Investigation Analysis of Plasma arc cutting Parameters on the Unevenness surface of Hardox-400 material

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Abstract

Plasma arc cutting (PAC) is a thermal cutting process that makes use of a constricted jet of high-temperature plasma gas to melt and separate (cut) metal [2]. In this study 12mm plate thickness Hardox-400 has been cut by high tolerance voltage, cutting speed, and plasma gas flow rate included as main parameters in the analysis and their effect on unevenness of cut surface is evaluated. The design of experiments (DoE) techniques is used in order to outline the main parameters which define the geometry of the cut profile, as well as its constancy for Hardox-400 material plate. Despite the value selected for these parameters, the analysis shows that Hardox-400 plates can have different profiles, depending on the specific side considered. Unevenness can be obtained as a result of an experimental investigation aimed at selecting the proper values of process parameters of PAC system. Results of this screening step are analyzed by means of the Analysis of Variance (ANOVA) technique with use of design expert 8.0.7.1 software in order to clearly identify the main parameters, which define the unevenness quality attribute. The operating conditions have been carefully optimized through parameters adjustment like cutting speed, plasma gas and arc voltage in order to obtain good surface quality for all the sides of Hardox-400 plate.

Keywords: plasma arc cutting, hardox-400 material, DOE, Design expert software.
1. Introduction

Steel typically used for the construction of paver’s vehicles and in carpentry, thanks to its excellent quality in welding. Different options exist to profile a sheet or a plate; laser, plasma, oxy-fuel, water-jet and mechanical profiling are those most frequently used [1]. Limiting our attention to railway constructions and railway trucks in particular, they are typically welded structures built by starting from plates with a thickness in the range of 6 to 12 mm [7]. Plasma cutting in this case is cheaper and faster than laser or water jet cutting, and it provides better edge finish thanoxy-fuel. Plasma arc cutting was invented in the mid 1950’s and became commercially successful shortly after its introduction to industry [6]. Plasma cutting system is most economical and cut a verity of shape accurately. This is new technology is commonly called high tolerance plasma arc cutting system. HTPAC system share the key ability of generating very constricted and arcs, in other words high energy density along the torch axis which produces narrow and nearly square kerfs [4]. The challenge of today research in HTPAC is to increase the energy density generated by the system to achieve higher cutting thickness without losing the overall quality of cut shown in Figure.1 (a)

![Figure 1 (a) Schematic Diagram of plasma arc cutting](image)

The plasma arc cutting (PAC) process removes metal by using a constricted arc to melt a localized area of a work piece, removing the molten material with a high-velocity jet of ionized gas issuing from the constricting orifice [3]. The ionized gas is a plasma, hence the name of the process. Plasma arcs operate typically at temperatures of 18,000-25,000°F (10,000-14,000°C). Plasma is that it is the fourth state of matter. We normally think of the three states of matter as solid, liquid and gas. For the most commonly known substance, water, these states are ice, water and steam. If you add heat energy, the ice will change from a solid to a liquid, and if more heat is added, it will change to a gas (steam) [5]. When substantial heat is added to a gas, it will change from gas to plasma, the fourth state of matter, Shown in Figure.1 (b) plasma arc cutting.
2. Experimental setup

2.1 Base Material

Hardox-400 in standard plate supply has a ferrite structure; the chemical composition of this material is given in Table- 1 specimens, 50 mm wide, were machined from plates with thickness of 12 mm is typically used in the construction of pavers & plants. The external surfaces of the specimens were not machined, so as to maintain, as in real constructions, the "as-received" condition of the plates.

Table 1. Chemical Composition of Hardox-400 Material

| C   | Si  | Mn  | P   | S   | Cr  | Mo  | B   |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.13| 0.53| 1.24| 0.012| 0.002| 0.65| 0.019| 0.002|

Chemical composition change the Hardness values of hardox-400 material Hardox is no ordinary wear plate its toughness is very high under most extreme condition, such as high ratio of strain with varying temperature ,this makes Hardox particularly resistant to impact [9]. Above table shows that cr percentage is increases in hardox-400 material in compare of mild steel. So hardox-400 material become hard compare of mild steel. There is more Chromium percentage than mild steel in hardox-400 material so the addition of chromium results in the formation of various carbides of chromium which is very hard. A full factorial design contains all possible combinations of a set of factors. This is the most conservative design approach, but it is also the most costly in experimental resources. The full factorial design supports both continuous factors and categorical factors with up to nine levels. In full factorial designs, perform an experimental run at every combination of the factor levels.

2.2 Plasma Cut Specimens

A group of specimens was obtained by cutting them with a numerically controlled plasma cutting machine. The torch was water-cooled and had a nozzle with an outlet diameter of 2.5 mm the plasma gas was oxygen, 0.05m3/s, at a pressure of 10.bar.a current setting of 130 amps at 135volts was used. The distance between the torch and the plate was 3.3 mm, the cutting speed was varies given in table. The plasma cut specimens was also obtained in the longitudinal direction of the plates. The plasma cut surfaces did not look as regular as the milled surfaces. The plasma cut edges were not straight and the width of the plate on the reverse side was about 0.8 mm smaller than that on the torch side, 50.05 mm, while the nominal dimension was 50 mm. These differences are generally meaningless in large structures, but can be important in small structures, so that it can be concluded that close tolerances cannot be obtained by standard plasma cutting. Besides, small scratches were present on the cut surfaces. The loads to be applied in the tests on plasma cut specimens were evaluated by taking into account their actual dimensions.
2.3 Setting and measurement procedure

The unevenness is measured by using Plunger dial Depth meter which is Mittu Toyo Company and its Range 0-30 mm its accuracy is 0.001mm. The unevenness is average measured all four sides as shown in Figure. 2(a)

\[
M = \frac{\sum_{i=1}^{4} ml}{4}
\]

Where
- \(M\) = Mean unevenness
- \(m\) = unevenness of one side
- \(l\) = side of plate

Fig. 2(a) Unevenness measurement profile

| Factors (measuring unit) | Step | Low level | High level |
|--------------------------|------|-----------|------------|
| Cutting speed (mm/min)   | ±4.6%| 2100      | 2300       |
| Plasma Flow rate (l/h)   | ±5   | 70        | 80         |
| Voltage (v)              | ±5v  | 125       | 135        |

On each side of the plate, three profiles were inspected. The location of these points was selected according to the ISO 9013 standard. The middle profile was positioned at the centre of the side and the other two 15 mm apart from it. For each profile the unevenness value was calculated as the maximum difference between the horizontal coordinates of seven measured points Figure. 2(b) is cut by plasma gas cutting machine 50 X 50 cutting plate of hardox-400 material, shown in Figure 2(c) Irregular profile of Hardox cutting plate.

Fig. 2. (b) Cutting plate of hardox-400 material (c) Irregular profile of cutting
3. Design

Three process parameters were chosen as factors. (Cutting speed, Voltage, plasma flow rate). Besides the cutting speed \( f \), the arc voltage \( V \) was included in the analysis. The arc voltage not only defines arc power, but it is proportional to the torch standoff distance, which directly affect the shape of the kerf [8]. This design will give information just on the main effects and two factor interactions. In this screening stage, three factors, each at two levels, are of interest. Therefore, the whole number of treatment combinations should be equal to \( 2^3 \times 2 = 8 \). In order to reduce the experimental efforts, this design gives information just on the main effects and two factor interactions. For each treatment combination, two replicates were considered, thus requiring a whole number of \( 2^3 \times 2 = 16 \) plates. The runs were randomized to prevent systematic effects on the response.

| Trial No. | Cutting Speed (mm/min) | Voltage (V) | Plasma Flow Rate (l/h) | Data (unevenness) (micron) |
|-----------|------------------------|-------------|------------------------|---------------------------|
| 1         | 2100                   | 125         | 70                     | 420                       |
| 2         | 2100                   | 125         | 70                     | 422                       |
| 3         | 2100                   | 125         | 80                     | 654                       |
| 4         | 2100                   | 125         | 80                     | 660                       |
| 5         | 2100                   | 135         | 70                     | 570                       |
| 6         | 2100                   | 135         | 70                     | 565                       |
| 7         | 2100                   | 135         | 80                     | 610                       |
| 8         | 2100                   | 135         | 80                     | 600                       |
| 9         | 2300                   | 125         | 70                     | 421                       |
| 10        | 2300                   | 125         | 70                     | 423                       |
| 11        | 2300                   | 125         | 80                     | 537                       |
| 12        | 2300                   | 125         | 80                     | 535                       |
| 13        | 2300                   | 135         | 70                     | 495                       |
| 14        | 2300                   | 135         | 70                     | 490                       |
| 15        | 2300                   | 135         | 80                     | 575                       |
| 16        | 2300                   | 135         | 80                     | 580                       |

4. Analysis of Variance (ANOVA) Calculation

There is a standard statistical technique called analysis of variance (ANOVA) which is routinely used to provide a measure of confidence the technique does not directly analyze the data but rather determines the variance of data. Confidence is measured from the variance. The total contribution of each is calculated as shown below. Three factors are A, B, and C is cutting speed, voltage and plasma flow rate. They have a high and low level. So its two level are become A1, and A2 for cutting speed. For voltage B1 and B2 its high level and low level, and plasma flow rate C1And C2 it’s high and low level.

The results of analysis of variance (ANOVA) for Unevenness is shown in table 4. This table also shows the degrees of freedom (DF), sum of squares (SS), mean squares (MS), F-values (F-VAL.) and probability (P-VAL.) in addition to the percentage contribution (Contribution percentage) of each factor and different interactions. A low P-value (<0.05) indicates statistical significance for the source on the corresponding response (i.e., \( \alpha = 0.05 \), or 95% confidence level), this indicates that the obtained models are considered to be statistically significant, which is desirable as it demonstrates that the terms in the model have a significant effect on the response.
Table 4: Analysis of variance for 12 mm Hardox-400 plate

| Source of variance | Sum of square | DF | Means square | F value | P value | Prob>F | Percentage contribution |
|--------------------|--------------|----|--------------|---------|---------|--------|------------------------|
| Model              | 100000       | 7  | 14348.3      | 1029.463| <0.0001 |        |                        |
| A - Plasma flow rate| 55814.06    | 1  | 55814.06     | 4004.596| <0.0001 | 55.81  |                        |
| B - Voltage        | 10660.56     | 1  | 10660.56     | 764.883 | <0.0001 | 10.66  |                        |
| C - Cutting speed  | 12376.56     | 1  | 12376.56     | 888.0045| <0.0001 | 12.38  |                        |
| AB                 | 12939.06     | 1  | 12939.06     | 928.362 | <0.0001 | 12.94  |                        |
| AC                 | 1387.563     | 1  | 1387.563     | 99.55605| <0.0001 | 13.87  |                        |
| BC                 | 76.5625      | 1  | 76.5625      | 5.493274| 0.0471  | 0.076  |                        |
| ABC                | 7182.563     | 1  | 7182.536     | 515.3408| <0.0001 | 0.072  |                        |
| Pure factor        | 111.5        | 8  | 13.9375      |         |         |        |                        |
| Core total         | 1000548.4    | 15 |              |         |         |        |                        |

Fig. 4. Performance prediction plot for Unevenness for 12 mm plate from Design Expert

Design of Expert version 8.0.7.1. The performance prediction of unevenness responses has been shown in Figure 4; the actual and predicted values of response are very close and verify the fitness of polynomial response. In order to verify the model based on performance of variance analysis and F-ratio.

5. Optimization

In this experimental stage, at least three levels are needed for fitting a quadratic surface response to find an optimum in the response function. Thus, for this set, a balanced three-factor two-level design with 2 replicates (16 trials) has been designed at three cutting speed.

The optimization module in Design-Expert searches for a combination of factor levels that simultaneously satisfy the requirements placed on each of the responses and factors. Optimization of one response or the simultaneous optimization of multiple responses can be performed graphically or numerically. Also, one can simultaneously evaluate all the response models for any value of the independent variables using the point prediction node.

The voltage can be used not only for stabilizing the cut and reducing the mean unevenness, but also for controlling and minimizing the difference between sides, the visual investigation of the obtained plates showed an overall good cut quality. No instability or dross affected sides have been found in any of the specimens. It can be observed that the side stability was neither affected by the parameters nor by their interaction, but it was simply due to the natural variability of the process and the measurement procedure. It has to be remarked that in the first
experimental design it was possible to analyze the effect of cutting parameters on the deviation standard between because of the stability at the high level.

Here in Figure 5(a) shows the procedural window of design expert Figure 5(b) and Figure 5(c) shows the results obtain by minimum unevenness optimization at the 125 voltages, 2100 mm/min cutting speed and 70 L/Hr plasma flow rate. It is clear that the mean plate unevenness achieved was 421 micron. The improvement of the mean unevenness is well distributed among all the four sides. The stability of each side (described by the standard deviation within) is maintained or improved. Eventually, the variability between sides (described by the standard deviation between) is almost halved.
6. Conclusion

Cutting speed increase or decrease inversely proportional thickness of plate. The cutting speed reduces results in an excessive amount of molten metal which cannot be completely removed by the momentum of the plasma jet. First of all three process parameter like Voltage, Plasma gas and cutting speed than DOE are taken on the based DOE experiments are carried out. Then ANOVA analyses are done and after optimization experiments are carried out. It was found out that the arc voltage is main parameter and it influences all the aspects related with the cut quality rather than the effect on the arc power, beyond the arc voltage the cutting speed showed a noticeable effect. Results obtained in the experimental stage allowed one to observe that unevenness can be reduced by reducing the cutting speed. Eventually, it was shown that very good quality can be achieved for all the sides by varying the cutting speed, plasma flow rate and arc voltage only. As recorded optimized minimum unevenness for 12 mm Hardox plate is 421 micron at optimum value of 70L/Hr plasma flow rate, 125 V voltage and 2100 mm/min cutting speed.

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