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Parametric Investigation of Plasma Arc Cutting on Aluminium Alloy 6082

Sagar B. Patel[1], Tejas K. Vyas[2]
[1]PG Student, Mechanical Engineering Department, Parul Institute of Technology, sagarpatel301292@email.com
[2]Asst. Prof.,Mechanical Engineering Department, Parul Institute of Technology,*tejas.vyas@paruluniversity.ac.in*

ABSTRACT: Plasma arc cutting (PAC) is a non-conventional thermal cutting process that makes use of constricted jet of high temperature plasma gas to melt and separate the metal. Plasma arc machining is most important non-conventional machining methods because of high accuracy, finishing, high speed and ability to machining any hard surface. So it becomes a very preferable for industry. The current work aims to study the effects of process parameters in air plasma arc cutting on Aluminium alloy 6082 material. The 5 mm thick Aluminium alloy 6082 plates use as work material which is use in Bus and Truck frames and chassis, high pressure gas cylinder, structure application, Marine Frames, automobile frame, Furniture and fabrication work. Cutting current, speed, pressure and stand of distance were selected as process parameters. The trial cut experiments were performed to find out the range of each process parameters for detail experiment. Based on the range obtained by exploratory experiments, three levels of current, pressure, stand-off distance (SOD) and cutting speed were selected within this range for detailed experimentation. Detailed experiment was design and performs on the basis of Response Surface Methodology (RSM). The cut quality parameters like material removal rate (MRR), top kerf width (KT), bottom kerf width (KB) and bevel angle (BV) were measured and analyse. The main effect plots were generated for find out the effect of input parameter on response parameter at each level. The Analysis of Variance (ANOVA) was performed to find out percentage contribution of each process parameters on performance characteristics. Minitab 14 software was used to generate main effect plots and analysis of variance table.

Keywords: *Aluminium Alloy 6082, ANOVA, DOE, Plasma Arc Cutting (PAC), Process Parameter, Response surface methodology (RSM) etc.*

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1. INTRODUCTION

Nowadays, a wide range of thermal cutting techniques has been applied for shaping material in different field of mechanical engineering, shipbuilding and process technology [4].

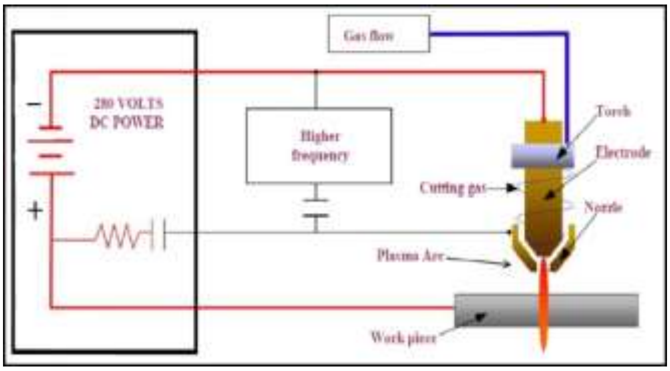

Fig-1: Schematic Diagram of Plasma Arc Cutting

Plasma arc cutting (PAC) is a non-conventional manufacturing process capable of processing a variety of electrically conducting materials. Stainless steel, manganese steel, titanium alloys, copper, magnesium, aluminium and its alloys and cast iron can be processed [4]. Plasma arc cutting is a process that is used to cut precision profiles patterns, sheets of different by the help of a plasma torch or Plasma gun [13]. Fig. 1 Shows the Schematic diagram of Plasma arc cutting. Plasma arc cutting process operates on direct current (DC), straight polarity having electrode negative with a constricted transferred arc. The electrode acts as the cathode, and the workpiece material acts as the anode [13].To establish the arc, a low-current pilot arc is initiated by a high-voltage, high-frequency discharge between the electrode and nozzle. Air or Gas from the power supply is used to force the pilot arc out of the nozzle orifice. Pilot arc is converting into a "transferred arc" between the electrode and the work piece.A very high temperature is produced by the arc which is used to melt the metal. The molten material is remove by high-velocity jet of hot ionized gas expelled from the nozzle orifice of the cutting torch and cut the material.

2. LITURETURE REVIEW

B. Abdulnasser et al [1] conducted work on aluminium alloy 1100. The material removal rate (MRR) and surface roughness (Ra) was measured and analyse. Two different thicknesses of specimens, 3 mm and 6 mm were used for performing experiment.The experiment was conducted based on Taguchi standard procedure with L_9 orthogonal arrays. The Arc current, cutting speed and Arc gap were used as process parameters. The material removal rate (MRR) was measured by determining the weight of the specimens before and after the cutting. From analysis of experiment confirm that current in Material Removal Rate was significant.

M. Santhanakumar et al [2]studied the quality of cut obtained under different cutting conditions by varying the process parameters (cutting speed, arc current and stand-off distance). The Kerf width (WK) and SR were used as the responses parameter. The galvanized iron sheet of thickness 4 mm was use as work materials. Taguchi method uses for performing experiment. A higher value of arc current, lower value of SOD combined with the moderate value of cutting speed improved the quality.

R. Adalarasan et al [3]conducted work on 304 L stainless steel. The cutting parameters arc current, torch stand-off, cutting speed and gas pressure play an important role in determining the quality of a cut. The process parameters chosen for the study were the cutting speed, stand-off distance, air pressure, arc current and each has three levels. Grey Taguchi based response surface methodology was used for optimization of process parameters. A lower value of arc current (60 A) was found to produce better responses as the increase in thermal content of the arc at higher amperage was reduce surface finish and increase the Kerf width.

Milan Kumar Das et al [5] were studied effect of process parameter on EN 31 steel. Gas pressure, Arc Current and Torch stand-off distance used as control parameter. Material Removal Rate and Surface Roughness were used as response parameter. The process parameter was optimizing by the use of Taguchi method couple with the Grey Relation Analysis. Analysis Of variance (ANOVA) was use for find the contribution of all process parameter. By the use of Grey Relation Analysis optimum process parameter for maximum Material removal rate and minimum surface roughness is given by middle level of gas pressure, high level of arc current and high level of stand-off distance.

SubbaraoChamarthi et al [10] used Hardox-400 12mm plate thickness and 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. By experiment find out that the arc voltage is main parameter and it influences all the aspects related with the cut quality rather than the effect on the arc power, beyond the arc voltage the cutting speed showed a noticeable effect.

TetyanaKavka et al [12] studied the effect of nature of gas on the plasma arc cutting of mild steel. The study has been carried out on the influence of the nature of gas on the arc behavior and the cutting performance of mild steel. Experimental result was obtained from the cutting of 16 mm thick mild steel plate at 60 A with steam, nitrogen, air, and oxygen as the plasma gases. From the experimental results it is concluded that nitrogen and air is used as plasma gases plasma gas generate more energy than other gases for the same current value.

K. Salonitis et al [13] studied on the quality of the cut. The quality of the cut has been monitored by measuring the kerf taper angle, the edge roughness and the size of the heat-affected zone (HAZ). The cuts were performed on 15 mm thickness S235 mild steel sheets, with the use of oxygen as plasma gas and air as shielding gas. The cutting current has the strongest effect on the HAZ. Increasing the cutting current and decreasing the cutting speed results in the increase of the HAZ. By the use of analysis of variance, it was found that the surface roughness and the conicity are mainly affected by the cutting height, whereas the heat affected zone is mainly influenced by the cutting current.

John Kechagias et al [15] conducted work on St37 mild steel plates. The process parameters were plate thickness, cutting speed, arc ampere, arc voltage, air pressure, pierce height, and torch standoff distance. From the ANOVA table showed that the arc ampere is the most important parameter that affects the right bevel angle by 50.89%. The torch stand-off distance affects the bevel angle by 15.9% and the plate thickness by about 6.22%.

R. Bini et al [16] worked on mild steel. The shield gas was a mixture of oxygen and nitrogen. Cutting speed, Voltage and mass flow rate of gas were use as control parameter. ANOVA analysis was performed on experimental data. The arc voltage is the main parameter and it influences all the aspects related with the cut quality Rather than the effect on the arc power, its proportionality with the standoff distance seems to be the true responsible for its importance. From the result very good quality can be achieved by varying the cutting speed and the arc voltage only.

AbdulkadirGullu et al [17] conducted work on AISI 304 stainless steel and St 52 carbon steel. The 6 mm thickness of material was used as work piece. Hardness measurements of materials whose micro structures had been investigated were performed on a Vickers hardness measurement device. The amount of material removed from cutting area is proportional to thickness of the workpiece. Cutting gap becomes small in thin material and bigger in thick material. The stand-off distance of the nozzle affected cutting quality during cutting operation.

Work was also done on different material like 10 mm Mild steel [6], AISI 316 [7], Steel ship plate [9], S235JR[11], AISI 1017steel [14].

3. EXPERIMENTATION

3.1 Material

For current study,140 x 50 x 5 mm Aluminium Alloy 6082plate was use as workpiece which has high strength and excellent corrosion resistance. Aluminium alloy 6082 sheet use in different application likebus and truck frames and chassis, aircraft structure, marine frames, trusses, bridge, transport application, high pressure gas cylinder, structure application, furniture, fabrication work.

Composition	Al	Si	Mg	O
Percentage	95.96	0.52	0.78	2.74

Table-1:Composition of AA 6082

3.2 Machine

The experiment was conduct using a Quality CUT 40 Air Plasma Cutting Machine. Machine has four main components as shown in fig 2. (1) Power supply, (2) Air supply, (3) Trolley unit, (4) Plasma torch head assembly unit. In this machine torch mounted on the automatic travel trolley. Stand-off distance (SOD) between workpiece and nozzle tip is adjust by rack and pinion mechanism. Cutting speed is change by regulator knob.

(A) Ground Clamp, (B) Work Stage, (C) Torch head assembly, (D)Work Piece

Fig-2: Machine Setup

3.3 Experiment Run

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response [18].The most frequently used second-order designs are the central composite and the Box–Behnken designs [18]. Four process parameter (current, pressure, standoff distance and Speed) was selected for this study. From the result of trail cut, the three level of current (30, 35, 40 A), Stand-off distance (4, 4.5, 5 mm) and pressure (4, 4.5, 5 bar) was select. The cutting speed for lower current range was 0.4 to 0.57 m/min and for the medium and high current the speed was 0.95 to 1.11 m/min was adopted. MRR was measure by weighting equipment and Top kerf width, Bottom kerf width and Bevel angle was measure by measuring microscope.

Run	Current	SOD	Pressure	Speed	MRR	KT	KB	BV
	A	mm	bar	m/min	(mm^3/min)	mm	mm	Deg.
1	30	4	4.5	0.5	2560.96	2.11	0.92	18
2	40	4	4.5	1	5264.54	2.42	1.16	16
3	30	5	4.5	0.5	2131.51	2.5	1.32	17
4	40	5	4.5	1	5623.26	2.59	1.55	12
5	35	4.5	4	0.95	2838.01	2.26	1.19	12
6	35	4.5	5	0.95	3308.53	2.06	1.07	14
7	35	4.5	4	1.11	3869.85	1.93	1.03	16
8	35	4.5	5	1.11	3774.95	1.9	0.82	18
9	30	4.5	4	0.5	1835.41	2.3	1.2	18
10	40	4.5	4	1	4357.82	2.4	1.35	14
11	30	4.5	5	0.5	1277.5	2.34	1.19	19
12	40	4.5	5	1	5135.41	2.14	1.38	14
13	35	4	4.5	0.95	4071.76	2	0.88	17
14	35	5	4.5	0.95	4057.79	2.12	1.2	15
15	35	4	4.5	1.11	4522.07	1.79	0.69	17

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16	35	5	4.5	1.11	4484.1	1.85	0.79	16
17	30	4.5	4.5	0.4	1236.3	2.45	1.28	16
18	40	4.5	4.5	0.95	4686.75	2.52	1.71	11
19	30	4.5	4.5	0.57	2200.75	2.22	1.15	20
20	40	4.5	4.5	1.11	5338.78	2.18	1.14	14
21	35	4	4	1	4558.92	2.2	0.95	17
22	35	5	4	1	3996.96	2.17	1.04	14
23	35	4	5	1	4287.1	1.84	0.67	16
24	35	5	5	1	4169.91	2.17	1.1	16
25	35	4.5	4.5	1	3511.32	2.21	0.97	19
26	35	4.5	4.5	1	4208.12	2.08	0.9	18
27	35	4.5	4.5	1	3693.48	2.06	0.83	19

Table-2: Observation Table

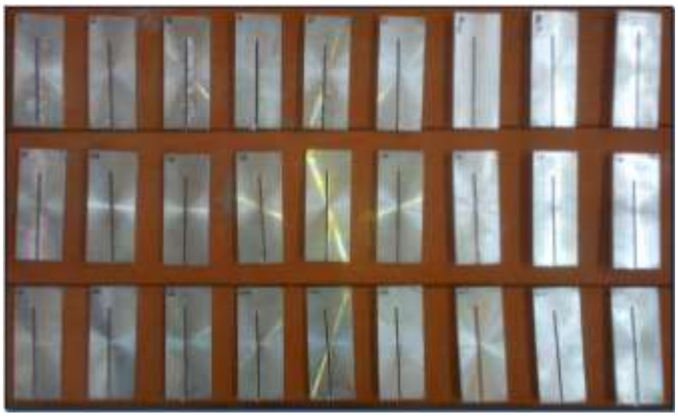

Fig-3: Workpiece after cutting

4. MAIN EFFECT PLOT

4.1 Main effect plot for MRR

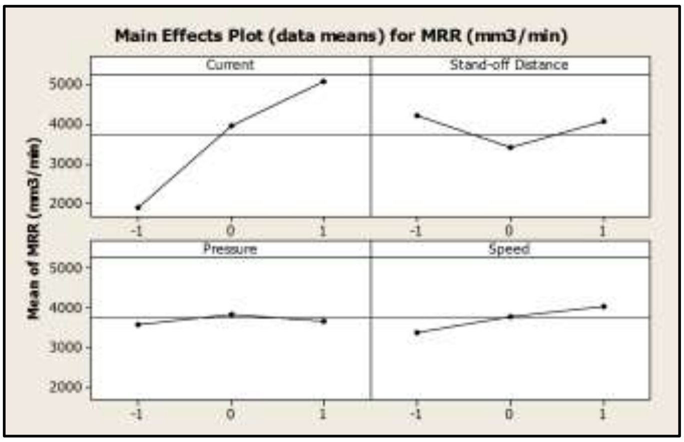

Fig-4:Main effect plot for MRR

From Fig-4, with increase in current more heat energy transfer in greater volume of material so Material removal rate increase. Material removal rate is decrease at intermediate level and increase at low and high level of stand-off distance. Material removal rate is increase with increase the speed because material removes in less time. With increase in pressure MRR increase at intermediate point and then reduce because of excessive pressure give cooling effect rather than blowing the molten material from heated zone.

4.2 Main effect plot for Top kerf width

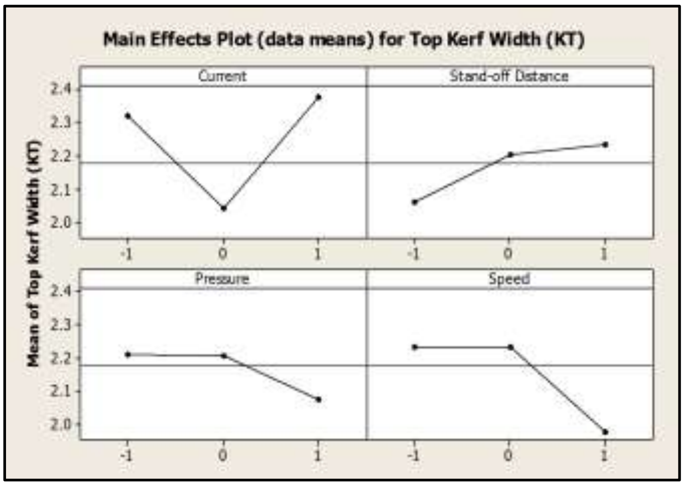

Fig-5: Main effect plot for Top kerf width

From fig-5, with increase in current high heat energy is generating. Due to high heat energy more material detaches at the top of the material so kerf width increase. At low cutting speed high heat concentrate at top of the material so kerf width increases. Width increase in speed less heat energy is concentrate at top of the material so kerf width decreases. At low stand-off distance less heat concentrate area at top surface of the material.so small kerf width generate at low level stand-off distance.

4.3 Main effect plot for Bottom kerf width

From Fig-6, Increase in current, the energy in plasma arc cutting increase which is proportionally propagated to the bottom of the material and increase the bottom kerf width. Bottom kerf width is decrease at intermediate point. At low level current reduce the cutting speed so high heat energy transfer to the bottom of the material.With increasing the stand-off distance large area available for heat transfer so more heat transfer at bottom of the material and bottom kerf width decrease.High Pressure cause cooling effect on material and less concentration of heat at bottom of the material so bottom kerf width decrease.

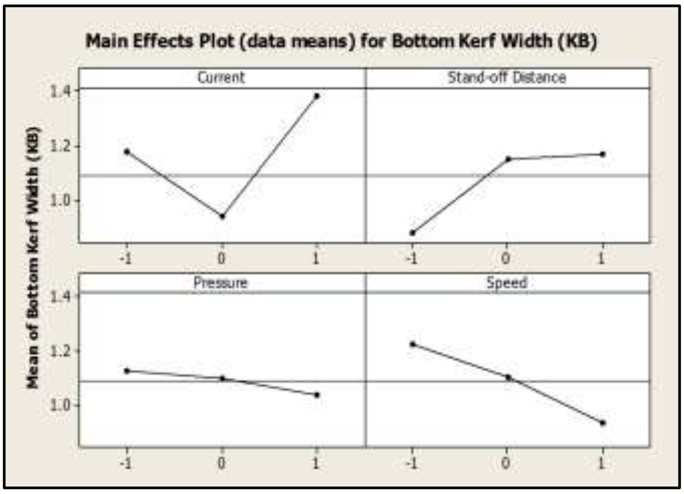

Fig-6: Main effect plot for Bottom kerf width

4.4 Main effect plot for Bevel angle

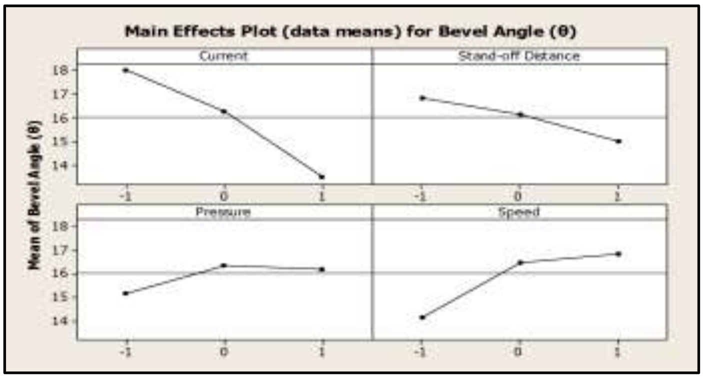

Fig-7: Main effect plot for Bevel angle

From Fig-7,with increase in current bevel angle is decrease because of necessary amount of energy transfer for cutting material. When increase the speed then high heat at top surface and less heat at bottom surface. Due to the heat difference bevel angle is generate. The bevel angle reduces with increase stand-off distance as the plasma zone with uniform temperature comes in contact with the cross section being cut.

5. ANALYSIS OF VARIANCE (ANOVA)

The analysis of variance (ANOVA) is the statistical technique most commonly applied to the results of the experiments to determine the percentage contribution of each factors.

5.1 Analysis of Variance for MRR

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Contribution (%)
Current	2	32180706	31586465	15793233	220.98	0.000	85.03
SOD	2	2798056	1854428	927214	12.97	0.000	07.39
Pressure	2	214840	252898	126449	1.77	0.199	00.57
Speed	2	1367310	1367310	683655	9.57	0.001	03.61
Error	18	1286447	1286447	71469			
Total	26	37847359					

Table-3: Analysis of Variance for MRR

P value less than 0.0500 indicate that parameters are significant. Values greater than 0.1000 indicate the parameters are less significant. From ANOVA table-3, it is observed that all parameters show most significant parameter for material removal rate. The percentage contribution of current, stand-off distance, pressure and speed on MRR are 85.03%, 07.39%, 00.57% and 03.61% respectively.

5.2 Analysis of Variance for Top kerf width

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Contribution (%)
Current	2	0.6269	0.42056	0.21028	18.61	0	52.06
SOD	2	0.08754	0.09012	0.04506	3.99	0.037	7.27
Pressure	2	5509	0.0595	0.02975	2.63	0.099	4.57

Speed	2	0.23137	0.23137	0.11569	10.24	0.001	19.21
Error	18	0.20337	0.20337	0.0113			
Total	26	1.20428					

Table-4: Analysis of Variance for Top kerf width

From Table-4,the percentage contribution of current, stand-off distance, pressure and speed on Top kerf width are 52.06%, 07.27%, 04.57% and 19.21% respectively. Here current, SOD and speed show significant effect on top kerf width and pressure has less significant effect.

5.3Analysis of Variance for Bottom kerf width

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Contribution (%)
Current	2	0.88614	0.79378	0.39689	44.84	0.000	54.90
SOD	2	0.27296	0.25519	0.12759	14.42	0.000	16.91
Pressure	2	0.03301	0.04145	0.02072	2.34	0.125	02.04
Speed	2	0.26261	0.26261	0.13131	14.83	0.000	09.87
Error	18	0.15932	0.15932	0.00885			
Total	26	1.61405					

Table-5: Analysis of Variance for Bottom kerf width

From Table-5,the percentage contribution of current, stand-off distance, pressure and speed on Bottom kerf width are 54.84%, 16.91%, 02.04% and 09.87% respectively. Current contribute highest parcantagecontribution on bottom kerf width. Current, SOD and speed show significant effect on bottom kerf width and pressure has less significant effect.

5.4Analysis of Variance for Bevel angle

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Contribution (%)
Current	2	62.530	71.454	35.727	30.87	0.000	44.36
SOD	2	10.794	17.343	8.671	7.49	0.004	07.66
Pressure	2	8.352	15.676	7.838	6.77	0.006	05.92
Speed	2	38.454	38.454	19.227	16.61	0.000	27.28
Error	18	20.833	20.833	1.157			
Total	26	140.963					

Table-6: Analysis of Variance for Bevel Angle

From Table-6, it is observe that current shows most significant parameter then other parameters. The percentage contribution of current, stand-off distance, pressure and speed on Bevel angle are 44.36%, 07.66%, 05.92% and 27.28% respectively.

6. CONCLUSION

- From the some exploratory experiment it was found that 5 mm thickness aluminium alloy 6082 can cut in the range of current between 30 A and 40 A. Material was not throughout cut at high speed and low current. For good quality cut all parameters has appropriate value.
- For MRR the current, stand-off distance and speed are more significant parameter follow by pressure. Current contribute highest 85.03% on MRR. MRR is increase at pressure slight increase and then decrease and for stand-off distance the effect is reverse as compared to pressure.
- Current, stand-off distance, pressure and speed are contribute 52.06%, 07.27%, 04.57% and 19.21% respectively on top kef width. For top kerf width with increase in current top kef width is decrease and then increase with increase current. With increase in stand-off distance top kerf width is increase.
- For bottom kerf width current, stand-off distance and speed are most significant parameter followed by pressure. With increase in speed and pressure bottom kerf width falls off. While for current bottom kerf width is increases and then decreases. In case of stand-

off distance, bottom kerf width increase with increase stand-off distance. Current contribution highest 54.84% on Bottom kerf width.

- For bevel angle the current and speed is most significant parameter then pressure and stand-off distance. The percentage contribution of current, stand-off distance, pressure and speed on Bevel angle are 44.36%, 07.66%, 05.92% and 27.28% respectively. With increase in current and stand-off distance bevel angle reduces. While for pressure, it increases and then decreases with increase in pressure.

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