

# Optimization of Machining Process Parameters in Plasma Arc Machining

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**ABSTRACT:** In last forty years there is tremendous research in machining and development in technology. With increase in competition in market and to attain high accuracy now a days the Unconventional Machining are become lifeline of many industry. From several varieties of Unconventional Machining, we have selected Plasma Arc machining. In our work, we are going to optimize the machining process parameters of plasma arc machining. The appropriate orthogonal array has been selected regarding number of factors available in that industry and the experimentation was carried out. For this experiment we have chosen Stainless Steel 316L (SS316 L) material. Various input parameters like current, gas pressure, speed and arc gap were used in this experiment and obtaining the responses such as machining time, hardness and kerf width. Taguchi method, Signal to Noise (S/N) ratio between the input parameters and output responses are also predicted in this paper. Optimization results has been determined with the help of main effect plot and ANOVA table and obtained by Grey relational analysis (GRA) method.

**KEYWORDS:** Taguchi method, GRA, MINITAB 17 SOFTWARE, ANOVA table.

## I. INTRODUCTION

Plasma cutting is a process that is used to cut steel and other metals (or sometimes other materials) using a plasma torch. In this process, an inert gas (in some units, compressed air) is blown at high speed out of a nozzle, at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and moves sufficiently fast to blow molten metal away from the cut. Plasma can also be used for plasma arc welding and other applications. The plasma arc torch has a space or area surrounding the circumference of the electrode, between the inside circumference of the torch tip or nozzle. It is in this chamber that the plasma gas is heated and ionized. This heating causes the plasma gas to greatly expand in volume and pressure. The plasma gas exits from the constricting orifice of the torch nozzle or tip at very high speeds and temperatures; up to 30,000 degrees F. (16,000 degrees C.) and 6000 m/s (20,000 ft/s). Intensity and velocity of the plasma is determined by several variables including the type of gas, its pressure & volume, the flow pattern, the amount of electric current, the size and shape of the constricting tip or nozzle orifice, and the tip to work distance.

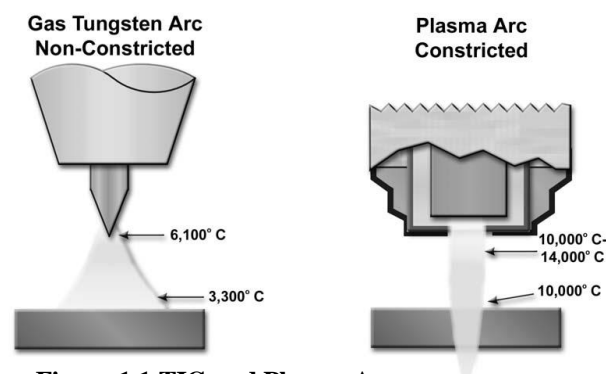


Figure 1.1 TIG and Plasma Arcs

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The PAC process uses this high temperature, constricted, high velocity jet of ionized gas exiting from the constricting orifice of the torch tip to melt a much localized area and remove the molten material from the metal being cut by the force of the plasma jet. The force of the arc pushes the molten metal through the work piece and severs the material. Extremely clean and accurate cuts are possible with PAC. Because of the tightly focused heat energy, there's very little warping, even when cutting thin gauge sheet metal thickness. PAC also offers quality gouging and piercing capabilities.

Plasma arc cutting can increase the speed and efficiency of both sheet and plate metal cutting operations. Manufacturers of transportation and agricultural equipment, heavy machinery, aircraft components, air handling equipment, and many other products have discovered its benefits. Basically Plasma Arc Cutter comprises of 8 major parts such as air compressor, AC plug, power supply, plasma torch, ground clamp, electrode, nozzle and workpiece

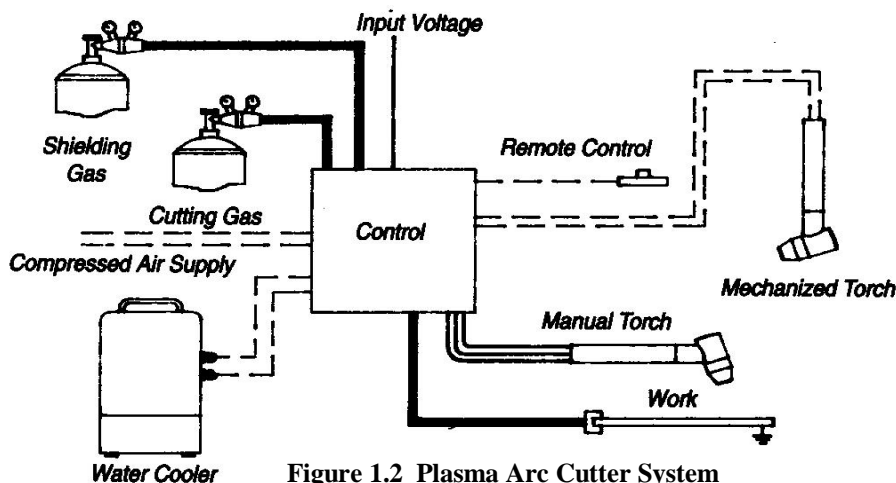


Figure 1.2 Plasma Arc Cutter System

== Dotted Lines Indicate Optional Equipment

### II. LITREATURE REVIEW

Subbarao Chamarthi et al used 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. Bhuvanesh .R et al used Plasma arc cutter Selco Genesis 90 to cut Standard AISI 1017 Steel of 200mm x100 mm x 6 mm manually based on the selected parameters setting. The material removal rate (MRR) was measured by determining the weight of the specimens before and after the cutting process. The surface roughness (SR) analysis was conducted using Mitutoyo CS-3100 to determine the average roughness value (Ra). Taguchi method was utilized to achieve optimum condition for both outputs studied.

Salonitis.K et al investigated experimentally the plasma arc cutting process in order to assessing the quality of cut. The quality of cut is assessed by measuring the conicity, edge roughness and size of heat affected zone (HAZ). The input parameters considered are cutting power, cutting speed, cutting height and plasma gas pressure. The statistical analysis is performed in order to determine the contribution of each parameter in the obtained quality of cut. The regression analysis is done to develop empirical model in order to describe the effect of parameters on the quality of cutting. Using the design of experiment and analysis of variance it is found that the surface roughness and conicity are mainly affected by the cutting height, whereas the heat affected zone (HAZ) is mainly influenced by the cutting current. Abdul Kadir

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Gullu et al investigated the variation in structural specification occurred in the AISI 304 and St 52 carbon steel after cut by the plasma arc. As per the experimental results it is found that the burning of particulars and distribution amount were increased when the cutting is carried out using speed and it is observed that the hardness will decreased from the outer surface toward the core while the hardness at the outer surface affected by the high temperature is increased. Thus they revealed that the area of 0.399–0.499 mm of stainless steel materials and 0.434–0.542mm of carbon steel materials were more affected by heat according to cutting speed.

W.J.Xu and et all were conducted experiment on ceramic during plasma arc cutting. They measured cutting qualities by varing process parameter the flow rate of injected water and the magnetizing current using nozzles of different diameters. From the experiment they found that both water constriction and magnetic constriction of plasma arc forms a three dimensional constriction with improved shape and uniformity of the arc column and hydro magnetic constriction is capable of improving arc stability. E. Gariboldi et al investigated the quality of cutting on pure titanium sheet through high tolerance plasma arc cutting process under various cutting conditions. The 5mm thick sheet of pure titanium is cut at the various feed rates and with the adaption of oxygen or nitrogen as cutting and shielding gas. While the oxygen is used as the cutting gas the oxidation reaction will occur and result in higher feed rates and unevenness and kerf width of better quality were achieved. Yaha hisman selic et al cut the sheet material S235JR using the CNC plasma cutting machine at different cutting speeds, cutting current, and arc voltage and measured the effect of variation on temperature distribution, hardness, thickness of heat affected zone and surface roughness of the material after cut. From the results of the experiments he had concluded that the quality of plasma CNC machine depend on the cutting current, cutting speed, arc voltage and material thickness. To get the best surface roughness the cutting current and the cutting voltage kept low and cutting speed must be high for the thin sheet and while using CNC plasma machine prevent hardness increase, and have a minimum HAZ. While the thickness of the cutting sheet increase the cutting current must be increase and cutting voltage is to be decrease. However this leads to decrease in corresponding cutting speed.

Miroslav Radovanovic et al had done a modeling of the plasma arc cutting process using Artificial Neural Networking (ANN). Aimed to develop the ANN mode to predict the ten point height of irregularities (Rz) taking input parameters such as cutting speed, cutting current and plate thickness. After prediction of data the accuracy of ANN has been validated. Using this model one can select the machining conditions which correspond to the cutting region with minimal surface roughness. W. J. Xu et al [10] used the hydro magnetically confined plasma arc to cut ceramic plates. From the experiments and analysis the characteristics of hydro magnetic confined plasma was explored. The effect of secondary confinement on arc properties, on cutting quality and optimal process parameters were determined. In this paper author conducted various experiments using water constricted arc, magnetic constricted arc and hydro magnetic constricted arc. After analyzing the result of experiments it is concluded that by using the hydro magnetic constricted arc a reduced kerf width and improved cut quality on ceramic surface is achieved. Theoretical and experimental results both have proven the feasibility and validity of the newly advanced hydro magnetic confined PAC.

### III. PROBLEM IDENTIFICATION

Plasma arc cutting can be characterized in terms of distinct speeds. At cutting speeds above, the plasma jet does not cut through metal plate. At speeds below, the molten metal from the kerf sticks to the bottom of the plate, forming the so-called dross and how to properly select a plasma cutting system. Plasma can cut in a wide range of cutting parameters (currents, metal thicknesses and nozzle orifice diameters) for plasma arc cutting of stainless steel materials.

The plasma arc cutting process employs a plasma torch with a very narrow bore to produce a transferred arc to the work piece at an average current density of within the bore of the torch. The energy and momentum of the high-velocity plasma jet generated by the plasma torch melts, vaporizes and removes the metal from the region of impingement of the nozzle. Others problem is:

- a) What type of metal is to cutting?
- b) What is primary input power when cutting process?
- c) How thick is the metal want to cut?
- d) Traditional way of cutting takes a lot of time.
- e) The effective way to conduct the cutting process for Stainless Steel.

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- f) The most important factors that influence the cutting process?
- g) What are the best conditions to achieve optimum performances?

### 3.1 Scope

This work focuses on

- a) The optimization of cutting parameters of Plasma Arc Cutting (PAC).
- b) The material used to cut was Stainless Steel of specification 316 L.
- c) Design of Experiments (DOE) layout to be used for testing and analyzing with Taguchi Method.
- d) All of data was analyzed by using Minitab 17 Software to produce the best combination setting in plasma cutting for Stainless Steel.

## IV. DESIGN OF STUDY

It is found already many work has been done in MRR and Surface finish but very little work has been done on optimization of Plasma Arc Cutting. Here in my thesis work I will try to find out optimal value of machining time and hardness. Stainless Steel (316L) materials are cheaply available and widely used in Plasma Cutting Machine. Taguchi method using design of experiments approach can be used to optimize a process. Here we will to apply D.O.E approach for modelling of machining time in PAC process and the various input parameters will be taken under experimental investigation and then model will be prepared then again experimentation work will be performed. The results obtain will be analyzed and the models will be produced by using MINITAB software. This will help in improving the effective and efficient working of the PAC process. The various input parameters are Voltage, Current Flow, Arc Gap, Kerf, Cutting speed and Cutting gas pressure

### 4.1 Material Selection

Stainless Steel is essentially a low carbon steel which contains chromium at 10% or more by weight. It is this addition of chromium that gives steel its unique stainless, corrosion resisting properties. The chromium content allows the formation of a tough, adherent, invisible, corrosion resisting chromium oxide film on the steel surface

Test specimen having dimension 235mm x 300mm x 5 mm were prepared for the experimental work. The material for test specimen was Stainless Steel 316 L. Here L stands for Low Carbon Content.



Fig.3.1 Specimen before machining



Fig.3.2 Specimen after machining

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## 4.1.1 Material Properties

**Table 1.1 Material Properties**

COMPOSITION	PERCENTAGE
Fe	
C	<0.03%
Cr	16-18.5%
Ni	10-14%
Mo	2-3%
Mn	<2%
Si	<1%
P	<0.045%
S	<0.03%

## 4.2 DESIGN OF EXPERIMENT

Optimization of process parameters is the key step in the Taguchi method in achieving high quality without increasing the cost. This is because optimization of process parameters can improve performance characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. Especially, a large number of experiments have to be carried out when the number of the process parameters increases.

### 4.2.1 Parameter Design Based on Taguchi method

Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of performance characteristic in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to a better performance characteristic.

Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. This is true for the optimization of a single performance characteristic. However, optimization of multiple performance characteristics cannot be straightforward as in the optimization of a single performance characteristic. The higher S/N ratio for one performance characteristic may correspond to the lower S/N ratio for another performance characteristic. As a result, the overall evaluation of the S/N ratio is required for the optimization of the multiple performance characteristics. To solve this problem, the grey relational analysis is adopted in this study.

### 4.2.2 Grey-based Taguchi method for optimization of process parameters

In the grey relational analysis, the S/N ratio determined from Taguchi method is first normalized in the range between zero and unity, which is also called the grey relational generating. Next, the grey relational coefficient is calculated from the normalized S/N ratio to express the relationship between the desired and the actual S/N ratio. Then, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade. As a result, optimization of complicated multiple performance characteristics can be converted into the optimization of a single grey relational grade. The optimal level of the process parameters is the level with the highest grey relational grade. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the grey relational analysis and statistical analysis of variance, optimal combination of the

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process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

The objective of this paper is to study MRR and Surface roughness, the design variables can be summarized as follows:

- a) Two levels of the Gas Pressure (6.5Bar and 7.5Bar).
- b) Three levels of Current Flow Rate (40A, 60A and 80A).
- c) Three levels of Cutting Speed (2550mm/min, 3000mm/min and 3600mm/min).
- d) Three levels of Arc Gap (2mm,4mm and 6mm)

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely Gas Pressure, Current, Cutting Speed and Arc gap) which would constitute the L16 orthogonal array.

The two most important outputs are Material Removal Rate and Surface Roughness the same have been selected as response parameters for this research work also. The effect of the variation in input process parameter will be studied on these two response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor. The following machining parameters were kept fixed.

**Table 1.2 Fixed Machining Parameter**

S. No.	Machining Parameters	Fixed Value
1	Material Type	Stainless Steel (316 L)
2	Material Thickness	5mm

### 4.2.3 Selection of Orthogonal Array and Process Parameters

In this experiment, there are four parameters at three levels each. The degree of freedom (DOF) of a two level parameter is 2 (Number of Levels minus 1), hence total DOF for the experiment is 4. The DOF of the orthogonal array selected should have higher than that of total DOF of the experiment.

**Table 1.3 Parametric Level Assignment**

Parameter	Unit	Level 1	Level 2	Level 3
Gas Pressure	bar	6.5	7.5	-
Current Flow Rate	ampere	40	60	80
Cutting Speed	mm/min	2550	3000	3600
Arc Gap	mm	2	4	6

**Table 1.4 Experimental Layout in Levels**

Runs	Gas Pressure	Current	Cutting Speed	Arc Gap
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	2	1	1	3
5	2	1	2	1
6	2	1	3	2

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7	1	2	1	1
8	1	2	2	2
9	1	2	3	3
10	2	2	1	2
11	2	2	2	3
12	2	2	3	1
13	1	3	1	2
14	1	3	2	3
15	1	3	3	1
16	2	3	1	3

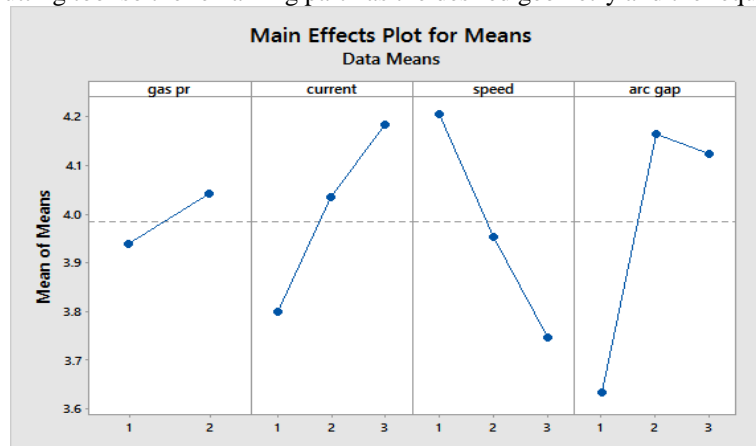
The above table shows the L16 (3\*4) Taguchi design (orthogonal array). L16 means 16 runs. 3\*4 means 4 factors with 3 levels each. This array is orthogonal; factor levels are weighted equally across the entire design. The table columns represent the control factors, the table rows represent the runs (combination of factor levels), and each table cell represents the factor level for that run.

### V. RESULTS AND DISCUSSIONS

Objective of this study is to find out optimal condition of Plasma Arc Cutting Machine for maximizing hardness and minimizing machining time and kerf width. For this single specimen of Stainless Steel material was bought in which 16 cuts were made. The material properties of Stainless Steel (316L) are given in table.3.1.As per literature review Gas Pressure, Current Flow Rate, Cutting Speed and Arc Gap were considered as most important parameters. In order to perform minimum experiments Taguchi method has been employed. For this L16 orthogonal array is considered .Experiment results and various response graph for machining time, hardness and kerf width were obtained.

#### 5.1 Effect of Responses in Taguchi Method

Machining time is the time when a machine is actually processing something. Generally, machining time is the term used when there is a reduction in material or removing some undesirable parts of a material . One of the important aspects in manufacturing calculation is how to calculate and find the machining time in machining operation. Generally, machining is the family of processes or operations in which excess material is removed from the starting work piece by a sharp cutting tool so the remaining part has the desired geometry and the required shape.



**Figure 1.3 Effect Of Machining Time With Respect To Input Parameters.**

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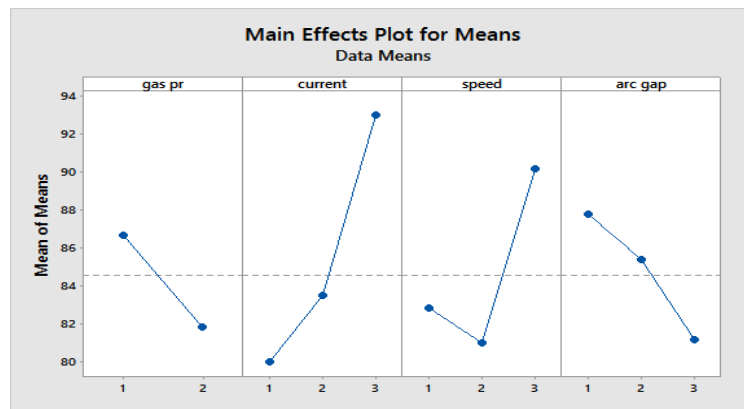
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From the above graph (Figure 1.3), responses effects can be seen and it is analyzed

- When gas pressure increases; machining time increases gradually.
- When current increases; machining time also increases.
- When speed increases; machining time decreases gradually.
- When arc gap increases; machining time sudden increase and then decreases.

For example, in a drill press, machining time is when the cutting edge is actually moving forward and making a hole. Machine time is used in other situations, such as when a machine installs screws in a case automatically.

In metallurgy hardness is defined as the ability of a material to resist plastic deformation. The dictionary of Metallurgy defines the indentation hardness as the resistance of a material to indentation.

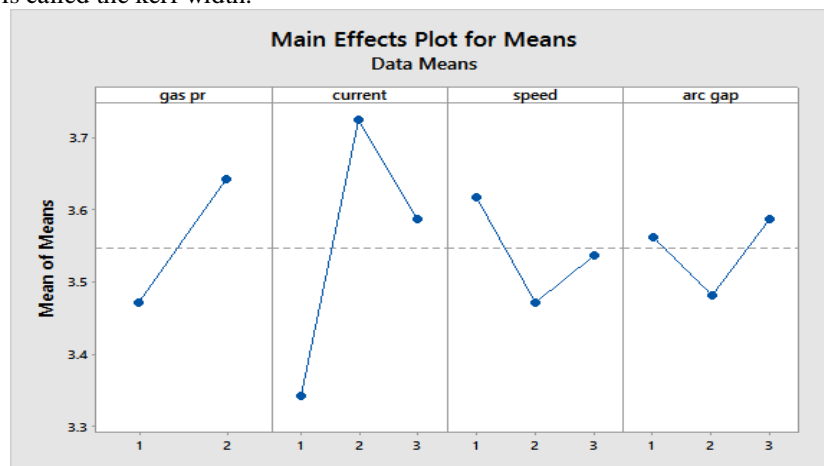


**Figure 1.4 Effect of hardness with respect to input parameters.**

From the graph (Figure 1.4), responses effects can be seen and it is analyzed

- When gas pressure increases; hardness decreases gradually.
- When current increases; hardness also increases.
- When speed increases; hardness decreases and increases gradually.
- When arc gap increases; hardness decreases gradually.

The laser melts away a portion of material when it cuts through; this is known as the laser kerf. The width of the portion after the cut is called the kerf width.



**Figure 1.5 Effect of kerf width with respect to input parameters.**

From the graph(Figure 1.5), responses effects can be seen and it is analyzed



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- When gas pressure increases; kerf width increases gradually.
- When current increases; kerf width also increases and decreases.
- When speed increases; kerf width decreases and increases gradually.
- When arc gap increases; kerf width decreases and increases gradually.

Machining time, hardness and kerf width vs. gas pr, current, speed, arc gap:

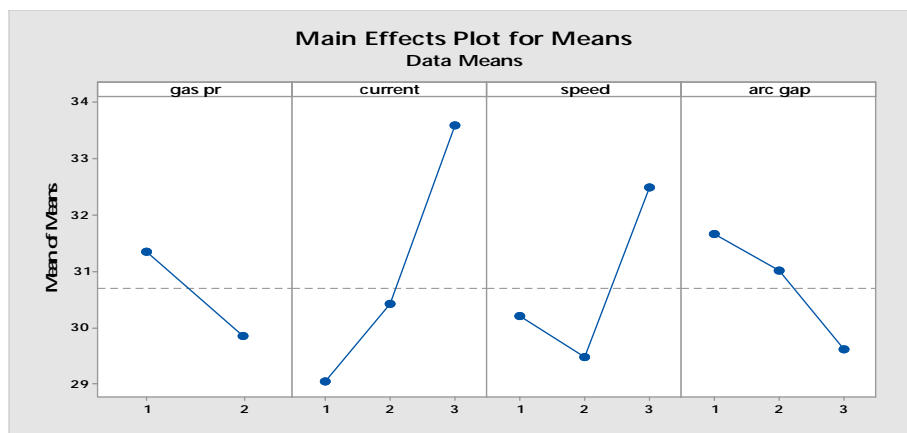


Figure 1.6 Effect of responses with respect to input parameters.

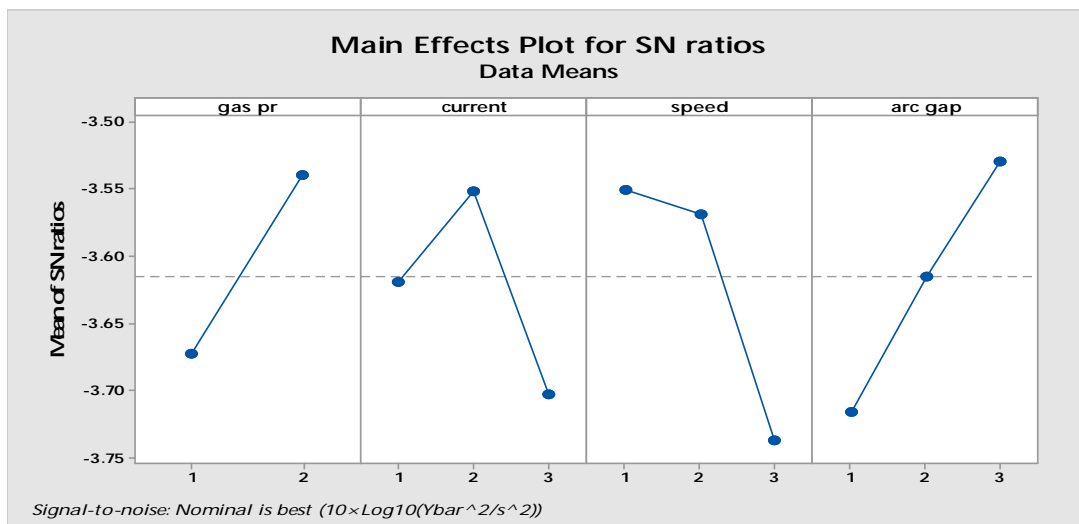


Figure 1.7 S/N ratio with respect to input parameters and output responses

Table 1.5 Taguchi Analysis

Level	gaspr	current	speed	arc gap
1	-3.673	-3.619	-3.551	-3.716
2	-3.540	-3.552	-3.569	-3.615
3	-3.703	-3.737	-3.530	
Delta	0.133	0.151	0.186	0.186
Rank	4	3	2	1

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**Table 1.6 Response Table for Means**

Level	gaspr	current	speed	arc gap
1	31.36	29.05	30.22	31.67
2	29.85	30.42	29.48	31.02
3	33.59	32.50	29.63	
Delta	1.51	4.54	3.02	2.04
Rank	4	1	2	3

### 5.2 Effect of Responses in Grey Relational Analysis

A-Gas pressure(bar)      B-Current(amps)      C-Speed(mm/min)      D-Arc gap(mm)  
R1-Kerf width(mm)      R2-Machining time(sec)      R3-Hardness(HRC)

**Table 1.7 Grey Relational Analysis**

Input Control Parameters					Output responses			Normalizing Sequence			Deviation Sequence			Grey Relational Coefficient			Grey Relational Grade
RUNS	A	B	C	D	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	Grade
1	7	40	2500	2.00	3.4962	3.19	70	0.603	1.000	0.278	0.397	0.000	0.722	0.557	1.000	0.409	0.655
2	7	40	3000	4.00	3.3429	4	77	0.775	0.484	0.472	0.225	0.516	0.528	0.690	0.492	0.486	0.556
3	7	40	3600	6.00	3.3566	4.1	83	0.760	0.420	0.639	0.240	0.580	0.361	0.676	0.463	0.581	0.573
4	8	40	2500	6.00	3.4687	4.3	71	0.634	0.293	0.306	0.366	0.707	0.694	0.577	0.414	0.419	0.470
5	8	40	3000	2.00	3.1432	3.5	89	1.000	0.803	0.806	0.000	0.197	0.194	1.000	0.717	0.720	0.812
6	8	40	3600	4.00	3.2461	3.71	90	0.884	0.669	0.833	0.116	0.331	0.167	0.812	0.602	0.750	0.721
7	7	60	2500	2.00	3.5722	4.2	92	0.517	0.357	0.889	0.483	0.643	0.111	0.509	0.437	0.818	0.588
8	7	60	3000	4.00	3.463	4.1	89	0.64	0.42	0.806	0.36	0.58	0.194	0.581	0.46	0.720	0.588
9	7	60	3600	6.00	3.4809	3.65	90	0.620	0.707	0.833	0.380	0.293	0.167	0.568	0.631	0.750	0.650
10	8	60	2500	4.00	3.8421	4.76	75	0.213	0.000	0.417	0.787	1.000	0.583	0.389	0.333	0.462	0.394
11	8	60	3000	6.00	3.9587	3.9	60	0.082	0.548	0.000	0.918	0.452	1.000	0.353	0.525	0.333	0.404
12	8	60	3600	2.00	4.0317	3.6	95	0.000	0.739	0.972	1.000	0.261	0.028	0.333	0.657	0.947	0.646
13	7	80	2500	4.00	3.5177	4.26	96	0.579	0.318	1.000	0.421	0.682	0.000	0.543	0.423	1.000	0.655
14	7	80	3000	6.00	3.4492	4.27	90	0.656	0.312	0.833	0.344	0.688	0.167	0.592	0.421	0.750	0.588
15	7	80	3600	2.00	3.5717	3.68	93	0.518	0.688	0.917	0.482	0.312	0.083	0.509	0.616	0.857	0.661
16	8	80	2500	6.00	3.8141	4.53	93	0.245	0.146	0.917	0.755	0.854	0.083	0.398	0.369	0.857	0.542

**Table 1.8 Response Table for Grey Relational Grade**

Factors	Level 1	Level 2	Level 3	Level 4	Max - Min
Gas Pressure	0.564	0.677	0.523	0.611	0.154
Current	0.693	0.565	0.556	0.561	0.137
Speed	0.580	0.669	0.600	0.527	0.142
Arc Gap	0.551	0.580	0.619	0.625	0.075

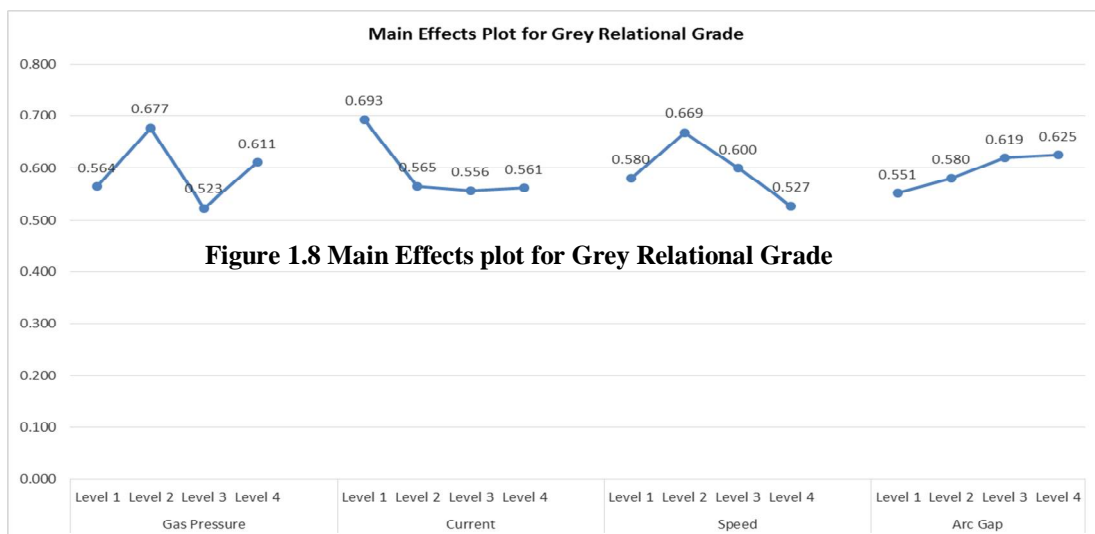
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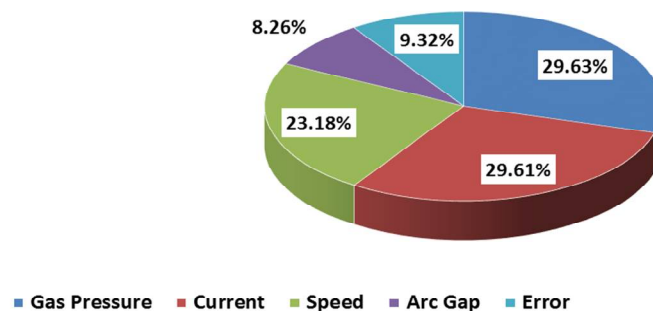
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**Table 1.9 % Contribution Table for Grey Relational Analysis**

Factors	DoF	SS	MS	F Value	% Contribution
Gas Pressure	3	0.0526	0.0175	4.2402	29.63%
Current	3	0.0526	0.0175	4.2378	29.61%
Speed	3	0.0412	0.0137	3.3167	23.18%
Arc Gap	3	0.0147	0.0049	1.1824	8.26%
Error	4	0.0166	0.0041		9.32%
Total	16	0.1777	0.0111		100.00%



**ANOVA % Contribution of Input Parameters**



**Figure 1.9 ANOVA % Contribution of Input parameters**

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## VI. CONCLUSION

The grey relational grade obtained from the grey relational analysis and Taguchi's method were used to optimize the process parameters of Plasma Arc Machining with multiple characteristics (Gas pressure, Speed, Current, Arc gap) the experimental results shows that the parameters Pressure and Current plays a vital role in machining. Based on the Pressure and Current the responses (Machining time, Hardness, kerf width) can be optimized.

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