# Study and optimization of Process Parameter in Plasma arc Cutting

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***Abstract :*** The plasma arc cutting process was developed for difficult to machine materials in order to overcome the inefficiency and ineffectiveness of conventional machining method when it come to complex shape and work piece. Plasma cutting is a process that cut through electrically conductive material by means of jet of hot plasma. In this research work the study has been carried out on the PAC of Carbon steel by considering gas pressure (bar), current flow rate (A), cutting speed (mm/min) and arc gap (mm) as the process parameters and analysing the effect on the surface roughness (Ra), material removal rate. A comprehensive review was carried out on development in analysis and optimization of PAC for Carbon steel (A36). The Experimental study has been carried out by using Taguchi design methods and ANOVA analysis for Material removal rate (MRR), Surface roughness by performing cuts of different run sets of L9 orthogonal Array.

***Index Terms -*** **Plasma, Carbon Steel (A36) Material Removal Rate, Surface Roughness, Taguchi Design, ANNOVA.**

## I. Introduction to Plasma

### 1.1 Principle of Plasma Arc Cutting

Plasma Arc Cutting (PAC) is a non-conventional process which can perform several electrically conducting materials, stainless steel, aluminium and its alloys, magnesium, titanium alloys, manganese steel and cast iron. Plasma cutting process is invented about 30 years ago for processing hard and difficult to machine materials.

This process uses a concentrated electrical arc which melts the material through a high-temperature plasma beam. All conductive materials can be cut. Plasma cutting units with cutting currents from 20 to 1000 amperes to cut plates with inert gas, 5 to 160 mm thicknesses. Plasma gases are compressed air, nitrogen, oxygen or argon/ hydrogen to cut mild and high alloy steels, aluminium, copper and other metals and alloys. The plasma arc process has always been seen as an alternative to the oxy-fuel process. In this part of the series the process fundamentals are described with emphasis being placed on the operating features and the advantages of the many process variants.

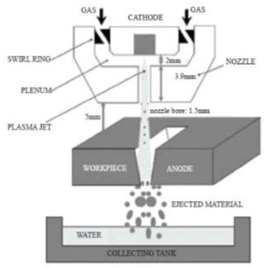



***Figure 1: The principle of the plasma cutting [40]***

The plasma is additionally tied up by a water-cooled nozzle. With this energy densities up to 2x106 W/cm$^2$ inside of the plasma beam can be achieved. Because of the high temperature the plasma expands and flows with supersonic velocity speed to the work piece (anode). Inside the plasma arc temperatures of 30 000$^o$C can arise, that realize in connection with the high kinetic energy of the plasma beam and depending on the material thickness very high cutting speeds on all electrically conductive materials.

For the cutting process first of all a pilot arc ignition by high voltage between nozzle and cathode takes place. This low-energy pilot arc prepares by ionization in parts the way between plasma torch and work piece. When the pilot arc touches the work piece (flying cutting, flying piercing), the main arc will start by an automatic increase in power The basic principle is that the arc formed between the electrode and the work piece is constricted by a fine bore, copper nozzle. This increases the temperature and velocity of the plasma emanating from the nozzle. The temperature of the plasma is in excess of 20 000°C and the velocity can approach the speed of sound. When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material and molten material is removed in the efflux plasma.

The process differs from the oxy-fuel process in that the plasma process operates by using the arc to melt the metal whereas in the oxy-fuel process, the oxygen oxidizes the metal and the heat from the exothermic reaction melts the metal. Thus, unlike the oxy-fuel process, the plasma process can be applied to cutting metals which form refractory oxides such as stainless steel, aluminium, cast iron and non-ferrous alloys.

The power source required for the plasma arc process must have a drooping characteristic and a high voltage. Although the operating voltage to sustain the plasma is typically 100 to 160V, the open circuit voltage needed to initiate the arc can be up to

400V DC. On initiation, the pilot arc is formed within the body of the torch between the electrode and the nozzle. For cutting, the arc must be transferred to the work piece in the so-called 'transferred' arc mode. The electrode has a negative polarity and the work piece a positive polarity so that the majority of the arc energy (approximately two thirds) is used for cutting. [43]

In the conventional system using a tungsten electrode, the plasma is inert, formed using either argon, argon-H2 or nitrogen. However, as described in Process variants, oxidizing gases, such as air or oxygen can be used but the electrode must be copper with hafnium. The plasma gas flow is critical and must be set according to the current level and the nozzle bore diameter. If the gas flow is too low for the current level, or the current level too high for the nozzle bore diameter, the arc will break down forming two arcs in series, electrode to nozzle and nozzle to work piece. The effect of 'double arcing' is usually catastrophic with the nozzle melting. The quality of the plasma cut edge is similar to that achieved with the oxy fuel process.

However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge. As these limitations are associated with the degree of constriction of the arc, several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut.

The process variants have principally been designed to improve cut quality and arc stability, reduce the noise and fume or to increase cutting speed. The inert or uncreative plasma forming gas (argon or nitrogen) can be replaced with air but this requires a special electrode of hafnium or zirconium mounted in a copper holder, by shearing. The air can also replace water for cooling the torch. The advantage of an air plasma torch is that it uses air instead of expensive gases. It should be noted that although the electrode and nozzle are the only consumables, hafnium tipped electrodes can be expensive compared with tungsten electrodes.

This relatively new process differs from conventional, dry plasma cutting in that water is injected around the arc. The net result is greatly improved cut quality on virtually all metals, including mild steel. Today, because of advances in equipment design and improvement in cut quality, previously unheard of applications, such as multiple torches cutting of mild steel, are becoming common place. [43]

## II. Literature Review

**Ashish bandyopadhyay et al[1],** The experimental study carried out on AISI 304 Stainless steel by using ADOR plasma AP-100 machine and find out the best operating parameter by a full factorial design and ANOVA. They concluded that multiobjective optimization is well agreement with confirmatory test and percentage error are less than 10%. ANOVA seen that speed and thickness of material pressure has a little effect on MRR and pressure only significant parameter on surface roughness and concluded that the maximum and minimum surface roughness is 23.85 $\mu m$ and 3.76 $\mu m$ and similarly MRR are 88.884 g/min and 21.982 g/min.

**Navneet kanna et al [2],** The study carried out on the Quard 400 material by Multi therm 4000, Messer cutting system India private limited to determine the effects and optimization of two process parameter as cutting speed and plasma gas pressure on Surface roughness and Material removal rate using response surface method coupled with ANOVA and concluded that the 4000mm/min Cutting speed, 90 Psi pressure with Material removal rate 2.35g/sec and Mean surface roughness of 1.40 $\mu m$. Material removal rate increase of cutting speed and Mean surface roughness decrease with increase of cutting speed.

**Antonio martin meizoso et al[3],** The investigation carried out on Plasma arc cutting and LAM by rank correlation analysis, multidimensional data analysis and decision trees on high strength low alloy strip and plate and also conclude that major influence parameter in Plasma arc cutting is Current, Torch standoff, Cutting speed and Plasma gas flow on Surface quality.

**C. S. Malvi et al [4],** Study out the effect on MRR in AISI 1017 MS material on manual Plasma arc cutting by using different variable Pressure, Current, Voltages and used Taguchi with Doe and ANOVA for optimize it and conclude that the optimum Material removal rate can be obtained at Pressure 20bar, Current 35A and Speed 240mm/min. The Material removal rate value was obtained 95.577 $mm^3$/sec.

**S. Vatausianos et al [5],** Study carried out on CNC Plasma cutting system (KaitenbachKf 2512-HPR 260) with a duct flow torch and cut are performed on 15mm thick S235 Mild steel sheet by using different process parameter as Cutting Speed, Current, Cut height and Pressure in Order to optimize Surface Roughness and Heat affected Zone by using DOE and ANOVA. They would concluded that surface roughness and the conicity are mainly affected by the cutting height, whereas the heat affected zone is mainly influenced by cutting current.

**W S Severance et al [6],** should be studied out the effect of Cutting speed on the Kerf, Surface and Cut quality squerness and Jet tilt on Speed the Bevel angle are increased and surface quality reduced and also tilt of jet increased but there is not only simultaneous between bevel angle and tilt of jet they are proven individual.

**M. Monno et al[7],** has performed an experiment in order to obtain the main process parameter on the output unevenness in a real cutting application by considering two sequential experimental design and analysed it by ANOVA analysis and concluded that the Arc voltage is main parameter and it influences all the aspect related with the cut quality rather than of Arc Power and on other side reducing the arc voltage the thermal stress on the torch component on specially electrode and nozzle increases and thus accelerate their wear. And also that very good quality can be achieved for all the side by varying the cutting speed and arc voltage only.

**E. Negoescu et al[8],** Study out the cutting performance on aluminium polyethylene composite material by using Italian plasma arc cutting machine telwin PL 3612 and used parameter main voltage 230V, Current 23A, Power 7 KVA, Pressure 0.41Mpa, Feed rate 50mm/min and Arc length 5mm and various output parameter Surface quality and Heat affected zone should be measured and concluded that the Kerf dimension 2mm thermally influence area of Polyethylene core is around 5mm and the burr in bottom side of work piece is around 1mm.

**Valerian a Nemchinsky et al [9],** Performed by using PT torch with $600^0$c Power supply manufactured by ESAB. The Current range (200-400A), Gas used Oxygen and Flow rate 0.94 $mm^3/s$, Stand of distance 0.95 cm, Cutting Speed 40mm/s, Nozzle diameter (2.3-3.3 mm) and Material thickness (12.7-50.8 mm) in order to estimate $U_{max}$ and $U_{min}$. The estimated and calculated value are compared.

**K. Chan et al [10],** Study out the effect on monolithic 2124 aluminium alloy and aluminium base by considering the input parameter as a Pressure, Voltage and Current which are Fixed and Speed are Varied and different measurement are take regarding to this as Kerf Width, Surface Roughness and Heat affected zone and concluded that no difference between cutting Speed of both material and the optimized cutting speed 55-60 mm/s.

## III. Experimental Procedure

### 3.1 Experimental Setup

Experiments are conducted on the Plasma arc cutting system Hyperformance Plasma HPR260XD Auto Gas Make with Hypertherm, INC USA In this study, the experimental plan two controllable variables, namely as Cutting speed, Arc gap. The response variables considered in the present study are: material removal rate (MRR), Surface roughness ($R_a$), MRR is expressed as the ratio of weight difference of the work piece before and after machining to the machining time and in the present study it is measured by weight loss of the material and expressed by gm/sec. Roughness measurement is done using a surface roughness tester (SJ- 310) Mitutoyo. In the machining parameter design, three levels with equal spacing of the cutting parameter are selected as shown in table 3.1.

Table 3.1: Design Factor and their levels

| Parameter | Unit | Level 1 | Level 2 | Level 3 | DOF |
|---|---|---|---|---|---|
| Cutting Speed | mm/min | 1780 | 1880 | 1980 | 1 |
| Arc Gap | Mm | 3.2 | 3.6 | 3.8 | 1 |

### 3.2 Selection of Work piece material

Rectangular block of 100mm * 50mm and 20mm height made of Carbon steel grade A36 which is a carbon steel with high degree of hardness, compressive strength is selected as work piece. Mechanical and chemical properties of Carbon steel grade A36 are shown in table 3.2.

Table 3.2: Mechanical and chemical property

| Yield Strength (Mpa) | Ultimate Tensile Strength (Mpa) | % Elongation |
|---|---|---|
| 282 | 422 | 27 |

| C | Mn | S | Si | Ni | Ti | Al |
|---|---|---|---|---|---|---|
| 0.108 | 0.940 | 0.006 | 0.210 | 0.008 | 0.003 | 0.033 |

### 3.3 Experimental results

After deciding parameters and levels as shown above orthogonal array L9 decided as per degree of freedom of each factor and dof of interaction among the parameters. Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review. Now perform experiment as per orthogonal array (L9) on Plasma Arc Cutting Machine, output like MRR and surface roughness is being given in table 3.3.

Table 3. 3: Experimental Layout

| Experiment No | Material Removal (gm) | Time (sec) | Material Removal Rate (gm/sec) | Surface Roughness ($R_a$) (µm) |
|---|---|---|---|---|
| 1 | 199 | 13.31 | 14.95116454 | 1.695 |
| 2 | 197 | 12.26 | 16.0685155 | 0.992 |
| 3 | 195 | 12.2 | 15.98360656 | 0.975 |
| 4 | 207 | 11.02 | 18.78402904 | 1.06 |
| 5 | 201 | 11.23 | 17.8984862 | 1.111 |
| 6 | 213 | 10.73 | 19.85088537 | 1.462 |
| 7 | 196 | 12.06 | 16.25207297 | 1.538 |
| 8 | 193 | 10.58 | 18.24196597 | 1.855 |
| 9 | 203 | 10.57 | 19.20529801 | 2.063 |

Then we calculated S/N ratio for MRR and surface roughness of specimens.

Then we obtain optimal conditions has been calculated for MRR and surface roughness of specimen. The following table shows readings of MRR and surface roughness at each experiment, it also shows S/N ratio for MRR and surface roughness at each experiments. And that is seen in table 3.4.

Table 3.4: Experimental Layout and S/N ratios for MRR and Surface Roughness (Actual Factor Levels)

| **A** | **B** | **MRR** | **$R_a$** | **S/N Ratio MRR** | **S/N Ratio $R_a$** |
|---|---|---|---|---|---|
| 1780 | 3.2 | 14.951 | 1.695 | 23.493 | -4.5833 |
| 1780 | 3.6 | 16.068 | 0.992 | 24.119 | 0.069 |
| 1780 | 3.8 | 15.983 | 0.975 | 24.073 | 0.219 |
| 1880 | 3.2 | 18.784 | 1.06 | 25.475 | -0.506 |
| 1880 | 3.6 | 17.898 | 1.111 | 25.056 | -0.914 |
| 1880 | 3.8 | 19.850 | 1.462 | 25.955 | -3.298 |
| 1980 | 3.2 | 16.252 | 1.538 | 24.218 | -3.739 |
| 1980 | 3.6 | 18.241 | 1.855 | 25.221 | -5.366 |
| 1980 | 3.8 | 19.205 | 2.063 | 25.668 | -6.289 |

**IV. Result and Discussion**

**4.1Analysis of variance (ANOVA)**

The analysis of variance is performed to investigate the influence of process parameters on the quality characteristic. The test for significant of the model, individual coefficient and the $R^2$ for the result have been calculated mathematically and using MINITAB. Table 3.5 and table 3.6 show the analysis of variance of the responses and also provide the significant models (<0.05) at 95% confidence level.

Table 3. 5: ANNOVA table for MRR

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Cutting Speed | 2 | 15.966 | 7.9829 | 10.84 | 0.024 |
| Arc Gap | 2 | 4.275 | 2.1376 | 2.90 | 0.166 |
| Error | 4 | 2.946 | 0.7366 | | |
| Total | 8 | 23.187 | | | |

Table 3.6: ANNOVA table for Surface roughness

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Cutting Speed | 2 | 0.72696 | 0.36348 | 2.78 | 0.175 |
| Arc Gap | 2 | 0.04987 | 0.02494 | 0.19 | 0.834 |
| Error | 4 | 0.52336 | 0.13084 | | |
| Total | 8 | 1.30018 | | | |

**4.2 Grey analysis**

The experimental result obtained from MRR and surface roughness tests are present in table 3. The final response needed for processing grey relational grade which is obtained though the following set of calculation.

**4.2.1 Grey Relational Generation**

The first step in grey relational analysis is to perform the grey relational generation in which the result of the experiment are normalized in the range of 0 to 1. For the normalizing of Material removal rate data, Higher the better criterion and for Surface roughness Parameter lower the better criterion are used as MRR is to be maximized and surface roughness Is to be minimized.

**Larger the Better Criterion**:

$$X_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

**Smaller the Better criterion:**

$$X_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Where $x_i$ (k) is the value after grey relational generation, min $y_i(k)$ is the smallest value of $ay_i(k)$ for the $k^{th}$ response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the $k^{th}$ response. An Ideal sequence is $x_0$ (k) (k=1, 2, 3... 9) for the response. The processed data after greay relational generation is given in Table 3.7. Larger normalized results correspond to the better performance and the best normalized result should be equal to 1.

Table 3.7: Normalized Results of GRA

| Ex No | Cutting Speed | Arc Gap | MRR | SR($R_a$) |
|---|---|---|---|---|
| 1 | 1780 | 3.2 | 0.000 | 0.338 |
| 2 | 1780 | 3.6 | 0.228 | 0.984 |
| 3 | 1780 | 3.8 | 0.211 | 1.000 |
| 4 | 1880 | 3.2 | 0.782 | 0.922 |
| 5 | 1880 | 3.6 | 0.602 | 0.875 |
| 6 | 1880 | 3.8 | 1.000 | 0.552 |
| 7 | 1980 | 3.2 | 0.266 | 0.483 |
| 8 | 1980 | 3.6 | 0.672 | 0.191 |
| 9 | 1980 | 3.8 | 0.868 | 0.000 |

**4.2.2 Grey Relational Coefficient**

Grey relational coefficient are calculated to express the relationship between the ideal and actual experimental results. The grey relational coefficient $\xi_i$ (k) can be calculated as:

$$\xi_i(k) = \frac{\Delta_{min} + \Psi\Delta_{max}}{\Delta_{0i}(k) + \Psi\Delta_{max}}$$

Where $\Delta_{0i}$ =[$x_0$ (k) – $x_j$ (k)] is difference of the absolute value between $x_0$ (k), $x_j$ (k), $\Delta_{min}$ and $\Delta_{max}$ are respectively the minimum and maximum values of the absolute differences ($\Delta_{0i}$)of all comparing sequences. Ψ is a distinguishing coefficient, $0 \leq \Psi \leq 1$, the purpose of which is to weaken the effect of $\Delta_{max}$ when it gets too big, and thus enlarges the difference significance of relational coefficient. The suggested value of the distinguishing coefficient is 0.5, due to moderate distinguishing effect and good stability of outcomes. Therefore, Ψ is adopted as 0.5 for further analysis in the present study. The Grey relation coefficient of each performance characteristic is shown in table 3.8.

Table 3.8: GRA Coefficient

| | Deviation | | GRA Coefficient | |
|---|---|---|---|---|
| Ex No | MRR | SR ($R_a$) | MRR | SR ($R_a$) |
| 1 | 1.000 | 0.662 | 0.333 | 0.430 |
| 2 | 0.772 | 0.016 | 0.393 | 0.970 |
| 3 | 0.789 | 0.000 | 0.388 | 1.000 |
| 4 | 0.218 | 0.078 | 0.697 | 0.865 |
| 5 | 0.398 | 0.125 | 0.556 | 0.800 |

| | | | | |
|---|---|---|---|---|
| 6 | 0.000 | 0.448 | 1.000 | 0.528 |
| 7 | 0.734 | 0.517 | 0.405 | 0.491 |
| 8 | 0.328 | 0.809 | 0.604 | 0.382 |
| 9 | 0.132 | 1.000 | 0.791 | 0.333 |

### 4.2.3 Grey Relational Grade and grey Relational ordering

The grey relational grade is treated as the overall response of the process instead of the multi response of MRR and surface roughness. The grey relational coefficient are calculated for the experimental data using Ψ = 0.5. The Grey relational grade $\gamma_i$ is obtained by averaging the Grey relation coefficient as follow:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

Where n is the number of process responses. Higher value of Grey relational grade implies stronger relational degree between the ideal sequence $x_0$ (k). Table shows the experimental results for the grey relational grade and their orders. Thus multi response optimization problem can be converted into single response optimization problem.

Table 3.9: Grey Relation Grade and Order

| Ex No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **GRA Grade** | 0.382 | 0.681 | 0.694 | 0.781 | 0.678 | 0.764 | 0.448 | 0.493 | 0.562 |
| **Rank** | 9 | 4 | 3 | 1 | 5 | 2 | 8 | 7 | 6 |

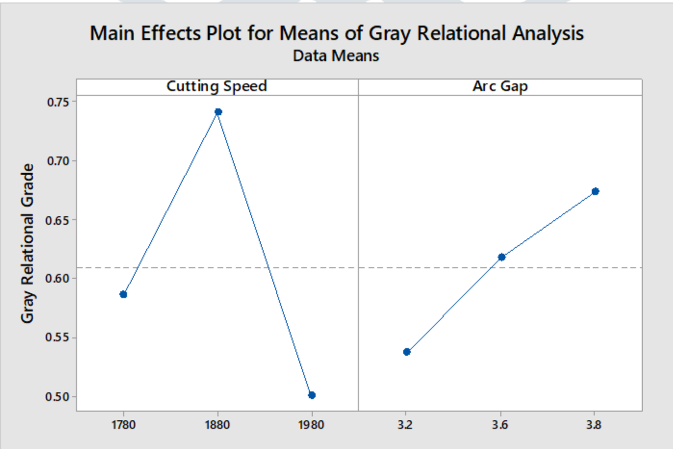
Table 3.10: Response table for Grey relational grade

| Symbol | Process Parameter | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| **A** | **Cutting Speed** | 0.587 | 0.741 | 0.501 | 239 | 1 |
| **B** | **Arc Gap** | 0.537 | 0.617 | 0.673 | 134 | 2 |

Total Means Value of the Grey relational Grade: 0.609

### 4.2.4 Factor Effect

Graph show the main effect plot. In the main effect plot, if the line for a particular parameter is near horizontal, then the parameter has no significant effect. On the other hand, a parameter for which the line has the highest inclination will have the most significant effect. It is very much clear from the main effect plot that parameter a cutting speed is the most significant parameter while B arc gap quite significant effect. Since higher grey relational grade indicates that the system tend optimality, the optimal condition for each parameter is taken at those point where the mean grey relational grade is found to be the maximum. Hence the optimal process parameter combination for maximum Material removal rate and minimum surface roughness characteristics of PAC is given as A2B3 (middle level of Cutting speed and highest level of arc gap).




Graph 1. Main Effects Plot for Grey Relational Grade

### 4.2.5 Analysis of variance (ANOVA)

ANOVA is a statically technique that can infer some important conclusions on the basis of analysis of the experimental data. The method is very useful for revealing the level of significant of influence of factor or interaction of factor on a particular response. In the present study, ANOVA is performed using Minitab. Table shows the ANOVA result for overall grey relational grade of MRR and Surface roughness parameters. ANOVA calculation are based on the F-ratio, which is used to measure the significance of the parameters under investigation with respect to the variance of all the term included in the error term at the desired significance level, α. If the calculated value of F-ratio is higher than its tabulated value, then the factor is significant at the desired α level. In general, when the F-value increases, the significance of the parameter also increases. ANOVA table shows the percentage contribution of each parameter. It is clear from the ANOVA table that parameter Cutting Speed has got the most significant influence on MRR and Surface roughness, which is about 54% contribution.

Table 3.11: Result of ANOVA for Grey relational grade

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % Contribution |
|---|---|---|---|---|---|---|
| Cutting Speed | 2 | 0.08875 | 0.04438 | 3.79 | 0.119 | 54.17201 |
| Arc Gap | 2 | 0.02822 | 0.01411 | 1.2 | 0.389 | 17.22517 |
| Error | 4 | 0.04685 | 0.01171 | | | |
| Total | 8 | 0.16383 | | | | |

**2.6 Prediction of Optimum Value of GRG:**

$$\hat{\eta} = \eta_m + \sum_{i=1}^{q} (\bar{\eta}_i - \eta_m)$$

= 0.609 + (0.741 – 0.609) + (0.673 - 0.609)
= 0.805

**4.3. Confirmation Test**

After the optimal level of process parameters has been found out, a verification test needs to be carried out in order to check the accuracy of the analysis. Table shows the comparison of the estimated grey relational grade with the actual grey relational grade obtained in the experiment using the optimal test parameters. It may be noted that there is good agreement between the estimated and actual grey relational grade. The improvement of grey relational grade from the initial to optimal condition is 0.165 which is about 24% improvement from the initial conditions.

Table 3.12: Result of confirmation test

| Level | Initial parameter combination | | Optimal parameter combination |
|---|---|---|---|
| | A2B2 | | A2B3 |
| | | Prediction | Experimental |
| **MRR** | 17.89848 | | 19.924567 |
| **SR ($R_a$)** | 1.111 | | 1.262 |
| **Grade** | 0.678 | 0.805 | 0.834 |
| Improvement of Grey relational grade=0.165 (24%) | | | |

**V. CONCLUSION**

This thesis has presented an application of the Taguchi method to the optimization of the machining parameters of Plasma Arc Cutting Machine. As shown in this study, the Taguchi method provides a systematic and efficient methodology for determining optimal parameters with far less work than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal parameters. It has been shown that Material Removal Rate (MRR) and Surface Roughness (Ra) can be significantly improved in the Plasma Arc Cutting process using the optimum level of parameters.Plasma Arc Cutting Machine is widely utilized in LISEGA INDIA PVT LTD, HALOL to cut materials such as various carbon steel grade. This is the basis work where Plasma Arc Cutting was utilized to perform the material removal process at finishing stage. The Plasma Arc Cutting (PAC) machining of Carbon Steel (A36) has been performed with the application of combination with design of experiment (DOE).The PAC parameters studied were how to have setting for the parameter such as Cutting Speed and Arc gap of machine.

- It was observing that highest value of Material removal rate 19.850 g/sec is found at Cutting Speed 1880 mm/min and Arc Gap 3.8 mm.
- It was observing that minimum value of Surface Roughness 0.975 µm is found at Cutting Speed 1880 mm/min and Arc Gap 3.8 mm.
- From the ANOVA of MRR it has been found that cutting speed was significant on MRR and arc gap was not significant parameter but the contribution of cutting speed 68.85% and arc gap was 18.43% on MRR.
- From the ANOVA of Surface roughness it has been found that not any significant process parameter on Surface roughness but the error is acceptable limit.
- The multi parametric optimization is done by using grey relational analysis and found that cutting speed has 54.17% contribute and arc gap was 17.22% on grey relational grade and optimum parameter was cutting speed 1880 mm/min and arc gap was 3.8 mm.
- From the Grey relational grade and the confirmation test it has been found that 24% of improvement in Grey relational grade.

- From the Model Summery MRR of first order of R-sq of 87.29% and for surface roughness ($R_a$) is R- sq of 59.75% which is acceptable.

## VI. SCOPE OF FUTURE WORK

Based on result it has been found, this project had archive it main objective but an improvement still can done to improve more on the Metal Removal Rate (MRR) and Surface Roughness (Ra) of parts by features. Some of the suggestions to improve the result include the replication of the model which can reduce the variations of the data and increase the reliability of the data. Based on this work many improvements can be made and the scope can also be widened. Following are suggestion for future work:

- Using Plasma Arc Cutting system, add the parameter such as Kerf, Voltage, angle, material dimension and then compare the result obtained.
- Using other methodology in the same material of study to compare the results obtained such as Response Surface Methodology and Genetic Algorithm etc.
- Study for manual calculation for other method in DOE to improve knowledge and skills.
- No interaction is considered so we can consider interaction by applying L27 with more level design this will improve optimum condition as compare to L9 considered in this work.
- Also side clearance and thermal effect on material and work piece like Heat Affected Zone (HAZ) can also be considered to study the effect on properties of work piece.

## VII. Acknowledgements

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