4: SN ratio graph with smaller is better characteristics for TWR

Lower TWR shows the better performance of the process based on the parameters. It is observed from the Figure 4 that higher S/N ratio is found at 4A peak current, 100 micro seconds, 30% duty cycle and 20V gap voltage (Lowest). It is observed that the lower TWR is found at low level of peak current and pulse on time because low peak current has low energy density. So, the ions which are responsible for wear of tool have low energy density, which ultimately results in lower tool wear.
It is noticed from the experimental results that maximum value of TWR is obtained 6A peak current, 40 micro seconds pulse on time ,50V gap voltage and 90% duty cycle. Whereas, Lower value of TWR was obtained with 4A peak current 160 micro seconds pulse on time, 50V gap voltage and 30% duty cycle, as presented in Table 5. Figure 5 represents the different contour plots for TWR to understand the interaction effects of two parameters. It is clear from the Figure 5(a-c) that the optimal results in terms of TWR will be obtained with parameters under red color region. In Figure 5(b), interaction effect of peak current (Ip) and duty cycle (D) is presented. It is found from the Figure 5(b), that optimal results of TWR are obtained in all region of parameters except high level peak current and duty cycle as shown by blue color. The TWR variation with peak current and gap voltage is presented Figure 5(c). It is observed from contour graph that optimal results are obtained moderate peak current with any level of gap voltage.

4. Conclusions

A suitable selection of input process parameters is vital for execution any process which either controlled by of any computer-incorporated system. The present work describes the use of Taguchi Method for finding the optimal process parameter of electrical discharge machining. Optimize EDM process parameter is presented during EDM of duplex stainless steel. Following conclusions were drawn: (1): It is found from the observations that peak current (Ip) and pulse on time are most influential parameters, whereas, gap voltage (V) has least effect on machining.(2): Optimum MRR based on the S/N ratio is obtained at 6A peak current, 160 micro second pulse on time, 80 % Duty cycle and 80V of gap voltage. (3): Optimum TWR based on the S/N ratio is obtained at 4A peak current, 100 micro second pulse on
time, 30 % Duty cycle and 20V of gap voltage. (4): It can observe that current has highest percentage of contribution to get best result of Material removal rate whereas gap voltage has least contribution.

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