Optimization of Dimensional accuracy in plasma arc cutting process employing parametric modelling approach

Deepak kumar Naik, K.P. Maity*

Department of Mechanical Engineering, National Institute of Technology Rourkela, Odisha, India

Email address: naikdeepak81@gmail.com, kpmainty@gmail.com *

* Corresponding author

Abstract

Plasma arc cutting (PAC) is a high temperature thermal cutting process employed for the cutting of extensively high strength material which are difficult to cut through any other manufacturing process. This process involves high energized plasma arc to cut any conducting material with better dimensional accuracy in lesser time. This research work presents the effect of process parameter on to the dimensional accuracy of PAC process. The input process parameters were selected as arc voltage, standoff distance and cutting speed. A rectangular plate of 304L stainless steel of 10 mm thickness was taken for the experiment as a workpiece. Stainless steel is very extensively used material in manufacturing industries. Linear dimension were measured following Taguchi’s L_{16} orthogonal array design approach. Three levels were selected to conduct the experiment for each of the process parameter. In all experiments, clockwise cut direction was followed. The result obtained thorough measurement is further analyzed. Analysis of variance (ANOVA) and Analysis of means (ANOM) were performed to evaluate the effect of each process parameter. ANOVA analysis reveals the effect of input process parameter upon leaner dimension in X axis. The results of the work shows that the optimal setting of process parameter values for the leaner dimension on the X axis. The result of the investigations clearly show that the specific range of input process parameter achieved the improved machinability.

Keywords: Plasma arc cutting, Dimensional accuracy, Taguchi method, ANOVA.

1. Introduction

PAC is a thermal cutting manufacturing process which used to cut the high strength material, such as stainless steel, carbon steel, aluminum and non-ferrous materials. To achieve the higher accuracy, better quality and reduced time, PAC process was introduced in 1950.This is a faster cutting process as compared to other with greater flexibility. The limitation of this process is that it can cut only electrically conductive materials [1, 2].

Plasma is a forth state of matter and highly energized in nature. It behaves like a high temperature gas. An electric arc is generated between workpiece and the electrode. The workpiece acts as the anode and the electrode acts as the cathode in this process. The physics behind the PAC process is that the arc is constricted by a copper nozzle (fine bore). Due to this, the temperature increases up to 20,000° C . The plasma jet velocity emanating from the nozzle. Thus, the plasma gas the flow is increased so that the deeply penetrating plasma jet cuts the material and blown away the molten material [3]. Fig. 1 shows the mechanism of PAC process.
PAC process encompasses greater number of process parameter. To accomplish smooth operation of this process, it needs optimization of process parameters. Many researchers attained the investigations in this direction [4]. Optimization of quality indicators, such as dimensional accuracy, kerf characteristics and quality of the cut surface has been investigated by them [5-8]. In PAC operation, the effect of input variable onto the dimension accuracy performance were studied and introduced an optimal cutting condition using ANOVA and ANOM [9]. The optimal parameter setting was introduced using RSM and GRA coupled with PCA analysis in PAC on AISI 316 stainless steel [10]. Taguchi’s L_{27} orthogonal array employed to design the experimental run and optimize the process parameter of PAC on1017 steel [11].

The proposed investigation focuses on the effect of input variables onto the dimensional accuracy of 304L stainless steel. An optimization was carried out employing full factorial design of experiment method.

2. Materials and methods

In this research work experiments were performed on 304L stainless steel which is very extensively used material in manufacturing industries. Mainly aerospace and automotive industries employs this grade of stainless steel to produce finish goods. CNC plasma arc cutting machine of MESSER Company named BURNY 1250 was used to conduct the experiment. A rectangular plate having 10 mm thickness was taken for all the experiment.

Working gas selection in PAC operation plays a vital role to achieve a precise cutting. Argon and oxygen was used as inert and shielding gas respectively. The supply of oxygen was fixed at 20 Mpa, while argon was at 1.2 Mpa. Voltage kept constant at 400 volts. 2mm diameter of swirl nozzle of tungsten material was taken as electrode.

The input process parameters were selected as arc voltage, standoff distance (SOD) and cutting speed (CS). Two levels were selected to conduct the experiment for each of the process parameter. Taguchi’s L_{16} orthogonal array was choosed for the design of experimental run. The range of variables are furnished in Table 1.

| Symbol | Input parameters | Units | Level 1 | Level 2 |
|--------|------------------|-------|---------|---------|
| A      | Arc current      | A     | 70      | 80      |
| B      | Voltage          | V     | 140     | 150     |
| C      | SOD              | mm    | 3       | 4       |
| D      | CS               | Mm/min| 2500    | 3000    |

A rectangular cut of 40×50 mm was achieved for all 16 experiments as specified in the orthogonal matrix. In all experiments, clockwise cut direction was followed. Fig. 2 shows the direction of measurements. The leaner x dimension of the quadrilateral base was measured on its top surface. A digital vernier caliper of 1 micron was used to measure taken along X axis direction. Average of four measurements as well as deviation was measured for each workpiece. Deviation is the difference between the minimum and maximum value of four measurement. The result obtained thorough measurement is furnished in Table 2.
Table 2: Experimental result

| Run no | A   | B   | C | D   | Average X (mm) | Deviation (mm) |
|--------|-----|-----|---|-----|----------------|----------------|
| 1      | 70  | 140 | 3 | 2500| 49.328         | 0.41           |
| 2      | 70  | 140 | 3 | 3000| 49.300         | 0.39           |
| 3      | 70  | 140 | 4 | 2500| 49.478         | 0.35           |
| 4      | 70  | 140 | 4 | 3000| 49.460         | 0.33           |
| 5      | 70  | 150 | 3 | 2500| 49.241         | 0.36           |
| 6      | 70  | 150 | 3 | 3000| 49.223         | 0.34           |
| 7      | 70  | 150 | 4 | 2500| 49.413         | 0.29           |
| 8      | 70  | 150 | 4 | 3000| 49.393         | 0.28           |
| 9      | 80  | 140 | 3 | 2500| 49.415         | 0.47           |
| 10     | 80  | 140 | 3 | 3000| 49.360         | 0.46           |
| 11     | 80  | 140 | 4 | 2500| 49.575         | 0.41           |
| 12     | 80  | 140 | 4 | 3000| 49.554         | 0.43           |
| 13     | 80  | 150 | 3 | 2500| 49.335         | 0.42           |
| 14     | 80  | 150 | 3 | 3000| 49.320         | 0.41           |
| 15     | 80  | 150 | 4 | 2500| 49.503         | 0.35           |
| 16     | 80  | 150 | 4 | 3000| 49.499         | 0.36           |
3.Result and Discussion

3.1 Analysis of Means (ANOM)

ANOM (Analysis of means) was achieved onto the experimental result to find the rate of significant of process parameter. ANOM of leaner dimension and minimum deviation was performed and presented in Table 3 and Table 4 respectively. According to ANOM of linear dimension, SOD is the most significant process parameter followed by current, voltage and cutting speed. Also from the ANOM of minimum deviation, it is found that the current is the most significant process parameter followed by SOD, voltage and cutting speed. The ANOM graph was plotted for leaner dimension and minimum deviation and shown in Fig. 3 and Fig. 4 respectively. According to the ANOM diagram, the best optimal solution for optimizing the leaner X dimension is; current: 80 A, voltage: 140 V, SOD: 4 mm and cutting speed: 2500 mm/min. Minimization of the deviation is accomplished when; current: 70 A, voltage: 150 V, SOD: 4 mm and cutting speed: 3000 mm/min.

Table 3: ANOM (Leaner dimension)

|        | L1 | L2 | Delta | Rank |
|--------|----|----|-------|------|
| A      | 49.35 | 49.45 | 0.09  | 2    |
| B      | 49.43 | 49.37 | 0.07  | 3    |
| C      | 49.32 | 49.48 | 0.17  | 1    |
| D      | 49.41 | 49.39 | 0.02  | 4    |

Table 4: ANOM (Minimum deviation)

|        | L1 | L2 | Delta | Rank |
|--------|----|----|-------|------|
| A      | 0.344 | 0.414 | 0.07  | 1    |
| B      | 0.406 | 0.351 | 0.055 | 3    |
| C      | 0.408 | 0.350 | 0.057 | 2    |
| D      | 0.383 | 0.370 | 0.007 | 4    |
3.2 Analysis of Variance (ANOVA)

The impact of process parameter on leaner dimension and minimum deviation have been performed using ANOVA. This test reveals the significance of process parameter and performance indicator. Also needs for estimating the error variances for the parameters effects. The F-test has performed at 95% confidence level. The ratio of mean square deviations of each parameter and the mean square of corresponding parameter is the F-value. The factors are significant if P-value (probability of significance) is less than 0.05 at 95% confidence interval.

Table 5 and Table 6 portrays the result of ANOVA for leaner dimension and minimum deviation respectively. From Table 5, it reveals that all the cutting parameters are significant whose P-value is less than 0.05 at 95% confidence interval during the ANOVA test of leaner dimension. SOD is the most significant process parameter whereas it contributes 67.74 % followed by current 19.45 %, voltage 10.91 % and cutting speed 1.19 %. Also, Table 6 unveils that all the process parameter are significant except cutting speed. P-value of cutting speed is more than 0.05. Current is the most significant factor affecting deviation about 42.45 %. Also, SOD, current and cutting speed contributes 28.64 %, 26.21 % and 0.49 % respectively. This trend has also been observed from the ANOM graphs.

Table 5: ANOVA- Leaner dimension

| Source | DF | Seq SS | Adj MS | F     | P  | %   |
|--------|----|--------|--------|-------|----|-----|
| Current| 1  | 0.032852 | 0.032852 | 300.84 | 0  | 19.45 |
| Voltage| 1  | 0.018428 | 0.018428 | 168.76 | 0  | 10.91 |
| SOD    | 1  | 0.114413 | 0.114413 | 1047.8 | 0  | 67.74 |
| CS     | 1  | 0.002003 | 0.002003 | 18.34  | 0.001 | 1.19 |
| Error  | 11 | 0.001201 | 0.000109 |       |     |      |
| Total  | 15 | 0.168896 |        |       |     |      |

Table 6: ANOVA- Minimum deviation

| Source | DF | Seq SS | Adj MS | F     | P  | %   |
|--------|----|--------|--------|-------|----|-----|
| Current| 1  | 0.0196 | 0.0196 | 210.34 | 0  | 42.45 |
| Voltage| 1  | 0.0121 | 0.0121 | 129.85 | 0  | 26.21 |
| SOD    | 1  | 0.013225 | 0.13225 | 141.93 | 0  | 28.64 |
| CS     | 1  | 0.000225 | 0.000225 | 2.41  | 0.148 | 0.49 |
| Error  | 11 | 0.001025 | 0.000093 |       |     |      |
| Total  | 15 | 0.046175 |        |       |     |      |
4. Conclusions

In this research work the PAC process was experimentally investigated on 304L stainless steel. The influence of process parameters onto the X direction dimensional accuracy. Also, the deviation was established using ANOM and ANOVA. The following findings were concluded of this research experiment:

1. The optimal condition for the leaner dimensions on the X axis were; current: 80 A, voltage: 140 V, SOD: 4 mm and cutting speed: 2500 mm/min.
2. The optimum parameters values for the deviation were; current: 70 A, voltage: 150 V, SOD: 4 mm and cutting speed: 3000 mm/min.
3. ANOVA portraits that the X axis leaner dimension is contributed the most by the SOD (67.74 %) and the deviation is affected the most by the current (42.45 %).

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