"PARAMETRIC OPTIMIZATION OF PLASMA ARC CUTTING ON INCONEL 625 MATERIAL BY REGRESSION ANALYSIS"

NIRAV CHAUHAN [1], RAHUL CHAUHAN[2], MR. JAKSAN D. PATEL [3]

1Advance manufacturing Engineering (Mechanical Department), M.E.C, Mehsana- 384315, Gujarat, India

2Mechanical Engineering Department, M.E.C, Mehsana- 384315, Gujarat, India

ABSTRACT

For an effective and efficient application of machining processes it is often necessary to consider more than one machining performance characteristics for the selection of optimal machining parameters. In this study a plasma arc cutting system is utilized to cut plates from thick INCONEL625 sheets metals. The Design of Experiments (DOE) technique is used in order to outline the main parameters. In this study, gas pressure, current flow rate and arc gap will take as input process parameters to influence on surface roughness, kerf width and MRR. Experimental result concludes that for achieve good surface quality, current flow rate and arc gap must be required less. Now concentrate on effect of gas pressure on surface roughness, it concludes that with increase in gas pressure, surface roughness is decrease. So it concludes that for achieve good surface quality, gas pressure required must be more. Experimental result show that kerf width increase with increase gas pressure, current flow rate and arc gap and for material removal rate with increase in arc gap, material removal rate is decrease. So it concludes that for achieve good material removal rate, arc gap must be required less. It concludes that with increase in gas pressure and current flow rate, material removal rate is increase. So it concludes that for achieve good material removal rate, gas pressure and current flow rate must be required more. For material removal rate percentage contribution of arc gap is more in three response variables compare to other two process parameters.

Key word – *PAC, INCONEL625, Kerf Width, MRR, Surface Roughness.*

---

1 INTRODUCTION

Non-conventional manufacturing processes are not affected by the hardness, toughness and fragility of the material and can produce any complex shape on any piece material by proper control on the various physical parameters of the process. Unconventional manufacturing processes can be classified based on the type of energy i.e., mechanical, electrical, chemical, thermal or magnetic applied to the work piece directly and have the transformation of the desired shape or material removal of the work surface using different scientific mechanism. Thus, these non-conventional processes can be classified into various groups according to the basic requirements which are as follows: [19]

- **Type of energy required is**,
  Mechanical, electrical, chemical, etc.

- **The basic mechanism involved in processes such as**
  Erosion, ionic dissolution, vaporization, etc.

- **Immediate energy source required for the removal of material is**,
  Hydrostatic pressure, high current density, high voltage, ionized material, etc.
- **Medium to transfer these energies as**

High-speed particles, the electrolyte, electrons, hot gases, etc.

1.1 Why non-conventional Machining Process is required?

Need have machine newly developed metals and non-metals having some special properties like high strength, high hardness and high toughness.

A material posing the above mentioned properties are difficult to be machined by the conventional machining methods.

Sometimes it is required to produce complex part geometries that cannot be produced by conventional machining techniques.

Non-conventional machining methods also provide very good quality of surface finish which may also be an encouragement to these methods. [9]

1.2 Classification of Non-Conventional Machining Process:

Non-Conventional Machining process are classified based on energy required to remove the material

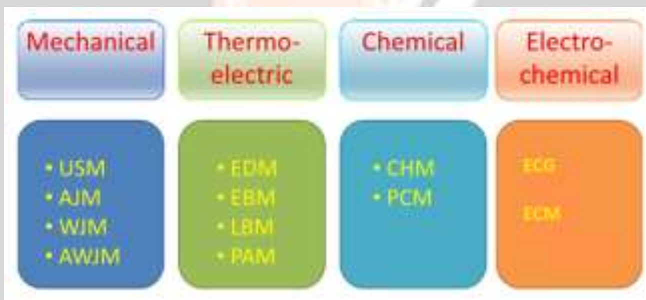


Fig.1: Classification of Non-Conventional Machining Process [22]

1.3 What is Plasma? [20]

One common description of plasma is to describe it as the fourth state of matter. We normally think of the three states of matter as solid, liquid and gas. For a common element, water, these three states are ice, water and steam. The difference between these states relates to their energy levels. When we add energy in the form of heat to ice, the ice melts and forms water. When we add more energy, the water vaporizes into hydrogen and oxygen, in the form of steam. By adding more energy to steam these gases become ionized. This ionization process causes the gas to become electrically conductive. This electrically conductive, ionized gas is called a plasma.

1.4 How Plasma Cuts Through Metal [20]

The plasma cutting process, as used in the cutting of electrically conductive metals, utilizes this electrically conductive gas to transfer energy from an electrical power source through a plasma cutting torch to the material being cut.

The basic plasma arc cutting system consists of a power supply, an arc starting circuit and a torch. These system components provide the electrical energy, ionization capability and process control that is necessary to produce high quality, highly productive cuts on a variety of different materials.

The power supply is a constant current DC power source. The open circuit voltage is typically in the range of 240 to 400 V. The output current of the power supply determines the speed and cut thickness capability of the system. The main function of the power supply is to provide the correct energy to maintain the plasma arc after ionization.

The arc starting circuit is a high frequency generator circuit that produces an AC voltage of 5,000 to 10,000 volts at approximately 2 megahertz. This voltage is used to create a high intensity arc inside the torch to ionize the gas, thereby producing the plasma.

The Torch serves as the holder for the consumable nozzle and electrode, and provides cooling (either gas or water) to these parts. The nozzle and electrode constrict and maintain the plasma jet.

2 MATERIALS AND EXPERIMENTAL PLANE

2.1 Work Piece Description

INCONEL 625 is a modern materials and, due to their characteristics, they are widely used, especially in the aerospace industry. These materials are applied among others in the construction of turbine bodies, jet engine components, tanks, combustion chambers, turbine blades and exhaust valves etc. Inconel 625 is used both in casting and plastic deformation technology. Inconel 625 alloy is a material of choice for gas turbine engine ducting, combustion liners, furnace hardware, spray bars and special seawater applications in aerospace, chemical, petrochemical and marine industries.

(a) Before cut **(b) After cut**

Fig. 2: Work Piece

Table 1: Chemical Composition (Test Well Lab.)

Element	Ni	Cr	Mo	Nb	Fe	C	Mn	Si	P	S	Al	Ti	Co
Content (%)	61.67	20.79	8.62	3.37	4.43	0.057	0.190	0.310	0.008	0.005	0.164	0.130	0.086

2.2 Control Parameters

Table 2: Process parameters with levels value

Sr.No	**Control Factor**	**Level**			**Unit**
		1	**2**	**3**	
1	Gas Pressure	8	12	16	Bar
2	Current flow rate	200	240	280	Amp
3	Arc gap	3	5	7	mm

2.3 Performance Evaluation Criteria

Table 3: Performance Evaluation Criteria

Kerf width (KW)	Surface Roughness (Ra)	Material removal rate (mm^3/min)

2.4 Fixed machining parameter

Table 4: Fixed machining parameter

Sr no.	Machining parameter	Fixe value
1	Material Type	Inconel 625
2	Material Thickness	10 mm
3	Operating voltage	95 V

2.5 Experimental design matrix

Table 5: Experimental design matrix

Sr no.	Gas pressure (bar)	Current flow rate (amp)	Arc gap (mm)	Sr no.	Gas pressure (bar)	Current flow rate (amp)	Arc gap (mm)	Sr no.	Arc gap (mm)	Current flow rate (amp)	Arc gap (mm)
1	8	200	3	**10**	12	200	3	**19**	16	200	3
2	8	200	5	**11**	12	200	5	**20**	16	200	5
3	8	200	7	**12**	12	200	7	**21**	16	200	7
4	8	240	3	**13**	12	240	3	**22**	**16**	**240**	**3**
5	8	240	5	**14**	12	240	5	**23**	16	240	5
6	8	240	7	**15**	12	240	7	**24**	16	240	7
7	8	280	3	**16**	12	280	3	**25**	16	280	3
8	8	280	5	**17**	12	280	5	**26**	16	280	5
9	8	280	7	**18**	12	280	7	**27**	16	280	7

3. RESULTS

Table 6: Experiment reading

Sr no.	**Gas pressure (bar)**	**Current flow rate (amp)**	**Arc gap (mm)**	**Kerf width (mm)**	**Surface roughness (µm)**	**Material removal rate (mm^3/min)**	**Sr no.**	**Gas pressure (bar)**	**Current flow rate (amp)**	**Arc gap (mm)**	**Kerf width (mm)**	**Surface roughness (µm)**	**Material removal rate (mm^3/min)**
1	8	200	3	1.404	3.89	2.21	**15**	12	240	7	1.800	3.59	2.14
2	8	200	5	1.424	3.95	2.12	**16**	12	280	3	1.680	3.52	2.40
3	8	200	7	1.434	3.98	1.98	**17**	12	280	5	1.890	3.56	2.29
4	8	240	3	1.434	3.92	2.28	**18**	12	280	7	2.020	3.60	2.19
5	8	240	5	1.450	3.97	2.18	**19**	16	200	3	1.590	3.14	2.37
6	8	240	7	1.500	4.01	2.03	**20**	16	200	5	1.660	3.18	2.23
7	8	280	3	1.500	3.77	2.18	**21**	16	200	7	1.790	3.20	2.17
8	8	280	5	1.580	3.86	2.28	**22**	**16**	**240**	**3**	**1.620**	**3.19**	**2.42**
9	8	280	7	1.660	4.07	2.33	**23**	16	240	5	1.820	3.27	2.37
10	12	200	3	1.500	3.42	2.32	**24**	16	240	7	1.700	3.29	2.19
11	12	200	5	1.590	3.47	2.18	**25**	16	280	3	1.800	3.22	2.41
12	12	200	7	1.720	3.51	2.10	**26**	16	280	5	1.750	3.38	2.34
13	12	240	3	1.520	3.44	2.38	**27**	16	280	7	1.690	3.41	2.29
14	12	240	5	1.790	3.47	2.27							

3.1 Regression

3.1.1 Regression Equation for Kerf Width

The regression equation is
Kerf Width = 0.6405 + 0.02825 Gas Pressure + 0.002025 Current flow rate
+ 0.0351667 Arc gap

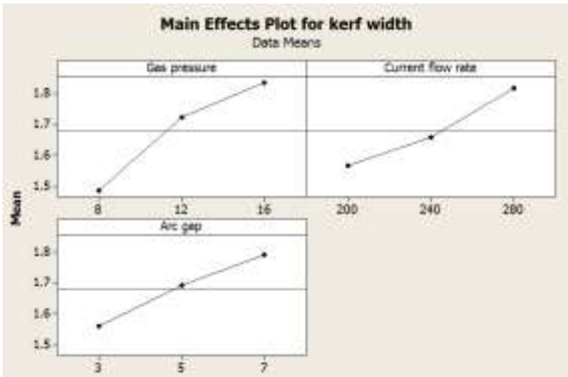
3.1.2 Regression Equation for Surface Roughness

The regression equation is
Surface Roughness = 4.21287 - 0.0852778 Gas Pressure + 0.000902778 Current Flow rate
+ 0.0319444 Arc gap

3.1.3 Regression Equation for material removal rate

The regression equation is
MRR = 1.91824 + 0.0166667 Gas Pressure + 0.00143056 Current flow rate
- 0.0430556 Arc gap

3.2 Main Effects Plot



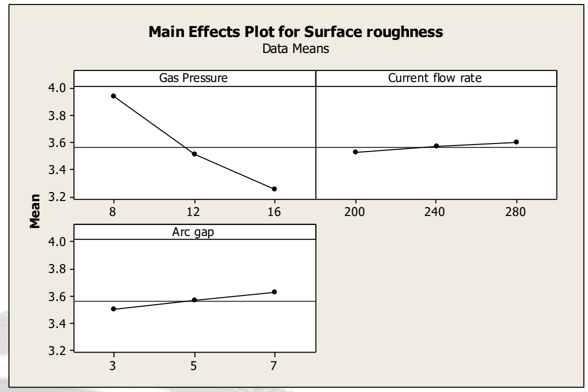


Fig.3: Effect of control factor on Kerf width **Fig. 4: Effect of control factor on Surface Roughness**

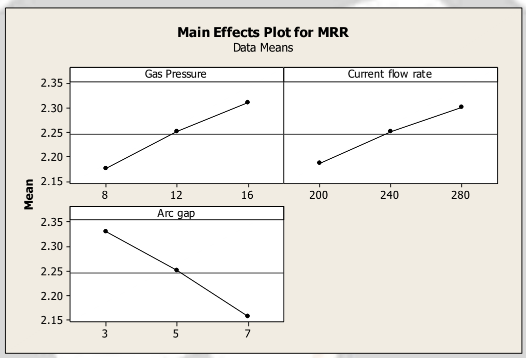


Fig. 5: Effect of control factor on Material removal rate

3.3 Normalization of S/N Ratio for Response Parameters

In the grey relational analysis, a data pre-processing is first performed in order to normalize the raw data for analysis. Normalization is a transformation performed on a single data input to distributed the data evenly and scale it into an acceptable range for further analysis. In this study, a linear normalization of the response parameters are normalized for further analysis using following equations. [13]

In Grey relational generation, the normalized Kerf width and surface roughness corresponding to the smaller-the-better (SB) criterion which can be expressed as:

$$X_{i\,(k)} = \frac{\max yi(k) - yi(k)}{\max yi(k) - \min yi\,(k)}$$

The normalized material removal rate corresponding to the larger-the-better (SB) criterion which can be expressed as:

$$X_{i\,(k)} = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi\,(k)}$$

Where Xi (k) is the value after the Grey relational generation for the SB criteria.

Min yi(k) is the smallest value of yi(k) and for the kth response, and max yi(k) is the largest value of yi(k) for the kth response.

An ideal sequence is x0(k) (k=1, 2…, m) for the responses. T he definition of the Grey relational grade in the course of the Grey relational analysis is to reveal the degree of relation between the 32 sequences [x0(k) and xi(k), k = 1,2,…,m and i = 1,2,…,32].[23]

Table 7: Normalized experimental reading

Sr. no.	Normalized experimental reading			Sr. no.	Normalized experimental reading		
	Kerf width	Surface roughness	Material removal rate		Kerf width	Surface roughness	Material removal rate
1	1	0.193548	0.522727	**15**	0.357143	0.516129	0.363636
2	0.967532	0.129032	0.318182	**16**	0.551948	0.591398	0.954545
3	0.951299	0.096774	0	**17**	0.211039	0.548387	0.704545
4	0.951299	0.16129	0.681818	**18**	0	0.505376	0.477273
5	0.925325	0.107527	0.454545	**19**	0.698052	1	0.886364
6	0.844156	0.064516	0.113636	**20**	0.584416	0.956989	0.568182
7	0.844156	0.322581	0.454545	**21**	0.373377	0.935484	0.431818
8	0.714286	0.225806	0.681818	**22**	**0.649351**	**0.946237**	**1**
9	0.584416	0	0.795455	**23**	0.324675	0.860215	0.886364
10	0.844156	0.698925	0.722727	**24**	0.519481	0.83871	0.477273
11	0.698052	0.645161	0.454545	**25**	0.357143	0.913978	0.977273
12	0.487013	0.602151	0.272727	**26**	0.438312	0.741935	0.818182
13	0.811688	0.677419	0.909091	**27**	0.535714	0.709677	0.704545
14	0.373377	0.645161	0.659091				

3.4 Calculation of Grey Relational Coefficient

Grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Grey relation coefficient and grey relational grade are calculated from normalized S/N ratio using following equations.

$$\gamma\ (y_o(k),\ y_i(k)) = \frac{\Delta \min + \varepsilon \Delta max}{\Delta oj(k) + \varepsilon \Delta max}$$

Where,

j=1, 2,…, n ; k=1,2…m. where n is the number of experiment data and m is the number of responses.
$Y_o(k)$ is the reference sequence ($y_o(k)$=1,2,…m); $y_j(k)$ is the specific compression sequence.
$Y_{oj} = \|y_o(k) - y_j(k)\|$ = the absolute value of the difference between $y_o(k)$ and $y_j(k)$.

Δmin = min.min$\|y_o(k) - y_j(k)\|$ is the smallest value of $y_j(k)$

VjεiVk
Δmax = max. max$\|y_o(k) - y_j(k)\|$ is the largest value of $y_j(k)$.

VjεiVk
Where, ε is the distinguishing coefficient, which is defined in the range of 0 to 1 The Plasma arc process parameters are equally weighted in this study, and therefore ε=0.5.[23]

Table 8: Grey Relational Coefficient

Sr NO.	Grey Relational Coefficient			Sr NO.	Grey Relational Coefficient		
	KW	SR	MRR		KW	SR	MRR
1	1	0.382716	0.511628	**15**	0.437500	0.508197	0.440000
2	0.939024	0.364706	0.423077	**16**	0.527397	0.550296	0.916667
3	0.911243	0.356322	0.333333	**17**	0.387909	0.525424	0.628571
4	0.911243	0.373494	0.611111	**18**	0.333333	0.502703	0.488889
5	0.870056	0.359073	0.478261	**19**	0.623482	1	0.814815
6	0.762376	0.348315	0.360656	**20**	0.546099	0.920792	0.536585
7	0.762376	0.424658	0.478261	**21**	0.443804	0.885714	0.468085
8	0.636364	0.392405	0.611111	**22**	**0.587786**	**0.902913**	**1**
9	0.546099	0.333333	0.709677	**23**	0.425414	0.781513	0.814815
10	0.762376	0.624161	0.687500	**24**	0.509934	0.756098	0.488889
11	0.623482	0.584906	0.478261	**25**	0.437500	0.853211	0.956522
12	0.49359	0.556886	0.407407	**26**	0.470948	0.659574	0.733333
13	0.726415	0.607843	0.846154	**27**	0.518519	0.632653	0.628571
14	0.443804	0.584906	0594595				

3.5 Calculation of Grey Relational Grade (GRG) and GRG NO.

The grey relational grade is calculated by averaging the grey relational coefficient corresponding to each performance characteristic. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade.

$$\bar{y}_j = \frac{1}{k}\sum_{i}^{m} \gamma ij$$

Where $\bar{y}_j$ is the grey relational grade for the j^{th} experiment and k is the number of performance characteristics. [23]

By GRA method the GRG of test give that the consistent investigational mixture is best circumstance for optimization and provides improved creation eminence. By the use of GRA method we can find the optimum parameter of Plasma Arc Cutting process. In this method the experiment number 22 has optimum result. Has the best multiple presentation characteristic among 27 experiments, because it has the maximum grey relational grade of **0.830233** which is shown in table 9

Table 9: Grey Relational grade and GRG NO.

Sr NO.	Grey Relational Coefficient			Grey relational grade	GRG No.	Sr NO.	Grey Relational Coefficient			Grey relational grade	GRG No.
	KW	**SR**	**MRR**								
1	1	0.382716	0.511628	0.631448	10	**15**	0.437500	0.508197	0.440000	0.461899	26
2	0.939024	0.364706	0.423077	0.575602	15	**16**	0.527397	0.550296	0.916667	0.664787	8
3	0.911243	0.356322	0.333333	0.533633	21	**17**	0.387909	0.525424	0.628571	0.513968	23
4	0.911243	0.373494	0.611111	0.631949	9	**18**	0.333333	0.502703	0.488889	0.441642	27
5	0.870056	0.359073	0.478261	0.569130	16	**19**	0.623482	1	0.814815	0.812766	2
6	0.762376	0.348315	0.360656	0.490449	24	**20**	0.546099	0.920792	0.536585	0.667825	7
7	0.762376	0.424658	0.478261	0.555098	18	**21**	0.443804	0.885714	0.468085	0.599201	16
8	0.636364	0.392405	0.611111	0.546627	19	**22**	**0.587786**	**0.902913**	**1**	**0.830233**	**1**
9	0.546099	0.333333	0.709677	0.529703	22	**23**	0.425414	0.781513	0.814815	0.673914	6
10	0.762376	0.624161	0.687500	0.691346	5	**24**	0.509934	0.756098	0.488889	0.584974	14
11	0.623482	0.584906	0.478261	0.562216	17	**25**	0.437500	0.853211	0.956522	0.749078	3
12	0.49359	0.556886	0.407407	0.485961	25	**26**	0.470948	0.659574	0.733333	0.621285	11
13	0.726415	0.607843	0.846154	0.726804	4	**27**	0.518519	0.632653	0.628571	0.593248	13
14	0.443804	0.584906	0594595	0.541102	20						

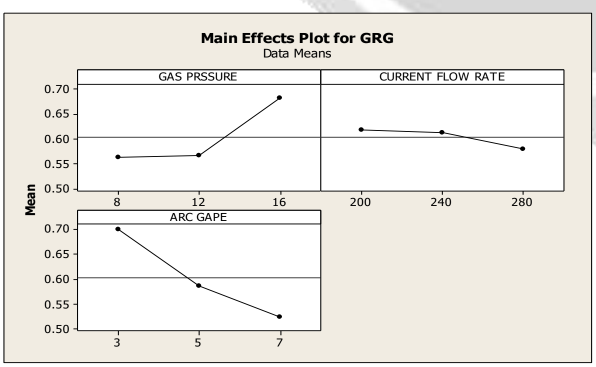


Table 10: Main effect of factors on GRG

Symbol	Control factor	Level 1	Level 2	Level 3
A	Gas pressure	0.562627	0.565525	0.681392
B	Current flow rate	0.617778	0.612273	0.579493
C	Arc gap	0.699279	0.585741	0.524523

Fig 6: Main effect of factor on GRG

4 OPTIMIZATION AND EXPERIMENTAL VALIDATION

4.1 Confirmation test result for Kerf Width

Table 11: Confirmation test result for Kerf Width

Optimal Level	Optimal Level Kerf width value (mm)	Confirmation test Kerf width value (mm)	Error
Gas pressure (bar) Current flow rate (amp) Arc gap (mm)	1.620	1.563	3.51%

Confirmation test result is shown in table 5.6 for Kerf width. This examination result of optimal Kerf width is 1.620 mm and confirmation test Kerf width is 1.563 mm. The test error is 3.51%. Error is also less than 10 %, so our Experimental work is validated for Mathematical regression model.

4.2 Confirmation test result for Surface roughness

Confirmation test result is shown in table 5.7 for Surface roughness. This examination result of optimal Surface roughness is 3.19 µm and confirmation test Surface roughness is 3.100 µm. The test error is 2.82%. Error is also less than 10 %, so our Experimental work is validated for Mathematical regression model.

Table 12: Confirmation test result for Surface roughness

Optimal Level	Optimal Level Surface roughness value (µm)	Confirmation test Surface roughness value (µm)	Error
Gas pressure (bar) Current flow rate (amp) Arc gap (mm)	3.19	3.100	2.82%

4.3 Confirmation test result for MRR

Table 13: Confirmation test result for MRR

Optimal Level	Optimal Level MRR value (mm^3/min)	Confirmation test MRR value (mm^3/min)	Error
Gas pressure (bar) Current flow rate (amp) Arc gap (mm)	2.42	2.308	4.62%

Confirmation test result is shown in table 5.8 for MRR. This examination result of optimal MRR is 2.42 mm^3/min and confirmation test MRR is 2.308 mm^3/min. The test error is 4.62%. Error is also less than 10 %, so our Experimental work is validated for Mathematical regression model.

5 CONCLUSION

In the presented work, experiment are carried out for response variables are surface Roughness, kerf width and material removal rate with process parameters as gas pressure, current flow rate and arc gap. There are 27 experimental readings taken for all variables to conduct the parametric study.

1. For experimental work it will be considered three levels for process parameters respectively. Experimental result shows that from 8 to 16 bar gas pressure, surface roughness is decrease and from 200 to 280 map current flow rate and 3 to 7 mm arc gap surface roughness is increase. So it concludes that for achieve good surface quality, current flow rate and arc gap must be required less. Now concentrate on effect of gas pressure on surface roughness, it concludes that with increase in gas pressure, surface roughness is decrease. So it concludes that for achieve good surface quality, gas pressure required must be more.
2. Experimental result show that kerf width increase with increase gas pressure, current flow rate and arc gap through 8 to 16 bar, 200 to 280 amp and 3 to 7 mm respectively. So for achieve good kerf width, it advisable to keep all input parameter less in value.
3. From the experimental results for ANOVA analysis it conclude that for surface roughness And kerf width percentage contribution of gas pressure is more in three response variables compare to other two process parameters
4. Experimental result shows that for material removal rate with increase in arc gap, material removal rate is decrease. So it concludes that for achieve good material removal rate, arc gap must be required less. Now concentrate on effect of gas pressure and current flow rate on material removal rate, it concludes that with increase in gas pressure and current flow rate, material removal rate is increase. So it concludes that for achieve good material removal rate, gas pressure and current flow rate must be required more. For material removal rate percentage contribution of arc gap is more in three response variables compare to other two process parameters.
5. In grey relational analysis total performance of multi objective optimization is depending on value of grey relational grade. According to performed experiment design, it observed that the combination of process parameter no. 22 has the highest grey relation grade. Thus, the experiment No. 22 gives the best multi-performance characteristics among the 27 experiments. From the grey relational analysis Thus it is revealed that response will be optimum gas pressure 16 bar, current flow rate 240 amp and arc gap 3mm.
6. Regression equation are also developed for utilize to predication of responses in future without carry out experiment.

References

Papers

1. W.J.Xu, J.C.Fang, Y.S.Lu (2002) “Study on ceramic cutting by plasma arc” journal of material processing technology 129 (2002) 152-156.
2. E. Gariboldi, B. Previtali (2005) “High tolerance plasma arc cutting of commercially pure titanium” Journal of Materials Processing Technology 160 (2005) 77–89.
3. Abdulkadir Gullu, Umut Atici (2005) “Investigation of the effects of plasma arc parameters on the structure variation of AISI 304 and St 52 steels” Materials and Design 27 (2006) 1157–1162.
4. A.G. Malikov, A.M. Orishich, V.B. Shulyat’ev. (2008) “Experimental Optimization of Steel Laser Cutting with Oxygen” International Conference on Methods of Aerophysical Research, ICMAR 2008.

5. R. Bini, B.M. Colosimo, A.E. Kutlu, M. Monno (2008) "Experimental study of the features of the kerf generated by a 200A high tolerance plasma arc cutting system" journal of materials processing technology 1 9 6 (2 0 0 8) 345–355.
6. Arsen Narimanyan (2009) "Unilateral conditions modelling the cut front during plasma cutting: FEM solution" Applied Mathematical Modelling 33 (2009) 176–197.
7. LIU Gu , WANG Liu-ying , CHEN Gui-ming, HUA Shao-chun (2010) "Parameters Optimization of Plasma Hardening Process Using Genetic Algorithm and Neural Network" JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 20n, 18(12): 57-64
8. K P Maity, Vivek Singh and Sachin Bhartiya (2012) "Analysis of Process Parameters of Plasma Arc Cutting of Stainless Steel Using Taguchi Method" Applied Mechanics and Materials Vols. 110-116 (2012) pp 3551-3556.

Books

9. Advanced Machining Process, McGraw-Hill
10. Module 9 Non-conventional Machining, Lesson 38 Electro Chemical Machining Version 2 ME, IIT Kharagpur
11. Introduction of Unconventional Manufacturing Process
12. Response surface Methodology, Raymond H.Myers, Doullas C. Montgomery
13. Quality Engineering Using Robust Design
14. Modern machining method.
15. Plasma Arc Cutting of Bridge Steels, Issue 384 by Ian D. Harris
16. Manufacturing Processes Reference Guide by Robert H. Todd, Dell K. Allen, and Leo Alting.
17. Advanced Methods of Machining By J.A. McGeough
18. Fundamentals of Metal Machining and Machine Tools, Third Edition by Geoffrey Boothroyd

Sites

19. http://www.plasma-cutter.org/history/ (01/04/2016 09:14 AM)
20. http://www.hypertherm.com/en/Training_and_education/Intro_to_plasma/What_is_plasma/what_is_plasma.jsp (31/03/2016 08:41 AM)
21. http://www.weldguru.com/plasma-arc-cutting.html (01/04/2016 11:57 PM)
22. https://www.google.co.in/search?q=Classification+of+Non-Conventional+Machining+Process&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjx4dOkje3LAhWEjpQKHarGAFMQ_AUIBygB&biw=1366&bih=623#imgrc=2GL7o5rGrDYUMM%3A (01/04/2016 02:52 PM)

Dissertation

23. Parametric Optimization of Roller Burnishing process for Surface roughness and surface hardness.