

# PARAMETRIC OPTIMIZATION OF PLASMA ARC CUTTING PROCESS PARAMETER FOR INCONEL718 ALLOY MATERIAL USING GREY RELATIONAL ANALYSIS

1 Panchani Tejas, 2 Vikram Patel, 3 Priyank Patel

1<sup>st</sup> Research Scholar, 2<sup>nd</sup> Asst.Prof, 3<sup>rd</sup> Asst.Prof,

1<sup>st</sup> [panchanitejas92149@gmail.com](mailto:panchanitejas92149@gmail.com) , 2<sup>nd</sup> [vikram2221@gmail.com](mailto:vikram2221@gmail.com), 3<sup>rd</sup> [priyank6006@yahoo.com](mailto:priyank6006@yahoo.com)

**Abstract** - Now a day with the increase in competition in market and to achieve high accuracy the nonconventional machining like PAC is become life line of any industry. Plasma arc cutting (PAC) is a widely used process for the cutting of different types of metals in several operating conditions. PAC is considered challenging technology compared to its main competitors: oxy-fuel and laser cutting. Today, because of advances in equipment design and improvement in cut quality, previously unheard of applications, such as multiple torch cutting of mild steel, are becoming common place. The aim of the work is the optimization of PAC of INCONAL 718 plates, this experimental analysis of the influence of Current, Cutting Speed and Arc Gap on the maximum MRR in cutting specimens made of INCONAL 718 Material. The Response Process Parameters are measure in Plasma Machining Operations Such as MRR, HAZ and Surface Roughness have been considered for Each Experiment. Experimentation was planned as per Taguchi's L9 Orthogonal array. We have been using techniques Such as, analytical hierarchy process (AHP), multi-objective optimization on the basis of ratio analysis (MOORA), and Grey Relational Analysis (GRA) for Optimal Process Parameters of Plasma Cutting machine. The weight for each criterion (response) is obtained by Analytical Hierarchy Process using judgments of the decision maker. All method is applied to ranking of the process parameters of Plasma Machine.

**Index Terms** - Plasma machine, Layer Current, Cutting speed, Arc Gap, AHP, MOORA, GRA Method.

## I. INTRODUCTION

Plasma arc cutting is a thermal non-traditional cutting process. Plasma arc cutting process operates on direct current, straight polarity having electrode negative with a constricted transferred arc as shown in Figure 1.1.

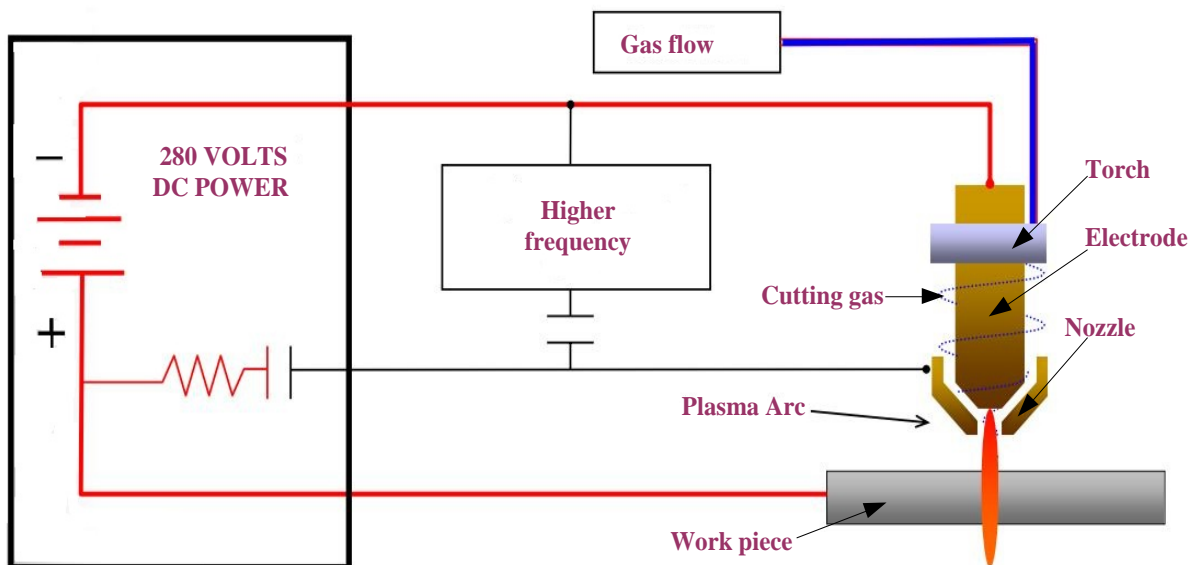


Figure 1.1 Plasma Arc Cutting Schematic Diagram

In any plasma arc cutting process, heated gas is transformed into a plasma gas, resulting in extremely high temperatures. To establish the arc, a low-current pilot arc is initiated by a high-voltage, high-frequency discharge between the electrode and nozzle of the torch. Air/Gas from the power supply is used to force the pilot arc out of the nozzle orifice. Once the pilot arc has been established, the work piece needs to be brought into the circuit. The important step is converting the pilot arc (between the electrode and nozzle) into a "transferred arc" between the electrode and the work piece. As the torch approaches the work piece and the pilot arc contacts the plate, the nozzle and work piece start to share the plasma current. The power supply forces all the current to go through the work piece and increases the current to the cutting level and melting a specific area of metal with the heat of a constricted arc, then removing the molten material with high-velocity jet of hot ionized gas expelled from the nozzle orifice of the cutting torch and cut the material. After the cutting is completed, the plasma cutting arc is removed from the work piece and the electrical circuit is open which stops flowing current. <sup>[19]</sup>

**II. LITERATURE REVIEW**

**Das et al. (2014)** conducted experiment on EN31 steel through plasma cutting, they found that the gas pressure is effective parameter on responses whereas the torch heights are less effective factor on responses. [1] **Gariboldi et al. (2005)** conducted experiment for the quality of cuts performed on titanium sheets using high tolerance plasma arc cutting (HTPAC) process. They developed an analytical model to simulate the thermal effects of the material interaction with the torch in the case of slow cuts with oxygen. [2] **Bini et al. (2008)** conducted experiment on a 200A high tolerance plasma arc cutting (HTPAC) system is utilized to cut plates from 15mm thick mild steel sheets metals. [3] **Iosub et al. (2008)** worked on the plasma cutting process of composite materials. They determined influence of the plasma jet on the one laminar composite materials, melting temperature, damage of composite structure, structural changes in the heat affected area and surface quality of work piece. They also suggested getting good result for cutting composite materials focused on high power plasma cutting machine, laser cutting and water jet technology. [4] **Colombo et al. (2011)** studied behavior of hafnium cathodes at the beginning of their service life when operating at high current levels in the plasma arc cutting (PAC). [5] **Ilii et al. (2010)** presents an analysis of the plasma arc cutting (PAC) process, by using the systemic approach method. The cutting speed (vt) represents one of the most important parameters in the case of plasma cutting process, due to the fact that this parameter has a direct influence on the productivity of the process and on the quality of the obtain surfaces also. [6] **Asiabanpour et al. (2009)** reported on automated plasma cutting for two-dimensional metallic parts in a short period of time. They concluded that the effect of torch height, tool type, and cut direction plays a critical role in surface quality characteristics. [7] **Darji et al. (2014)** present an intelligent and logical MCDM methods Extended TODIM, OCRA, ARAS, EVAMIX to evaluate suitable material for pipes. The comparison is done with the result obtained by the previous researchers, which is found to be the same. The methods proposed are more specific and efficient compared with the previous methods.[8] **Rao et al. (2006)** presents The procedure is based on a combined multiple attribute decision making method using TOPSIS and AHP methods together. A flexible manufacturing system suitability index" is proposed that evaluates and ranks flexible manufacturing systems for the given industrial application. [9] **Chakraborty et al. (2011)** It was found that in all these cases the results obtained using the MOORA method almost corroborate with those derived by the past researchers which prove the applicability, potentiality, and flexibility of this method while solving various complex decision-making problems in present day manufacturing environment.[10]

**III. EXPERIMENTAL PROCEDURE**

In this experiment material used for cutting is INCONAL 718 plate and Parts are cutting by the Plasma Arc cutting machine. For measuring MRR, HAZ and surface roughness of the parts having respective dimensions. Experimental run are create in minitab16. Orthogonal array L9 are develop in the taguchi. After cutting the parts, these parts measure the surface roughness by using surface roughness tester SJ210. The experimental work parameters and each level are shown in table 3.1.

**Table 3.1: Parameters Levels and Values**

Parameter	Units	Levels		
Current(A)	[A°]	200	250	300
Cutting Speed(B)	[mm/min]	2500	3000	3500
Arc Gap (C)	[mm]	2.5	3.5	4.5

- MRR in Cm<sup>3</sup>/sec

$$MRR = \frac{\text{Weight difference} \times \text{density of material}}{\text{Cutting time}}$$

$$= \frac{17.4 \text{ gms} / 8.19 \text{ g/cm}^3}{5.41 \text{ sec}} = 0.3927 \text{ cm}^3/\text{sec}$$

Repeat procedure for next 8 reading

**Results of L9 Orthogonal array on Surface Roughness and MRR for Alloy Steel AISI316L**

**Table 3.2: Results of Experiment**

Alternative	INPUT PARAMETERS			OUTPUT PARAMETERS		
	Current (A <sup>0</sup> )	Cutting Speed (mm/min)	Arc gap (mm)	MRR cm <sup>3</sup> /sec	SR (µm)	HAZ (µm)
A1	200	2.500	2.5	0.3927	3.671	35.3
A2	200	3.000	3.5	0.3492	3.780	88.4
A3	200	3.500	4.5	0.4899	5.365	100.3
A4	250	2.500	3.5	0.4.139	3.370	50.4
A5	250	3.000	4.5	0.4711	3.457	110.7
A6	250	3.500	2.5	0.2815	4.358	48.0

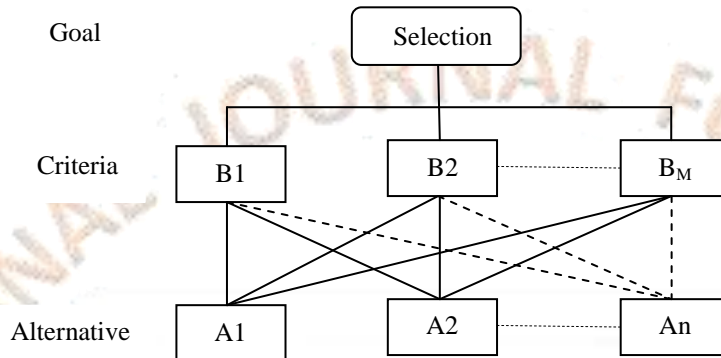
A7	300	2.500	4.5	0.5432	4.543	38.5
A8	300	3.000	2.5	0.3525	4.437	72.2
A9	300	3.500	3.5	0.4595	4.934	69.7

**IV. MULTIPLE ATTRIBUTE DECISION MAKING METHODS**

**4.1 Analytic Hierarchy Process / Multi-Objective Optimization on the Basis of Ratio Analysis (AHP/MOORA Method)**

Steps of the AHP method as follows:

**Step 1:** Developing the hierarchical structure. A decision problem is structured as a hierarchy structure. With the AHP, the goal, decision criteria and alternatives are arranged in a hierarchical structure similar to a family tree.



**Figure 4.1 A hierarchy of the decision making problem**

**Step 2:** Perform the pair wise comparisons.

In this step, comparison matrices are formed and pair wise comparisons are conducted. Decision criteria are compared in the corresponding level using fundamental comparison scale. The table below shows the comparison scale used by AHP.

$$A1_{M \times M} = \begin{matrix} B1 & \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & \dots & a_{1M} \end{bmatrix} \\ B2 & \begin{bmatrix} a_{21} & 1 & a_{23} & \dots & \dots & a_{2M} \end{bmatrix} \\ B3 & \begin{bmatrix} a_{31} & a_{32} & 1 & \dots & \dots & a_{3M} \end{bmatrix} \\ \dots & \begin{bmatrix} \dots & \dots & \dots & 1 & \dots & \dots \end{bmatrix} \\ \dots & \begin{bmatrix} \dots & \dots & \dots & \dots & 1 & \dots \end{bmatrix} \\ BM & \begin{bmatrix} a_{M1} & a_{M2} & a_{M3} & \dots & \dots & 1 \end{bmatrix} \end{matrix}$$

Where  $a_{ij}$  denotes the comparative importance of attribute  $i$  with respect to attribute  $j$  and  $B_i$  denoted the criteria in the matrix,  $a_{ij} = 1$ , when  $i = j$  and  $a_{ji} = 1/a_{ij}$ .

**Table No: 4.1 Scale of Relative Importance**

Scale	Importance	Meaning of attributes
1	equal importance	Two attributes are equally important
3	moderate importance	One attribute is moderately important over the other
5	strong importance	One attribute is strongly important over the other
7	very importance	One attribute is very important over the other
9	Absolute importance	One attribute is absolutely important over the other
2,4,6,8, compromise importance between 1,3,5,7 and 9		

**Step 3:** Determination of relative normalized weight. A relative normalized weight at each level of hierarchy structure is calculated using Equation (1) and Equation (2).

$$GM_j = \left[ \prod_{j=1}^M a_{ij} \right]^{\frac{1}{M}} \dots\dots\dots(1)$$

$$W_j = \frac{GM_j}{\sum_{j=1}^M GM_j} \dots\dots\dots(2)$$

**Step 4:** Consistency Test.

If the judgment matrix or comparison matrix is inconsistent then judgment should be reviewed and improved it to obtain the consistent matrix. Hence, consistency test will be carried out using following steps.

- Calculate matrices

$$A3 = A1 \times A2 \text{ and } A4 = A3 / A2$$

Where; A1= [aij] M×M

$$A2 = [W1, W2, \dots, Wj]^T$$

- Calculate Eigen value  $\lambda_{max}$ (average of matrix A4)
- Calculate the consistency index:  $CI = (\lambda_{max} - M) / (M - 1)$
- Calculate the consistency ratio:  $CR = CI/RI$ , select value of random index (RI) according to number of attributes used in decision-making .
- **If  $CR < 0.1$ , considered as acceptable decision, otherwise judgment of the analyst about the problem under study.**

**Step 5:** Creating the decision matrix.

The method starts with a decision matrix of responses of different alternatives to evaluation criteria.

$$A1_{M \times M} = \begin{matrix} B1 & \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & \dots & a_{1M} \\ a_{21} & 1 & a_{23} & \dots & \dots & a_{2M} \\ a_{31} & a_{32} & 1 & \dots & \dots & a_{3M} \\ \dots & \dots & \dots & \dots & 1 & \dots \\ \dots & \dots & \dots & \dots & \dots & 1 \\ a_{M1} & a_{M2} & a_{M3} & \dots & \dots & 1 \end{bmatrix} \end{matrix}$$

Where aij is the performance measure of ith alternative on jth attribute, m is the number of alternatives, and n is the number of attributes.

**Step 6:** Then a ratio system is built-up in which each performance of an alternative to an attribute is compared to a denominator which is a representative for all the alternatives concerning that attribute Brauers et al. [17] concluded that for this denominator, the best choice is the square root of the sum of squares of each alternative per attribute. This ratio can be expressed as below:

$$X_{ij}^* = \frac{X_{ij}}{\sqrt{\sum_{i=1}^m X_{ij}^2}} \dots\dots\dots (3)$$

Where j=1, 2, 3... n

Where xij\* is a dimensionless number which belong to the interval [0, 1] on behalf of the normalized performance of i<sup>th</sup> alternative on j<sup>th</sup> attribute.

**Step 7:** For multi objective optimization, these normalized performances are added in case of Maximization (for beneficial attributes) and subtracted in case of minimization (for non beneficial attributes). Then the optimization problem becomes:

$$Y_i = \sum_{j=1}^g X_{ij} - \sum_{j=g+1}^n X_{ij} \dots\dots\dots (4)$$

Where g is the number of attributes to be maximized, (n-g) is the number of attributes to be minimized, and Y<sub>i</sub> is the normalized assessment value of i<sup>th</sup> alternative with respect to all the attributes.

In some cases, it is often practical that some attributes are extra important than the others. In order to give more importance to an attribute, it could be multiplied by its corresponding weight (significance coefficient). When this attribute weights are taken into consideration, Eq. 5 becomes as follows:

$$Y_i = \sum_{j=1}^g W_j X_{ij} - \sum_{j=g+1}^n W_j X_{ij} \dots\dots\dots (5)$$

Where j=1, 2, 3... n

Where W<sub>j</sub> is the weight of j<sup>th</sup> attribute, which can be determined applying analytic hierarchy process (AHP).

**V. Illustrations of Example Using AHP/MOORA Method**

**Step 1:** A Laser Cutting Machine Process Parameters Selection Problem can be Decomposed Procedure Described in the Hierarchy Structure.

**Step 2:** A Relative Importance of between Attributes is assigned with Respect to the Goal. The Judgments are entered using Scale of Relative Importance of the AHP Method as Shown in Table No: 5.1.

**Table No: 5.1 Pair Wise Comparison Matrix for Different Criteria**

Attribute	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>
-----------	----------------	----------------	----------------

<b>B<sub>1</sub></b>	1	2	4
<b>B<sub>2</sub></b>	1/2	1	4
<b>B<sub>3</sub></b>	1/4	¼	1

**Step 3:** A Relative Normalized Weight of Attributes is Calculated Using Eq.1 and Eq.2.

**Table No.5.2: Relative Normalized Weight of Attribute**

Attributes	W <sub>i</sub>
(B1)= Material Removal Rate	W <sub>1</sub> = 0.5469
(B2)= Heat Affected Zone	W <sub>2</sub> = 0.3445
(B3)= Surface Roughness	W <sub>3</sub> = 0.1085

**Step 4: Consistency Test.**

If the judgment matrix or comparison matrix is inconsistent then judgment should be reviewed and improved it to obtain the consistent matrix.

$$A_3 = A_1 * A_2$$

Where, A1= [a<sub>ij</sub>] <sup>M\*M</sup>

A2 = [W1, W2... Wj] <sup>T</sup>

$$A_3 = A_1 \times A_2 = \begin{bmatrix} 1 & 2 & 4 \\ \frac{1}{2} & 1 & 4 \\ \frac{1}{4} & \frac{1}{4} & 1 \end{bmatrix} \times \begin{bmatrix} 0.5469 \\ 0.3445 \\ 0.1085 \end{bmatrix} = \begin{bmatrix} 1.6702 \\ 1.0521 \\ 0.3314 \end{bmatrix} A_4 = \frac{A_3}{A_2} = \begin{bmatrix} 1.6702 \\ 1.0521 \\ 0.3314 \end{bmatrix} \div \begin{bmatrix} 0.5469 \\ 0.3445 \\ 0.1085 \end{bmatrix} = \begin{bmatrix} 3.0538 \\ 3.0537 \\ 3.0533 \end{bmatrix}$$

- λ<sub>max</sub>= Average of matrix A4 = 3.0536
- CI = (λ<sub>max</sub>- M) / (M-1) = (3.0536 -3)/(3-1) = 0.0536/2 = 0.2681
- Here, CI is zero, there for CR also zero.
- CR = 0
- **If CR < 0.1, considered as acceptable decision, otherwise judgment of the analyst about the problem under study.**

**Step 5:** Here 9 (Alternatives A1 Up to A9) Process Parameters of Laser. Response Process Parameters of the Laser Cutting Machine such as Material Removal Rate, and Surface Roughness.

**Step 6: Normalization procedure.**

MOORA refers to a ratio system in which each response of an alternative on criteria is compared to a denominator, which is representative for all alternatives concerning that objective. This ratio can be calculate using Eq. 3 and value are shown in Table 5. 3.

**Table No: 5.3 Dimensionless Numbers (xi) for Each Alternative**

Alternative	MRR (mm <sup>3</sup> /sec)	HAZ (mm)	Surface roughness (µm)
A <sub>1</sub>	0.3086	0.1615	0.2871
A <sub>2</sub>	0.2744	0.4044	0.2956
A <sub>3</sub>	0.3850	0.4589	0.4196
A <sub>4</sub>	0.3253	0.2306	0.2635
A <sub>5</sub>	0.3702	0.5065	0.2703
A <sub>6</sub>	0.2212	0.2196	0.3408
A <sub>7</sub>	0.4269	0.1761	0.3553
A <sub>8</sub>	0.2770	0.3303	0.3470
A <sub>9</sub>	0.3611	0.3189	0.3858

**Step 7: Evaluation of positive and negative effects.**

For optimization, these normalized performances are added in case of maximization (for beneficial criteria) and subtracted in case of minimization (for non beneficial or cost criteria) by solving the following equation: Using Eq.5 the weight of each attribute, i.e. W<sub>MRR</sub>= 0.5469, W<sub>HAZ</sub>= 0.3445, W<sub>SR</sub>= 0. 1085. An ordinal ranking of Y<sub>i</sub> is shown in table 5.4 final preferences. Thus, the best alternative has the highest Y<sub>i</sub> value, while the worst alternative has the lowest Y<sub>i</sub> value.

$$Y_i = W_j \times X_{ij}$$

$$Y_1 (MRR) = 0.5469 \times 0.3086 = 0.1688$$

$$Y_1 (HAZ) = 0.3445 \times 0.1615 = 0.0556$$

$$Y_1 (SR) = 0.1085 \times 0.2871 = 0.0311$$

$$Y_i = \{ Y_1 (MRR) + Y_1 (HAZ) - Y_1 (SR) \} = \{ 0.1688 + 0.0556 - 0.0311 \} = 0.1131$$

**Table No: 5.4 Weighted Assessment Values (Y<sub>i</sub>) and Ranking for Selection of the Process Parameters**

Alternative	MRR in (mm <sup>3</sup> /sec)	HAZ (mm)	Surface roughness (µm)	Y <sub>i</sub>	Rank
A <sub>1</sub>	0.1688	0.0556	0.0311	0.1933	8
A <sub>2</sub>	0.1501	0.1393	0.0321	0.2573	4
A <sub>3</sub>	0.2106	0.1581	0.0455	0.3231	2
A <sub>4</sub>	0.1779	0.0794	0.0286	0.2287	6
A <sub>5</sub>	0.2025	0.1745	0.0293	0.3476	1
A <sub>6</sub>	0.1210	0.0757	0.0370	0.1597	9
A <sub>7</sub>	0.2335	0.0607	0.0385	0.2556	5
A <sub>8</sub>	0.1515	0.1138	0.0376	0.2277	7
A <sub>9</sub>	0.1975	0.1099	0.0419	0.2655	3

**VI. Results Validation Using GRA Method.**

**Step 1: Data Normalization**

If the target value of original sequence is infinite, then it has a characteristic of “the larger the better”. The original sequence can be normalized as follows:

$$Xi(k) = \frac{Yi(k) - \min Yi(k)}{\max Yi(k) - \min Yi(k)} \dots\dots\dots (6)$$

If the expectancy is “the smaller the better” than the original sequence should be normalized as follows:

$$Xi(k) = \frac{\max Yi(k) - Yi(k)}{\max Yi(k) - \min Yi(k)} \dots\dots\dots (7)$$

**Table No: 6.1 Data Normalization**

Data Normalization			
Alternative	MRR (cm <sup>3</sup> /sec)	HAZ (mm)	SR (µm)
A <sub>1</sub>	0.4249	0.0000	0.8491
A <sub>2</sub>	0.2587	0.7042	0.7945
A <sub>3</sub>	0.7963	0.8621	0.0000
A <sub>4</sub>	0.5059	0.2003	1.0000
A <sub>5</sub>	0.7245	1.0000	0.9564
A <sub>6</sub>	0.0000	0.1684	0.5048
A <sub>7</sub>	1.0000	0.0424	0.4120
A <sub>8</sub>	0.2713	0.4894	0.4652
A <sub>9</sub>	0.6802	0.4562	0.2160

**Step:2 Calculation of Deviation Sequence**

In this work to find out Grey Relation Coefficient one has to calculate deviation sequence using Eq.8 shown in table 6.2. The deviation sequences Δ<sub>oi</sub>, Δ<sub>max</sub> (k), and Δ<sub>min</sub> (k) for i=1-9 and k=1-3 can be calculated as follows:

**Experiment No: 1**

$$\Delta_{oi}(k) = |X0(k) - Xi(k)| \dots\dots\dots (9)$$

**Table No: 6.2 The Deviation Sequences**

The Deviation Sequences			
Alternative	MRR (cm <sup>3</sup> /sec)	HAZ (mm)	SR (µm)
A <sub>1</sub>	0.5751	1.0000	0.1509
A <sub>2</sub>	0.7413	0.2958	0.2055
A <sub>3</sub>	0.2037	0.1379	1.0000
A <sub>4</sub>	0.4941	0.7997	0.0000
A <sub>5</sub>	0.2755	0.0000	0.0436
A <sub>6</sub>	1.0000	0.8316	0.4952
A <sub>7</sub>	0.0000	0.9576	0.5880
A <sub>8</sub>	0.7287	0.5106	0.5348
A <sub>9</sub>	0.3198	0.5438	0.7840

Using table no: 6.2 Δmax and Δmin can be found as follows.

$$\Delta_{max} = \Delta_6 (1) = \Delta_1 (1) = \Delta_3 (1) = 1.0000$$

$$\Delta_{min} = \Delta_7 (1) = \Delta_5 (1) = \Delta_4 (1) = 0.0000$$

**Step:3 Calculate of Grey Relational Coefficient and Grey Relational Grade**

The distinguishing coefficient can be substituted for the grey relational coefficient in Eq.11. Table 6.3 lists the grey relational coefficient and grade for each experiment of the L9 Orthogonal array by applying Eq.8. Here weight age of each output parameters are calculated using Analytical hierarchy process. Here ψ = distinguishing or identification coefficient is taken 0.5.

Experiment No: 1(MRR)

$$\zeta_i(k) = \frac{\Delta_{min} + \psi \Delta_{max}}{\Delta_i(k) + \psi \Delta_{max}} \dots\dots\dots (10)$$

$$= \frac{0 + 0.5 \times 1}{0.5751 + 0.5 \times 1} = 0.4651$$

$$W1\zeta_1 (MRR) = 0.4651 \times 0.5469 = 0.2544$$

$$W2\zeta_1 (HAZ) = 0.3333 \times 0.3445 = 0.1148$$

$$W3\zeta_1 (SR) = 0.7682 \times 0.1085 = 0.0833$$

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n W_k \zeta_i(k) \dots\dots\dots (11)$$

$$= \frac{1}{3} \sum_{k=1}^3 (0.2544 + 0.1148 + 0.0833) = 0.1508$$

**Table No: 6.3 Calculated Grey Relational Coefficient and Grey Relational Grade**

Alternative	Grey Relational Coefficient			Grey Relational Grade	Order
	MRR (cm <sup>3</sup> /sec)	HAZ (mm)	SR (μm)		
<b>Weight</b>	<b>0.5469</b>	<b>0.3445</b>	<b>0.1085</b>		-
A <sub>1</sub>	0.2544	0.1148	0.0833	0.1508	7
A <sub>2</sub>	0.2203	0.2165	0.0769	0.1712	6
A <sub>3</sub>	0.3886	0.2700	0.0362	0.2383	2
A <sub>4</sub>	0.2751	0.1325	0.1085	0.1720	5
A <sub>5</sub>	0.3526	0.3445	0.0998	0.2656	1
A <sub>6</sub>	0.1823	0.1294	0.0545	0.1221	9
A <sub>7</sub>	0.5469	0.1182	0.0499	0.2316	3
A <sub>8</sub>	0.2226	0.1704	0.0524	0.1485	8
A <sub>9</sub>	0.3335	0.1650	0.0423	0.1803	4

According to performed experimental design, it is clearly observed from Table 6.3 and the Grey relational grade graph which shows the change in the response when the A<sub>5</sub> experiment number gives the best multi- performance characteristics of the LASER Cutting Process among the 9 experiments number.

**VII. Conclusion**

In this work, a GRA based on the Taguchi method is used to directly integrate three Plasma Arc cutting quality characteristics which are converted into a grey relational grade. The grade obtained for each experiment can immediately reflect the actual cutting results, including the MRR, HAZ and surface roughness. In this case, it is observed that the top-three ranked of the Plasma Arc Cutting Process Parameters almost match with those derived by GRA method and AHP/MOORA Method. The GRA method is highly stable as a comparison to the MOORA Method for decision making problems. It has been observed that GRA method is very simple, stable and robust. It requires minimum Mathematical calculations and computational time. The suggested methodology can be used for any type of selection problem involving many selection criteria. Another major advantage of this method is that the calculation procedure is not affected by the introduction of any extra parameter.

❖ **References**

1. M.K. Das, K. Kumar, T.K. Barman, P. Sahoo, "Optimization of Plasma Arc Cutting of EN 31 Steel Based on MRR and Multiple Roughness characteristics using Grey Relation Analysis", Procedia Materials Science, Vol.5, pp.1550 – 1559 (2014).
2. E. Gariboldi, B. Previtali, "High tolerance plasma arc cutting of commercially pure titanium", Journal of Materials Processing Technology, Vol.160, pp.77-89 (2005).

3. R. Bini, B.M. Colosimo, A.E. Kutlu, M. Monno, "Experimental study of the features of the kerf generated by a 200 A high tolerance plasma arc cutting system", journal of materials processing technology, Vol.196, pp.345-355 (2008).
4. A. Iosub, G. Nagit, F. Negoescu, "Plasma cutting of composite materials" International Journal Material Form Supply, Vol.1, pp. 1347-1350 (2008).
5. V. Colombo, A. Concetti, E. Ghedini, F. Rotundo, P. Sanibondi, "Advances in plasma arc cutting technology the experimental part of an integrated approach", plasma chemistry and plasma processing, vol.32, pp. 411-426 (2011).
6. S. Ilii, M. Coteata, A. Munteanu, "Experimental results concerning the variation of surface roughness parameter (Ra) at plasma arc cutting of a stainless steel work piece", international journal of modern manufacturing technologies, ISSN 2067-3604, Vol.2, pp. 31-36 (2010).
7. B. Asiabanpour, D.T. Vejandla D, C. Novoa, J. Jimenez, R. Fischer, "Optimizing the quality of parts manufactured by the automated plasma cutting process using response surface methodology", pp. 47-60 (2009).
8. V. P. Darji, R. V. Rao, (2014), "Intelligent Multi Criteria Decision Making Methods for Material Selection in Sugar Industry", Procedia Materials Science Vol.5 (2014), pp. 2585 – 2594.
9. R. VENKATA RAO, (2006), "Evaluating Flexible Manufacturing Systems using a Combined Multiple Attribute Decision Making Method", International Journal of Production Research, Vol. 46, No. 7, 1 April 2008, pp.1975-1989.
10. Shankar Chakraborty, (2011), "Applications of the MOORA method for Decision Making in Manufacturing Environment", International Journal Advance Manufacturing Technology (2011), Vol.54, pp.1155-1166.
11. Bogdan Allemann I, Goldberg DJ (eds): Basics in Dermatological Laser Applications. Curr Probl Dermatol. Basel, Karger, 2011, Vol 42, pp 7-23.
12. Dr J. Powell, Dr A. Kaplan, (2004) "Laser Cutting: From First Principles to the State of the Art" Proceedings of the 1st Pacific International Conference on Application of Lasers and Optics 2004.
13. "MINITAB User manual", Version 16, MINITAB corp.
14. "Mitutoyo surface roughness tester SJ-201 user's manual", mitutoyo instruments ltd, Japan 2007.
15. Rao, R. V. Decisionmaking in the manufacturing environment: using graph theory And fuzzy multiple attributed decision making methods, London, Springer-Verlag. ISBN:978-1-84628-818-0, 2007.
16. Saaty, T.L. The Analytic Hierarchy Process, Mc graw Hill, New York, 1981.
17. Saaty, T.L. Fundamental of decision making and priority theory with the AHP, RWS Publication Pittsburg, 2000.
18. Prasenjit Chatterjee, Shankar Chakraborty, (2014), "Flexible Manufacturing System Selection using Preference Ranking Methods: A Comparative Study", International Journal of Industrial Engineering Computations, Vol. 5, (2014).
19. "Modern Machining Processes" by P.C. Pandey, H.S. Shan, Tata Mcgraw- Hill publishing Company Limited, 35th reprint 2009, pp. 143-148.

