IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498
Vol.6, No.1, Jan-Feb 2016

Optimization of welding parameters using plasma arc welding for SS316 material

N.Sathiseelan

Department Of Mechanical Engineering
Sri Eshwar College Of Engineering
Coimbatore ,India

S.Baskaran

Department Of Mechanical Engineering
Sri Eshwar College Of Engineering
Coimbatore , India

Abstract— **The effect of various process parameters like welding current, arc gap and welding speed on tensile strength, impact strength and surface hardness of Plasma Arc Welding on stainless steel(316) is investigated by using standard statistical tool i.e., Taguchi method. The optimum value has been determined with the help of main effect plot and ANOVA table. The Regression equation for tensile strength, impact toughness and Surface hardness has been developed with the help of Minitab 15 Software. Confirmation test have done to confirm the value estimated through the software.**

Keywords- Plasma arc welding-tensile strength-impact toughness-surface hardness-Taguchi method

I. INTRODUCTION

The Plasma Arc Welding (PAW) process is essentially an extension of Gas Tungsten Arc Welding (GTAW). The energy density and gas velocity and momentum in the plasma arc are high. [1].PAC also offers quality gouging and piercing capabilities [2].Advanced materials exhibit very excellent technical properties. However, the high cost of both raw materials and processing limit their use. Alternatively, advanced machining such as Plasma Arc welding is normally used. Advanced material such as nickel-base alloys, titanium alloys and stainless steel can be used as the work piece in this type of welding and welding parameters such as welding current, welding speed and torch height affects the tensile strength, impact toughness and surface hardness [3].This study was intended to explain the effects of welding parameters on Plasma welding strength of stainless steel. Basically, classical experimental design methods are too complex and not easy to use. A large number of experiments have to be carried out when the number of the welding parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [4–7]. The Taguchi design method has been found to be a simple and robust technique for optimizing the welding parameters [8].

The present study is performed to fulfill the following two Objectives:

1. To study about the influence of Plasma Arc welding Parameters on Stainless Steel316.
2.To design a series of experiment using the help of Design of Experiments (DOE)layout in order to study about Plasma Arc welding (PAW).
3. To study about the best combination of solution for maximizing the Tensile strength, impact toughness and surface hardness

II. DESCRIPTION

Stainless steel 316 alloy of 3mm thick as base material and SS316L as a filler material are chosen and their chemical compositions are given in Table 1 and Table 2. The selection of the filler material is based on the mechanical properties and resistance to cracking in the weld. Alternating Current Plasma Arc Welding is used to weld the base metal Thoriated Tungsten electrode of diameter 3mm is used and the shielding gas used is Argon with flow rate of 40 Liters/min the position of the welding gun is vertical to the work piece. Trail experiments are conducted to establish the values of input variables and their ranges in which experiments has to be conducted. As many factors have the effect on formation of welding seam of SS316 alloy, it is necessary to limit them. Wire feed rate is kept constant at 550mm/min

TABLE 1: Chemical composition of base metal SS316 (weight percentage)

C	Mn	Si	Cr	Ni	Mo	P	S	N	Fe
0.08	2.00	0.75	16	10	2	0.045	0.030	0.1	bal

TABLE 2: Chemical composition of base metal SS316 L (weight percentage)

C	Mn	Si	Cr	Ni	Mo	P	S	N	Fe
0.03	2.00	0.75	16	10	2	0.045	0.030	0.1	bal

III. EXPERIMENTAL PROCEDURE

The base material employed in this study is 3-mm-thick SS316 alloy welded with SS316L filler material. In the present study, the effect of welding current, torch height and welding speed and their corresponding mechanical properties have been studied. The range of the process parameters selected under the present study Table 3. In the present investigation, the Taguchi method was employed to optimize the process parameters for maximizing the mechanical properties. The number of process parameters considered under this study is three, and the level of each parameter is two. The degrees of freedom of all the three parameters and their interactions are three. Hence, L8 (2*3) orthogonal array is selected. Each condition of the experiment was repeated twice to reduce the noise/error effects. The detail of the selected orthogonal array is presented in Table 4

TABLE 3: Working range of the process parameters

Symbol	Process parameters	Units	Lower level(1)	Higher level(2)
A	Welding current	Amps	85	95
B	Torch weight	mm	4	6
C	Welding speed	mm/sec	3.75	5.42

TABLE 4: Experimental layout L8 orthogonal array

Exp. no	Welding current	Torch height	Welding speed
P1	1	1	1
P2	1	1	2
P3	1	2	1
P4	1	2	2
P5	2	1	1
P6	2	1	2
P7	2	2	1
P8	2	2	2

The response parameters tensile strength, impact toughness and hardness of the material were evaluated for all the trials and then statistical analysis of variance (ANOVA) was carried out. Based on the ANOVA, the contribution of each process parameter and their interaction in influencing the quality characteristic is evaluated. The ANOVA also provides an indication of which process parameters are statistically significant. The optimum process parameter combination is predicted and verified. The base material of dimension 1200mm x165mmx3mm was used and the material has been designed as per ASTM standards for the experimental work.

The specimens for tensile strength were made as per the ASTM E8 standards (9). The configuration of the specimens used for plain tensile test is shown in Fig1.a the specimen for impact test was made as per ASTMA370 standards [9] and the test was conducted on a Charpy impact test machine. The configuration of the impact test specimen is shown in Fig1.Specimens for micro hardness tests (15-mm width) were taken at the middle of all the joints .Micro-hardness tests were carried out on the welded samples with a load of 20 kgf for duration of 30 sec using Rockwell hardness tester machine

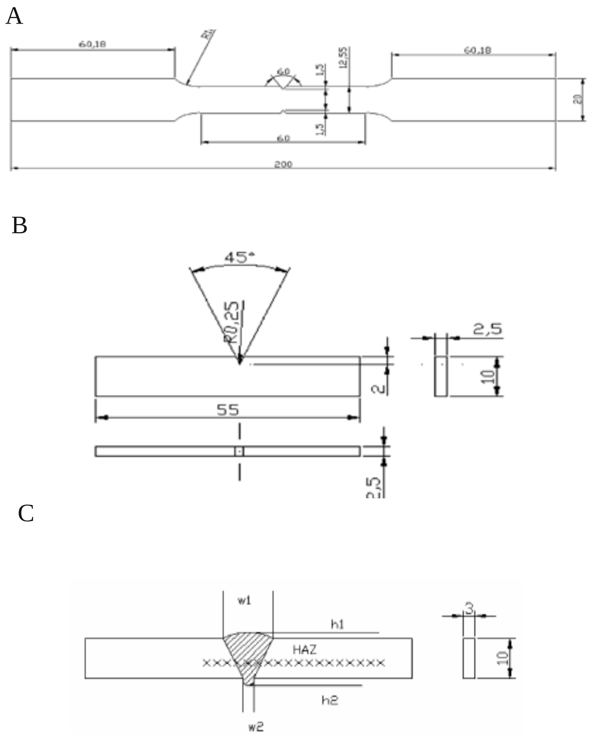


Figure1: Configuration of A. Tensile test specimen **B**. Charpy V-notch impact test specimen **C**. Hardness measurement in transverse to the weld

TABLE 5: Mechanical properties of SS316 alloy welds

ID	Tensile strength (Mpa)			Micro-hardness at the weld center (HR)			Impact toughness(J)		
	Trail 1	Trail `2	Trail 3	Trail 1	Trail 2	Trail 3	Trail 1	Trail 2	Trail 3
P1	503	495	498	58	65	63	88	92	90
P2	498	503	507	75	81	72	89	83	85
P3	509	505	501	65	72	75	82	90	89
P4	518	526	513	86	76	81	74	85	89
P5	509	502	499	51	74	67	89	85	93
P6	500	496	498	64	66	79	102	95	98
P7	486	490	494	82	79	70	95	103	105
P8	490	497	493	93	80	76	92	102	94

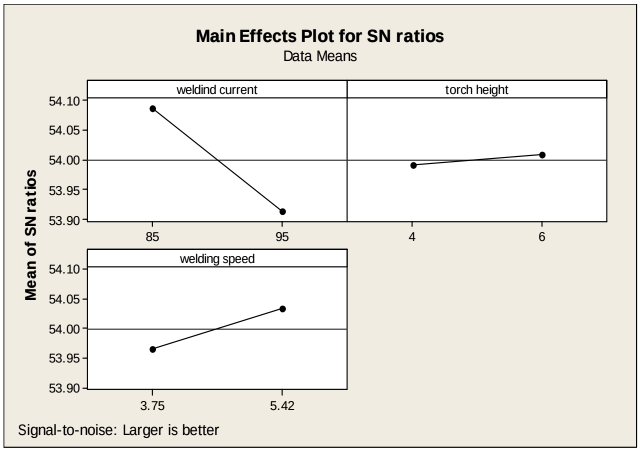
IV. RESULTS AND DISCUSSIONS

The tensile strength, impact toughness surface hardness obtained from the experimentation is tabulated as shown in Table 6 .The S/N ratio is calculated through the MINITAB software with quality objective being "larger is better" a maximization of tensile strength, impact toughness and surface hardness is desirable

TABLE 6: S/N ratio for tensile strength, impact toughness and Surface hardness

ID	Welding current (Amps)	Torch height (mm)	Welding mm/sec	S/N Ratio		
				Tensile strength	Impact toughness	Surface hardness
P1	85	4	3.75	53.9533	39.0849	35.8478
P2	85	4	5.42	54.0244	38.7904	37.6163
P3	85	6	3.75	54.0658	39.3697	37.0252
P4	85	6	5.42	54.3033	38.3291	38.1697
P5	95	4	3.75	54.0365	38.9878	36.1236
P6	95	4	5.42	53.9446	39.8687	36.9020
P7	95	6	3.75	53.8039	40.0864	37.7298
P8	95	6	5.42	53.8622	39.6454	38.3816

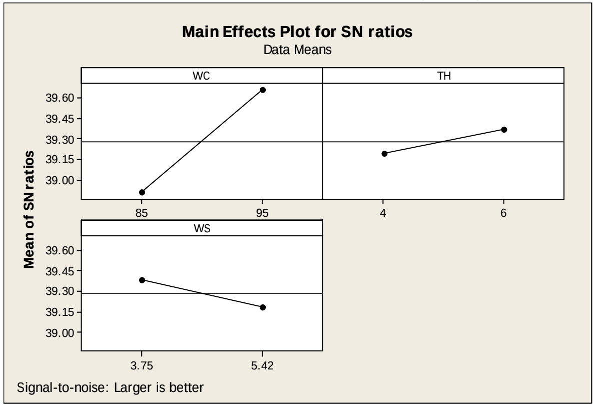
A. EXPERIMENTAL RESULTS FOR TENSILE STRENGTH



GRAPH 1: Effects of various factors on S/N Ratio of Tensile strength

By using MINITAB Software we obtain some interactions if we look at the graph we will observe that with increase in welding current tensile strength S/N ratio is decreasing. Tensile strength increases with increase in torch height and welding speed

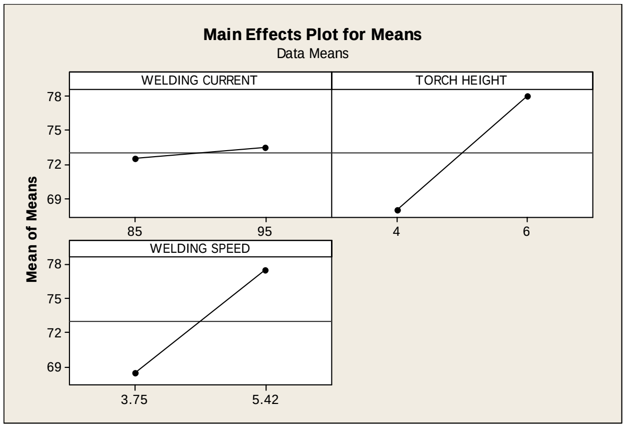
B. EXPERIMENTAL RESULTS FOR IMPACT TOUGHNESS



GRAPH 2**:** Effects of various factors on S/N Ratio of impact toughness

From the graph 4.2 we will observe that with increase in welding current and torch height impact toughness S/N ratio gets increased and there is a decrease in S/N ratio with increase in welding speed

C. EXPERIMENTAL RESULTS FOR SURFACE HARDNESS



GRAPH 3: Effects of various factors on S/N Ratio of Surface hardness

From the graph 4.3 we will observe that with increase in welding current, torch height and welding speed S/N ratio of surface hardness is increased

D. Analysis of Variance (ANOVA)

ANOVA analysis was used to determine the process parameters that significantly influencing the tensile strength, impact toughness and surface hardness (response) as well as their relative contribution to the response. Table 7,8,9 shows the results of ANOVA for tensile strength, impact toughness and surface hardness carried out for a confidence level of 95%, that is for significance level of alpha = 0.05. Percentage of contribution (P %) of each parameter on response and indicating the degree of influence on the result is given in the last column of Table 7, 8, 9. If the P value is less than 0.05, then the parameter or their interactions can be considered to be statistically significant.

TABLE 7**:** Analysis of means of Tensile strength

Parameters	**ParaDOFeters**	**SSDOF**	**AdSj MS**	**AFdj MS**	**FP**	**Contribution P (%)**	**Contribution (%)**
Welding current	**Welding 1 current**	205.031	2052031	970256	01020	0.0537.75	0.488
Torch height	**Torch 1 height**	3.001	32001	14201	0.1065	0.0403553	48.855
Welding speed	**Welding 1 speed**	32.401	321.6421	153628	0.8511	0.0250967	39.57
WC*TH	**WC*TH 1**	209.101	209.125	98.9125	0.1026	0.038.506	5.16
WC*WS	**WC*WS 1**	50.501	50.525	239.1026	0.1046	0.049.3	5.16
TH*WS	**TH*WS 1**	42.781	41.7285	202.1255	0.0365	0.037.89	0.27
Residual error	**Residual 1 error**	0.211	0.2010	- 2.000	–	- 0.03	0.488
Total	**Total 7**	543.029	5409.375	-	–	- 100	100

TABLE8: Analysis of means of Impact toughness

Parameters	**DOF**	**SS**	**Adj MS**	**F**	**P**	**Contribution (%)**
Welding current	1	128	128	20.90	0.013	47.69
Torch height	1	8	8	1.31	0.458	2.98
Welding speed	1	10.125	10.125	1.65	0.042	3.78
WC*TH	1	15.125	15.125	2.47	0.036	5.635
WC*WS	1	40.500	40.500	6.61	0.023	15.090
TH*WS	1	60.500	60.500	9.88	0.019	22.53
Residual error	1	6.125	6.125	-	-	2.28
Total	7	268.375		-	-	100

TABLE 9: Analysis of means of Surface hardness

From table 6 The P value for the factor torch height is 0.165which is not significant. There is 16.5% chance that this large could occur due to noise and from table 7 The P value for the factor torch height is 0.458 which is not significant. There is 45.8% chance that this large could occur due to noise the percentage contribution by each of the process parameter in the total sum of squared deviation SS can be used to evaluate the importance of the process parameter change on the quality characteristic

E. LINEAR REGRESSION MODEL

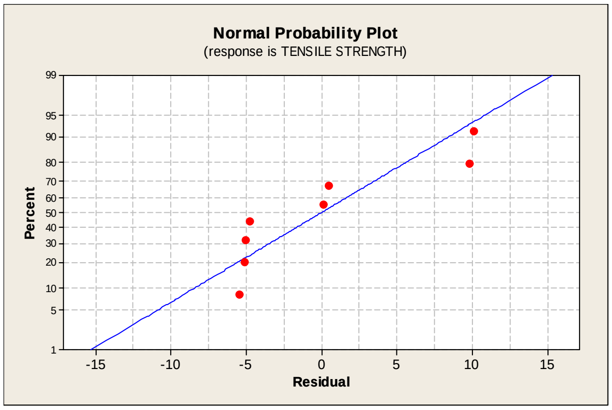
A linear regression model aims to develop a relationship between two or more decision variables and response variable. To derive a relation between welding current, torch height, welding speed, tensile strength, impact toughness and surface hardness a multiple linear regression model was developed using Minitab 15 software

TABLE 10: Regression equations for the mechanical properties

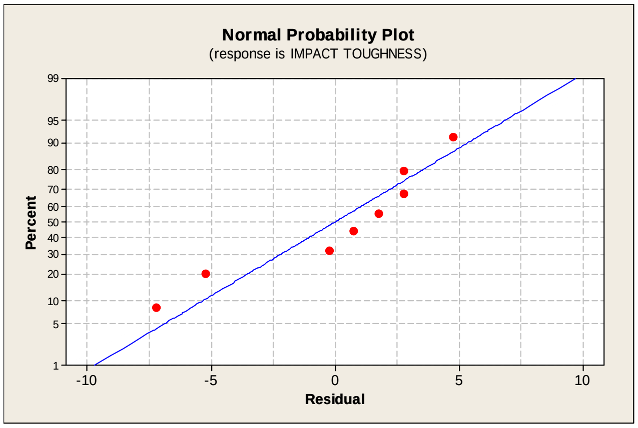
S.NO	Response	Regression equation	Coefficient of correlation
1	Tensile strength	Y=578 - 1.01 A+ 0.61 B + 2.41 C	0.45
2	Impact toughness	Y= 21+ 0.800 + 1.00 B – 1.35 C	0.55
3	Surface hardness	Y = 14.2+ 0.100A+ 5.00 B+5.39 C	0.88

Where, A=welding current, B=torch height, C=welding speed

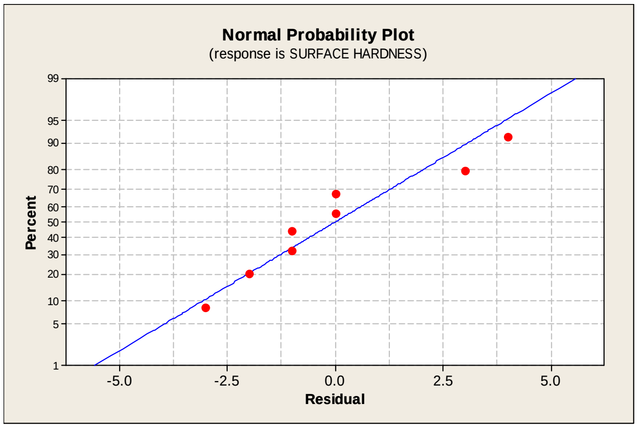
The sign associated with the coefficient terms of the factors determines the trend of response with respect to the factor. If the sign is positive the response increases when the factor is increased and vice versa. In order to validate the developed regression equation, residuals versus fits plot was generated through MINITAB software. The plots is shown in Graph 4, 5, 6



GRAPH 4: Residual versus Fits (response is tensile strength)



GRAPH 5: Residual versus Fits (response is impact toughness)



GRAPH 6: Residual versus Fits (response is Surface hardness)

It can be observed from the graph 4,5,6 that the most of the points lie in the close proximity of Central line. A very few points lie far away from the points which lie in the close proximity of central line. Hence the developed regression model predicts a feasible response for the given set of process parameters.

F. CONFIRMATION TEST

The experimental confirmation test is the final step in verifying the results drawn based on Taguchi's design approach. The optimal conditions are set for the significant factors (the insignificant factors are set at economic levels) and a selected number of experiments are run under specified cutting conditions. The average of the results from the confirmation experiment is compared with the predicted average based on the parameters and levels tested. The confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental results [12]. The optimum results are presented in Table 11. For validations of the optimum results, experiments are conducted as per the optimum conditions and mechanical properties are evaluated and the average results are presented in Table 12. It is observed that experimental values are closer to the optimum values

TABLE 11: Optimum values of the quality characteristics

Quality characteristics	Optimum condition	Optimum value
Tensile strength(Mpa)	A1B2C2	54.024
Impact toughness (J)	A2B2C1	40.8064
Surface hardness(HR)	A2B2C2	38.3816

TABLE 12: Validation of the optimum results

Quality characteristics	Optimum condition	Optimum value	Experimental value
Tensile strength(Mpa)	A1B2C2	54.024	53.4
Impact toughness (J)	A2B2C1	40.8064	39.994
Surface hardness(HR)	A2B2C2	38.3816	38.19

V. CONCLUSION

This study has discussed an application of the Taguchi method for investigating the effects of process parameters on the tensile strength, impact toughness and surface hardness value in plasma welding process for SS316 material

From the analysis of the results in the plasma welding process using the conceptual signal-to-noise (S/N) ratio approach, regression analysis, analysis of variance (ANOVA), and Taguchi's optimization method, the following can be concluded from the present study:

- As per analysis, the significant parameter for optimum tensile strength, impact strength and surface hardness are welding current, welding speed and the torch height
- The maximum tensile strength is calculated as 54.024Mpa,impact toughness as 40.8064 and surface hardness as 38.3816 by Taguchi's optimization method
- As per regression analysis, the mathematical models of first order for tensile strength, impact strength and surface hardness are showing significant results

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AUTHORS PROFILE

N.Sathiseelan is currently working as Assistant Professor in Department of Mechanical Engineering at Sri Eshwar College of Engineering,Coimbatore, Tamilnadu.Mobile:(0)9500304444 Email: nsathiseelan@gmail.com

S.Baskaran is currently working as Assistant Professor in Department of Mechanical Engineering at Sri Eshwar College of Engineering,Coimbatore, Tamilnadu.Mobile:(0)9790489152Email: baski.349@gmail.com @gmail.com