International Journal of Engineering & Technology, *7 (2.23) (2018) 467-471*

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Parametric Design on Weld Characteristics of Submerged Arc Welding Process Parameters

Sailender Mamunuri[1]*

[1]*Aircraft Research And Design Center, HAL, Bengaluru*
**Corresponding Author E-Mail:Sailumamu@Gmail.Com*

Abstract

A low carbon with manganese steel is apt for the fabrication of pressure vessels welds, which is designed for low-temperature service requirement. Submerged Arc Welding (SAW) is chosen process, due to incessant sound joint requirement and its inherent qualities like smooth bead, deep penetration and sound joint quality and reliable. SAW is renowned by huge quantity of parameters, which acts collectively influence the outputs performance, subsequently affects the joint quality. The objective is to optimize the variables parametrically for various outputs. Taguchi's orthogonal array, which is a design of experiment, is adopted to optimize as well for their effects on desired outputs. The author modified the process by introducing 'purging gas' in SAW. 'Purged' SAW results are contrasted against the traditional 'as-is' of SAW. Identified the variable significance effect is through analysis of variance with their contribution. Correlations between parameters and performance outputs are established via Regression Analysis. Build models competency are checked with F-test; determined quantitatively and showed graphically, for discussion of their effects to achieve the required quality. Using confirmation tests, the models are validated and found the outcomes are in the confines.

Keywords: *Analysis of Variance, Orthogonal Array, Regression Analysis, Submerged Arc Welding.*

1. Introduction

One among the world's vital materials is Steel, extensively useful in our current world since its durability, strength, affordable and infinitely recyclable [1]. ASTM A516 Gr.70, carbon-manganese steel, is apt for manufacturing welded pressure vessels, for moderate or lower temperature service design. Submerged arc welding (SAW) is selected since the strong continuous joint requirement. SAW is commonly utilized joining process, since its intrinsic features like smooth bead, deep penetration high quality and reliable. SAW offers economical large output compared against other conventional joining methods [2]. SAW is semi or fully-automatic joining process. SAW is well-known with huge quantity of parameters, which controls collectively in convoluted manner of the weldment quality. Insufficient joint strength will offer the welded flaw in structure. Then, it's obliging to control to achieve the desire weld quality. Few main independent parameters in SAW such as voltage of arc, current of weld, polarity, feed of electrode, speediness of welding and electrode stick-out, influence the joint quality. In numerous engineering functions is tackling the difficulty to predict appropriate parameters combinations for better weld. To optimize parameters numerous numbers of experiments are must, which are expensive and devours time. Phillip Ross [3] detailed Taguchi's philosophy, design of experiments, and is the simultaneous assessment of at-least two parameters to their capability for influencing the productivity and optimize parametrically. To systematize the affecting parameters, it involves the orthogonal arrays, at what echelons fluctuated rather to experiment all likely combinations. Douglas [4] presented descriptively statistical methods, normal distribution; confidence intervals basic concepts; tests of hypothesis to find means and variance. Y. S. Tarng et al. [5] is reported the Taguchi's application in optimizing SAW process. Formulated the experimental layout; analyzed every weldment variable effect on weld output and also predicted each welding parameter optimal setting. Also, verified the effectiveness via experimental results. Yayla et al. [6] are estimated the HY-80 steel weldments mechanical performances through various welding processes. Serdar et al. [7] focused at sensitivity investigation using building experimental expressions and fine tuned the variables requisite in achieving optimum joint-bead shape. Noted the results as, every minute change in parameters will participate an important function in joint superiority. Amanie et al. [8] are estimated the influences of current and weldment speed of A516-gr70 steel mechanical characteristics like impact and tensile in SAW process by various mechanical testing methods and remarked the observations studying from optical microscopy. Deepak et al. [9] are used Taguchi's experimental designs to perform experiments for optimizing the parameters and models build via regression in evaluating tensile strength. Sarkar et al. [10] introduced new approach by an analytical and hierarchal procedure based Taguchi's scheme which selects finest weldment variables for fabricating plain-carbon steel SAW along with conformation trial for verifying the optimal setting. Abhijit Saha et al. [11] have foreseen the optimizing SAW procedure variables of IS2062-B mild steel using another way for multi response characteristics like weldment bead-width and hardness via robust design of Taguchi's methodology. Vinodh et al. [12] used Taguchi's Method for optimizing parametrically of SAW parameters by analyzing welding characteristics through orthogonal array, signal-to-noise ratio, anova and confirmation analysis. Juan Pu et al. [13] utilized flux-aided backing in SAW procedure of D36 steel during the parameter optimization by Taguchi's method. The optimum variables are predicted and the individual significance of each variable at weld quality is estimated by investigating the SN ratio and ANOVA results. The variables importance order of weld-bead superiority is considered as: weld current > weld speed > groove angle > weld voltage. The author made a noted as weld-bead superiority is gradually increased with raise in weld-joint current and joint-speed, and decrease in groove angle. Nabendu et al. [14] were optimized parametrically on butt weld AISI 409-Ferritic stainless steel of gas-metal-arc welding procedure through primary factor investigation based Taguchi method.

The literature discloses the study on low-carbon steel by using SAW is limited. However no literature is on optimizing the procedure variables for purged SAW condition and correlating with models. Author's work, purging gas in traditional SAW is utilized to determine weldment variable effects in form of penetration and mechanical strength instead of using traditional SAW process via varying process parameter. Experimental results have been compared and found sufficient extent in the field of weld quality improvement. Finally, it will contribute to the superior material properties.

2. Materials and Methodology

2.1. Materials

ASTM-A516 Gr-70, carbon-manganese steel, is selected as material of weld-plate for the present work. It is enormously utilized in producing pressure vessels welds applications. The element constituents in the material by weight, in percentage, are: C-0.13, Mn-1.03, Si-0.12, S-0.021 and P-0.024. Its strength properties are: Ultimate Tensile Strength- 560.71 Mpa and 0.2% Yield Tensile Strength-396.5 Mpa. Due to the requirement of uninterrupted weld for lengthy services SAW process is chosen.

Coil form, electrode with diameter of 3.15 mm, coated with copper of ESAB-OK brand is of Autrod 12.40 L (bearing American Weld Society Code-A5.17) and granular flux of fluoride type is used. The constituents in weight of an electrode, in percentage, are: C-0.12, Mn-1.8, Si-0.08, S-0.018, P-0.018 and Cu-0.25.

2.2. Methodology

The designed experiments, is a robust method concern to lessen the process variations, statistically proved and mainly used to manufacture premium product economically to the manufacturer, defined by Dr. Taguchi, is selected for experimentation. The design experiments built for investigating various parameters influences on performance characteristics via mean and variance to define process performance. It includes orthogonal arrays, which systematize impacting the variables, at which the levels will varies, in place of performing all probable combinations experiments.

Table 1: L_9 orthogonal array matrix for experiments

Experiment	Parameters			
	I	II	III	IV
1	-1	-1	-1	-1
2	-1	0	0	0
3	-1	+1	+1	+1
4	0	-1	0	+1
5	0	0	+1	-1
6	0	+1	-1	0
7	+1	-1	+1	0
8	+1	0	-1	+1
9	+1	+1	0	-1

Further, it allows determining the most affecting factors on product quality, via collecting the necessary data, with a lowest number of experiments, hence saves re-sources and time. It is top utilized method, while few interactions presence among variables having middle variable number and few variables only contribute significantly. In this paper, L_9 orthogonal array, 3-levels, is chosen among 4-variables as Open-circuit-voltage (V), wire-feed-rate (F), weld-speed (S) and gap between nozzle and plate (D). The same array is represented in Table 1.

2.2.1. SN Analysis

SN (Signal-to-Noise) ratio is worked out for every characteristic to identify significant parameters and predicted optimum input parameters via SN values in addition to mean responses. It's a measure of performance for selecting control levels as the noise manager. SN equation calculated anchored in the optimizing characteristic. It consist the criteria called: (a) higher_the_better, (b) smaller_the_better and (c) nominal_the_better. In this work, SN is worked out to the selected criterion as higher_the_better, shown in equation 1:

$$S/N_i = -10\log\left[1/N_i + \sum_{j=1}^{n} 1/Y_{ij}^2\right] \tag{1}$$

Here Y_{ij} - quality parameter calculated value of ith run jth test and N - experiment number in a run.

2.2.2. Mathematical Models Development

Determining affect of variables with building the co-relations among runs and model values, numerical models were developed. The computed operational relationship among the responses is $y = f(V, F, S, D)$, here y is the response. It is expressed as equation 2, via linear regression model:

$$y = \beta_0 + \beta_1 V + \beta_2 F + \beta_3 S + \beta_4 D \tag{2}$$

Here ß0 is the response intercept constant; ß1, ß2, ß3 and ß4 are the coefficients of parameters.

2.2.3. Analysis of Variance

Analysis of variance establishes the models adequacy along with significant parameters involvement is identified. Further, Confirmation tests are performed with fresh group of variable for ensuring the analysis rightness. Analysis and illustrations are presented using Minitab 17.

3. Experimental Procedure

Trail experiments are carried out for fixing lower and higher limits of the parameters, later to fit these parameters in design matrix. For fixing of these parameters at 3-levels, author followed Welding Procedure Specification, as per ASME IX code and then investigated the variables which influences of the weldment properties. Table 2 represents the fixed variables, 3-levels and fitted in the above array for experiments.

Table 2: The fixed parameters to fit in the experimental matrix

Parameters	Levels		
	-1	0	+1
V, volts	29	34	39
F, m/min	2.5	4.0	5.5
S, m/min	0.2	0.3	0.4
D, mm	20	22	24

The experimental runs are performed using ADORE PS-800, a semiautomatic joining machine baring 800A source power, Fig. 1(a). A flat position, V-butt Joint design is chosen having 1.2mm land with dimensions as 150 x 300 x 8 mm, by connecting electrode as positive, positioning perpendicular to the base plate. Cleaned and buffed weld plate surfaces to make oxide free material for better joint superiority; positioned on backup strip of copper, which is positioned in the groove of MS calibrated fixture plate.

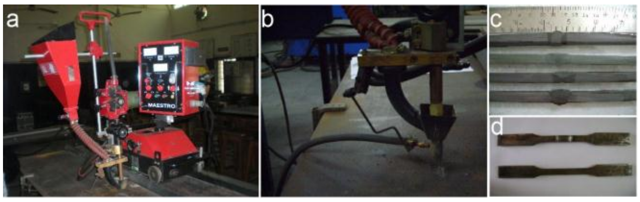

Fig. 1: Setup: (a) ‘as-weld’ condition (b) ‘purged’ condition (c) penetration sample specimen and (d) tensile sample specimen

The author introduced ‘purging gas (CO_2)’ in SAW along with electrode feed, Fig. 1(b), against traditional ‘as-weld’ of SAW (Fig. 1(a)). Once after the experiments, cross-sectioned weld coupons at different three locations with the help of power hack saw machine. Polished penetration specimen is etched by nital in 2% to record the results using callipers, Fig. 1(c). Strength test sample is made using wire-cut-electrical-discharge machine and hand grinded, Fig. 1(d). The sample preparation anchored in ASTM standards and testing held at MSME Test Station, Hyderabad, India

4. Results and Discussions

The responses are recorded for penetration and tensile strength, computed as per standard methodology from each specimen. The average value is calculated from the three specimens of every weldment coupon and presented the same, Table 4 of both welding circumstances and SN ratio. The SN is work out for every characteristic, recognized important parameter and also calculated optimum condition from mean and SN responses. These responses of each parameter in ‘as-weld’ and ‘purged’ weld conditions, at 3-levels are evaluated and the same represented, Table 4. The deviation amid their greatest and lower responses is higher specifies the comparative effect of parameter is higher on the responses.

Table 3: Weld characteristics response values obtained from ‘as-weld’ and ‘purged’ welding conditions

Weld Run	‘As-weld’ condition (T-Sample)				‘Purged’ condition (P-Sample)			
	Penetration, mm		Tensile Strength, Mpa		Penetration, mm		Tensile Strength, Mpa	
	Avg.	SN Ratio	Avg.	SN Ratio	Avg.	SN Ratio	Avg.	SN Ratio
1	6.7	16.5	545.5	54.7	8.0	18.1	549.7	54.8
2	6.0	15.5	541.1	54.6	9.7	19.8	547.4	54.7
3	8.8	18.8	546.2	54.7	8.9	19.0	554.5	54.8
4	3.9	11.9	238.8	47.6	5.2	14.4	248.9	47.9
5	7.5	17.4	272.0	48.7	9.2	19.3	286.1	49.1
6	9.5	19.5	568.6	55.1	10.4	20.4	574.4	55.1
7	5.4	14.6	270.5	48.6	4.8	13.7	278.4	48.8
8	4.9	13.8	571.6	55.1	9.1	19.2	572.8	55.1
9	10.1	20.1	585.0	55.3	11.9	21.5	584.6	55.3

Table 4: Signal to noise ratio for the responses

	Penetration		Tensile Strength	
	T-Sample	P-Sample	T-Sample	P-Sample
Parameters →	V	F	S	D
Rank	4	1	3	2
	4	1	3	2
	3	1	2	4
	3	1	2	4

4.1. Effect of Process Variables on the Responses

The calculations, Table 3 and Table 4, disclose the mainly significant variable which affects on penetration in ‘as-weld’ and ‘purged’ weld conditions, is wire-feed rate followed by nozzle-to-plate distance. From the evaluation, ave. SN values of this bead geometry characteristic, the optimal condition of variables indicates: V-1, F-3, S-1 and D-1 in both welding conditions, i.e. ‘as-weld’ and ‘purged’ welding conditions. The numbers 1, 2 and 3 are the representation of levels. The same, differences of these variables, at 3-levels, are graphically represented, Fig. 2(a) for ‘as-weld’ and Fig. 2(b) for ‘purging’ conditions.

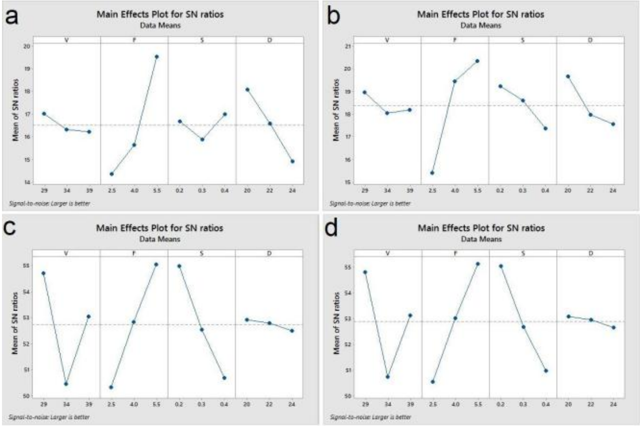

Fig. 2: SN ratio for: penetration of (a) T-sample & (b) P-sample and tensile strength of (c) T-sample & (d) P-sample

Table 5 represents the analysis of variance results, is computed on 95% confidence. It illustrates the parameter adequacy. Wire-feed rate contributes 71% trailed weld speed by 24.1% in traditional ‘as-weld’ condition, where in ‘purged’ weld condition, wire-feed rate contributes 76.1% trailed weld speed by 25.44%. Factors are contributing majorly are presented in surface graphs for both welding situations, Fig. 3 (a & b). Finishing by numerical models along with coefficients is publicized in equation 3 (‘as-weld’) and equation 4 (‘purged’) for penetration.

In both ‘as-weld’ and ‘purged’ conditions, the mainly significant variable which affects on tensile strength is wire-feed rate trailed by weld speed, which is observed through calculation of SN ratios, Table 3 and Table 4. The average SN values reveal V-1, F-3, S-1 and D-1 are the same variable combination obtained as the optimal condition in both ‘as-weld’ and ‘purged’ welding situations. The numbers 1, 2 and 3 are the representation of levels. These parameter variations for SN at 3-levels are represented for tensile strength, ‘as-weld’ in Fig. 2(c) & ‘purging’ in Fig. 2(d). The calculated analysis of variance with 95% certainty level results competency of parameters, Table 5 for tensile strength. In case of tensile strength, the wire-feed rate is contributing 55.55% in ‘as-weld’ condition and 57.94% in ‘purged’ condition. The major contribution factors in both welding situations are graphically presented as surface plots, Fig. 3 (c & d). Final mathematical models along with coefficients are publicized in equation 5 (‘as-weld’) and equation 6 (‘purged’) for tensile strength.

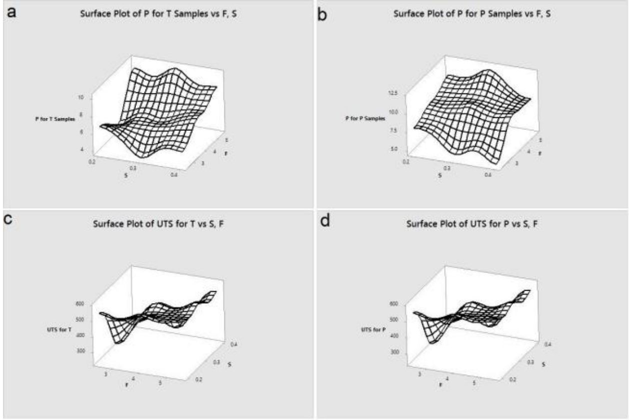

Fig. 3: Surface plot of: penetration for (a) T-sample & (b) P-sample and tensile strength for (c) T-sample & (d) P-sample

Table 5: Analysis of variance: penetration and tensile strength

Paramet rameters	Penetration				Tensile Strength			
	T-Sample		P-Sample		T-Sample		P-Sample	
	p	R-sq	*p*	R-sq	*p*	R-sq	*p*	R-sq
V	0.670	90.20%	0.786	90.65%	0.473	75.13%	0.439	75.71%
F	0.0		0.0		0.0		0.0	

	06		06		68		65	
S	0.842		0.139		0.083		0.083	
D	0.045		0.071		0.872		0.869	

4.2. Final Regression Models

The correlation among the factors and measured for variables are established from the following linear regression equations 3 and 5 ('as-weld' samples) and equation 4 and 6 ('purged' samples). The build models coefficients of determination (R^2) values reveal very good relationship amid foreseen and runs responses. Normal probability plots among foreseen responses and residuals are plotted, i.e. penetration is represented in Fig. 4(a) for 'as-weld'; Fig. 4(b) for 'purged' samples and tensile strength is publicized in Fig. 4(c) 'as-weld'; Fig. 4(d) for 'purged' samples. These results reveals that the data is closely trails the straight line. Thus, null hypothesis that is normal is the data allocation; alternative hypothesis which is its not-normal. The null hypothesis cannot be rejected, from the *p*-value, it is bigger than level of significance value (0.05), i.e. the data trails a normal-distribution, and it means that the proposed models are adequate. These predictions are in line with authors predictions.

Penetration for T-Samples =

$$14.73 - 0.0357\,V + 1.378\,F + 0.82\,S - 0.558\,D \tag{3}$$

Penetration for P-Samples =

$$16.73 - 0.0236\,V + 1.470\,F - 7.51\,S - 0.497\,D \tag{4}$$

Tensile Strength for T-Samples =

$$787 - 6.85\,V + 71.6\,F - 995\,S - 3.7\,D \tag{5}$$

Tensile Strength for P-Samples =

$$798 - 7.19\,V + 70.7\,F - 963\,S - 3.7\,D \tag{6}$$

4.3. Confirmation tests

Validate with new variables combinations the above work, two new experiments are performed. For confirmation tests, the parameters used are: V at 32volts, F at 3m/mm, S at 0.25m/mm and D at 21mm and V at 36volts, F at 4.5m/mm, S at 0.35m/mm and D at 23mm. The responses are represented, Table 6 and a comparison made between models foreseen outcomes developed in this work (equations 3-6) and the experimental values. This analysis discloses for the calculated variable errors. Therefore, the variable(s) relationships from equations 3 to 6 correlate against the outcomes in sensible degrees of approximation.

5. Conclusion

In both welding situations, penetration and tensile strength, the significant variables are recognized and the optimum input variables are predicted. It reveals, the mainly significant variable is wire-feed rate in both 'as-weld' and 'purged' conditions. The optimal situations in both welding characteristics are the same, obtained from SN ratio, i.e. open-circuit voltage at 29v, wire-feed rate at 5.5m/mm, weld speed at 0.2 m/mm, nozzle-to-plate distance at 20 mm, for variables at three-levels in 'as-weld' besides in 'purged' condition. The calculated *p*-values of analysis of variance provided the variables contribution rate of wire-feed rate, which shared significantly. Predicted values via linear regression models and experimental responses are validated through confirmation test responses and are fair in limits. In last, it is noted that, the welding strength characteristic of 'purged' weld condition responses are enhanced in comparison with traditional 'as-weld' condition.

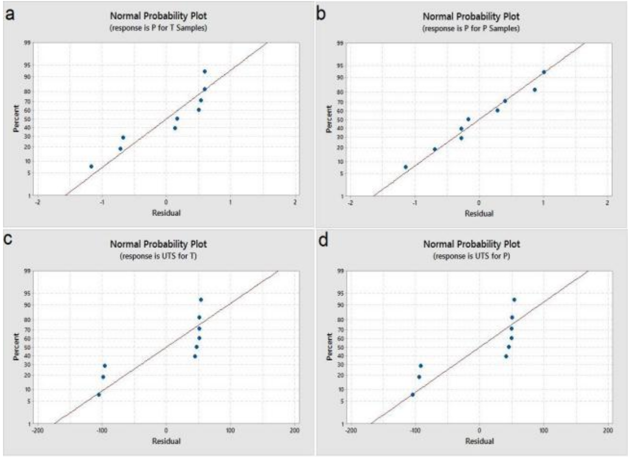

Fig. 4: Normal plot for penetration of (a) T-sample & (b) P-sample and tensile strength for (c) T-sample & (d) P-sample

Table 6: Comparison of the responses among the confirmation experiments and models

Sample	Parameters			
	Test No.	Experiment Value	Model Value	Error
Penetration				
T-Sample	T1	456.15	450.51	5.64
	T2	429.25	424.87	4.38
P-Sample	T1	461.57	455.45	6.12
	T2	435.16	429.71	5.45
Tensile Strength				
T-Sample	T1	456.15	450.51	5.64
	T2	429.25	424.87	4.38
P-Sample	T1	461.57	455.45	6.12
	T2	435.16	429.71	5.45

References

[1] Nicholas, *The white book of steel*, World Steel Association, Belgium, (2014).

[2] R. L. O'Brien, *Welding Process - Welding Handbook*, American Welding Society, USA, (1992).

[3] Phillip J. Ross, *Taguchi Techniques for Quality Engineering*, McGraw-Hill, Singapore, (1996).

[4] Douglas C. Montgomery, *Design and Analysis of Experiments*, John Wiley & Sons Inc, New York, (2004).

[5] Tarng YS & Yang WH (1998), Application of the Taguchi method to the optimization of the submerged arc welding process. *Journal of Materials and Manufacturing Process* 13(3), 455–467.

[6] Yayla P, Kaluc E & Ural K (2007), Effects of Welding Processes on the Mechanical Properties of HY 80 Steel Weldments. *Journal of Material and Design* 28, 1898-1906.

[7] Serdar K & Abdullah S (2008), Sensitivity analysis submerged arc welding process parameters. *Journal of Materials Processing Technology* 202, 500-507.

[8] Amanie J, Oguocha INA, Yang Y & Yannacopoulos S (2009), The Effect of Welding Speed on The Impact and Tensile Properties of SA516 Grade 70 Steel. *Joining of Advanced and Specialty Materials*, 2487-2492.

[9] Deepak Kumar & Sandeep Jindal (2014), Optimization of Process Parameters of Gas Metal Arc Welding by Taguchi's Experimental Design Method. *Journal of Surface Engineering and Materials Technology* 4(1), 24-27.

[10] Sarkar Abhijit, Roy J, Majumder Arindam & Saha SC, "Optimization of Welding Parameters of Submerged Arc Welding Using Analytic Hierarchy Process (AHP) Based on Taguchi Technique", *Journal of the Institution of Engineers (India): Mechanical Engineering Division*, 95, 2014, pp:159-168. http://dx.doi.org/10.1007/s40032-014-0114-4

[11] Abhijit Saha & Subhas Chandra Mondal (2015), Optimization of Process Parameters in Submerged Arc Welding using Multi-Objectives Taguchi Method. *Journal of Advances in Material Forming and Joining* 1, 221-232.

[12] Vinodh S, Karthik Bharathi S & Gopi N (2015), Parametric Optimization of Submerged Arc Welding Using Taguchi Method. *Design of Experiments in Production Engineering*, 183-194.

[13] Juan Pu, Shengfu Yu, & Yuanyuan Li, "Parameter optimization of flux-aided backing-submerged arc welding by using Taguchi method", International Journal of Modern Physics, Vol. B 31 (2017) https://doi.org/10.1142/S0217979217440465

[14] Nabendu Ghosh, Pradip Kumar & Pal Goutam Nandi, "Parametric Optimization of Gas metal arc welding process by PCA-based Taguchi method on Ferritic stainless steel AISI409", *Materials Today: Proceedings*, Vol.4, Issue.9 (2017), pp:9961-9966 https://doi.org/10.1016/j.matpr.2017.06.302