

A Computational approach in optimizing process parameters of GTAW for SA 106 Grade B steel pipes using Response surface methodology

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Abstract. Welding is one of the most common metal joining techniques used in industry for decades. As in the global manufacturing scenario the products should be more cost effective. Therefore the selection of right process with optimal parameters will help the industry in minimizing their cost of production. SA 106 Grade B steel has a wide application in Automobile chassis structure, Boiler tubes and pressure vessels industries. Employing central composite design the process parameters for Gas Tungsten Arc Welding was optimized. The input parameters chosen were weld current, peak current and frequency. The joint tensile strength was the response considered in this study. Analysis of variance was performed to determine the statistical significance of the parameters and a Regression analysis was performed to determine the effect of input parameters over the response. From the experiment the maximum tensile strength obtained was 95 KN reported for a weld current of 95 Amp, frequency of 50 Hz and peak current of 100 Amp. With an aim of maximizing the joint strength using Response optimizer a target value of 100 KN is selected and regression models were optimized. The output results are achievable with a Weld current of 62.6148 Amp, Frequency of 23.1821 Hz, and Peak current of 65.9104 Amp. Using Die penetration test the weld joints were also classified in to 2 categories as good weld and weld with defect. This will also help in getting a defect free joint when welding is performed using GTAW process.

1. Introduction

Gas tungsten arc welding (TIG) is a fusion welding process having wide applications in industry. It is widely applied in manufacturing process for different types of materials like Aluminum, Mild steel and different type of stainless steel alloy grades. The optimization of TIG welding process parameters play important role for the final product quality in terms of joint efficiency and mechanical properties [1]. The main objective of industries reveal with producing better quality product at minimum cost and increase productivity. TIG welding is most vital and common operation use for joining of two similar



or dissimilar part with heating the material or applying the pressure or using the filler material for increasing productivity with less time and cost constrain. TIG welding parameters such as welding current, gas flow rate, welding speed, that are influences on responsive output parameters such as tensile strength of welding [2]. Optimization can be done in different techniques like Taguchi method, response surface methodology, Genetic algorithm (GA), artificial neural network (ANN) etc. Nowadays, application of design of experiment (DoE), evolutionary algorithms and computational network are widely used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality [3]. Important process parameters namely current, welding speed and shielding gas flow rate were optimized using response surface methodology (RSM). The simultaneous effects of these parameters on tensile strength evaluated. Applying RSM, simultaneous effects of welding parameters on tensile strength was obtained through equation. Moreover, optimized values of welding process parameters to achieve desired mechanical properties were evaluated [4]. The weldments are subjected to tensile testing to find qualitative properties. The percentage contribution of each parameter and prediction of tensile strength is found by analysis of variance (ANOVA) technique [5]. The Taguchi method was employed to bead on welding trials to optimize Pulsed Current Gas Tungsten Arc (PCGTA) welding process parameters of alloy C-276. A L9 orthogonal array of Taguchi design involving nine experiments for four parameters (pulsed current, background current, % on time, pulse frequency) with three levels was used. Analysis of Variance (ANOVA) is performed to measure percentage contribution of each factor [6, 11]. TIG welding process, considering the effects of main variables on weld strength. The most effective effect of parameter on the weld strength has been studied. Weld strength varies under various conditions. By using Taguchi and ANOVA technique an optimal solution was found out, which provides us an optimal results of the varying condition [7]. Optimization was done to find optimum welding conditions to maximize tensile strength of welded specimen. Confirmation tests were also conducted to validate the optimum parameter settings [8, 12]. Friction welding process of aluminum alloy using RSM was investigated and optimal welding conditions that would yield maximum tensile strength were found out [9]. A mathematical model was developed by factorial design approach to find out the relationship between various process parameters and weld deposit area. The significant of the model was analyzed by ANOVA [10].

There are only limited studies found in tensile strength of SA 106 Grade B steel pipe. Therefore the present work is aimed to optimize the process parameters for pipe welding of SA 106 Grade B steel by developing a central composite design for predicting the optimum response using Response surface methodology.

2. Experiments and Methodology

The material selected for the welding process is SA 106 Grade B Steel which has wide variety of application in the area of automobiles, boiler parts, pressure vessels etc. It has excellent welding characteristics and good mechanical properties. The chemical composition of the sample specimen SA 106 Grade B steel was heated using tungsten electrode and cleaned using argon gas and waves were made to pass through the spectrometer, the corresponding wave lengths give the composition of the corresponding elements and is reported in the Table 1.

Table 1 Chemical composition of SA 106 Grade B steel

Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Ti	Pb
98.82	0.241	0.154	0.514	0.012	0.017	.092	.014	.032	.016	.082	.001	.002

Initial trials were carried out to establish the range of welding parameters for obtaining good weld with high tensile strength. Based on the trials the following range of parameters were established as shown in table 2.

Table 2. Range of Process Parameters for GTAW

Process parameter	Units	Level		
		Low	Medium	High
Peak current	Amp	100	140	200
Weld current	Amp	95	115	190
Frequency	Hz	30	45	50

Experiments were designed and conducted using the three level Central Composite Design (CCD). This response surface methodology had 15 sets of unique experiments based on the cube and face points and 5 experiments based on the centre point adding 20 experiments totally. The se repetitive experiments were carried out to ensure the environmental effects had no influence and also the run order had randomized to nullify the errors being accumulated in one sets of experiments. Based on CCD twenty experiments are planned and with results it's shown in table 5. The entire welding was performed using 1.2 mm Stainless steel 309L wire as continuously fed electrode. Argon was the inert gas used for shielding the weld surface from contaminants. A schematic joint representation was shown in the Figure 1 and the detail about the welding power source is shown in table 3.

Table 3. Technical details about Weld power source

Welding Current Range	50-250 A
Welding Voltage Range	415 V
Types of Cooling	AF
Gas Flow Rate	4 lit/min

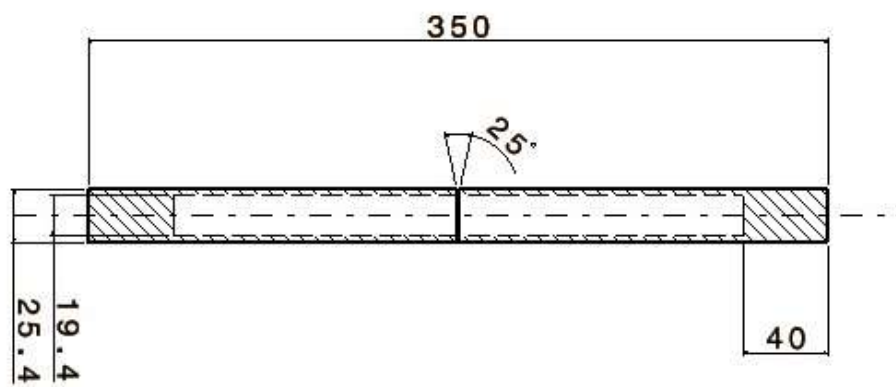


Figure 1. A schematic Joint design.

3. Results and Discussion

The welding was done as per the above said parameters by employing Response surface methodology. DOE with results were shown in the table 4. In order to determine the quality of welded joint a die penetrant test was performed by spraying solvent remover initially on the welded surface for cleaning. After a few minutes penetrant was sprayed on the weld surface and excess penetrant on the surface was wiped using cloth. Then developer was sprayed and thus cracks and small holes are visible on the surface. Length of the crack which is less than 1/4th of the diameter of the pipe is classified as small crack whereas if the length is greater than 1/4th of the diameter of the pipe, it is classified as large cracks as reported in the table 4.

Table.4 Die penetrant test Result.

Run Order	Current (Amp)	Frequency (Hz)	Peak Current (Amp)	Number of small holes	Number of large holes	Number of small cracks	Number of large cracks	Remarks
1	95	30	200	0	0	0	0	Good
2	142.5	40	150	0	0	2	0	Good
3	142.5	40	150	0	0	2	0	Good
4	142.5	40	150	0	0	0	1	Good
5	190	30	100	0	0	1	0	Good
6	142.5	23.182	150	1	0	0	0	Good
7	190	50	100	2	0	0	0	Good
8	95	30	100	0	0	1	0	Good
9	222.325	40	150	0	0	0	1	Good
10	142.5	40	234.1	0	0	1	0	Good
11	142.5	40	150	2	0	0	0	Good
12	62.615	40	150	0	1	0	0	Defective
13	142.5	56.818	150	0	0	0	0	Good
14	190	30	200	0	1	0	0	Good
15	142.5	40	65.91	0	0	0	0	Good
16	142.5	40	150	0	1	0	0	Defective
17	95	50	100	0	0	0	0	Good
18	142.5	40	150	0	0	1	0	Good
19	190	50	200	0	1	0	0	Defective
20	95	50	200	0	0	1	0	Good

3.1. Tensile testing:

Ultimate tensile strength of the specimens were determined using Tensile testing Machine. The samples were prepared at the dimensions of length of 350 mm, outer diameter of 25.4 mm and thickness of 3mm. On both sides of pipe after welding a solid shat if inserted using press fit to ensure proper grip on the specimen to ensure tension in both the ends. The results obtained were shown in table 5.

Table.5 weld Tensile strength.

Std Order	Run Order	Pt Type	Block	Current	Frequency	Peak Current	Tensile strength (KN)
5	1	1	1	95	30	200	75.2
15	2	0	1	142.5	40	150	48.6
20	3	0	1	142.5	40	150	48.6
18	4	0	1	142.5	40	150	48.6
2	5	1	1	190	30	100	55
11	6	-1	1	142.5	23.1821	150	64.8
4	7	1	1	190	50	100	40.4
1	8	1	1	95	30	100	72
10	9	1	1	222.325	40	150	36.4
14	10	-1	1	142.5	40	234.09	44.2
19	11	0	1	142.5	40	150	48.6
9	12	-1	1	62.615	40	150	16.8
12	13	-1	1	142.5	56.8179	150	70.2
6	14	1	1	190	30	200	36
13	15	-1	1	142.5	40	65.91	88.3
16	16	0	1	142.5	40	150	48.6
3	17	1	1	95	50	100	95
17	18	0	1	142.5	40	150	48.6
8	19	1	1	190	50	200	20
7	20	1	1	95	50	200	69.4

For determining the correlation existing between the input parameters and output response, ANOVA was performed. Anova also gives the information about the effect of linear fit, Regression and square fit for the model analysis. Based on the 'P' Value for a 95% confidence interval the significant terms and its effect are determined and is shown in table 6.

Table.6 Final Estimated Regression Coefficients for tensile strength

	Coef	SE Coef	T	P	Remarks
Constant	48.5950	4.955	9.808	0.000	Significant
Current	-9.3167	4.689	-1.987	0.065	Significant
Frequency	-0.3162	4.689	-0.067	0.947	Not Significant
Peak Current	-9.9560	4.689	-2.123	0.051	Significant
Frequency*Frequency	7.5493	4.523	1.669	0.116	Not significant

R-Sq = 42.85% R-Sq (adj) = 27.61%.

Initially all the individual parameters, their squares and interaction is used in the response surface analysis. The difference between R-Sq and R-Sq (adj) was 39.84 %. This was modified using removing the insignificant Parameters in the analysis. By avoiding the non- significant parameters the difference was reduced to 15.24%. The results show that current, peak current are significant parameters in the estimation of tensile strength. The ANOVA also says that Regression and linear are significant and is shown in table 7.

Table.7 Final Analysis of Variance for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	3376.80	3376.80	844.199	2.81	0.063
Linear	3	2540.48	2540.48	846.825	2.82	0.075
Square	1	836.32	836.32	836.320	2.79	0.116
Residual Error	15	4503.21	4503.21	300.214		
Lack-of-Fit	10	4502.94	4502.94	450.294	8187.16	0.000
Pure Error	5	0.28	0.28	0.055		
Total	19	7880.01				

Based on the analysis an empirical relationship to calculate the tensile strength was determined using the coefficients of current, Peak current and Frequency, the developed final empirical relationship is given by equation 1.

$$\text{Tensile strength} = 228.466 - 0.196141I - 6.07103F - .199119P + 0.0754926 F^2 \quad (1)$$

From the figures 2 and 3 it is observed that high tensile strength is achieved with low peak current values with low frequency, and high frequency. Which also proves that frequency has less effect on the output response tensile strength of the joint. Surface plot and contour plot for the responses are shown below.

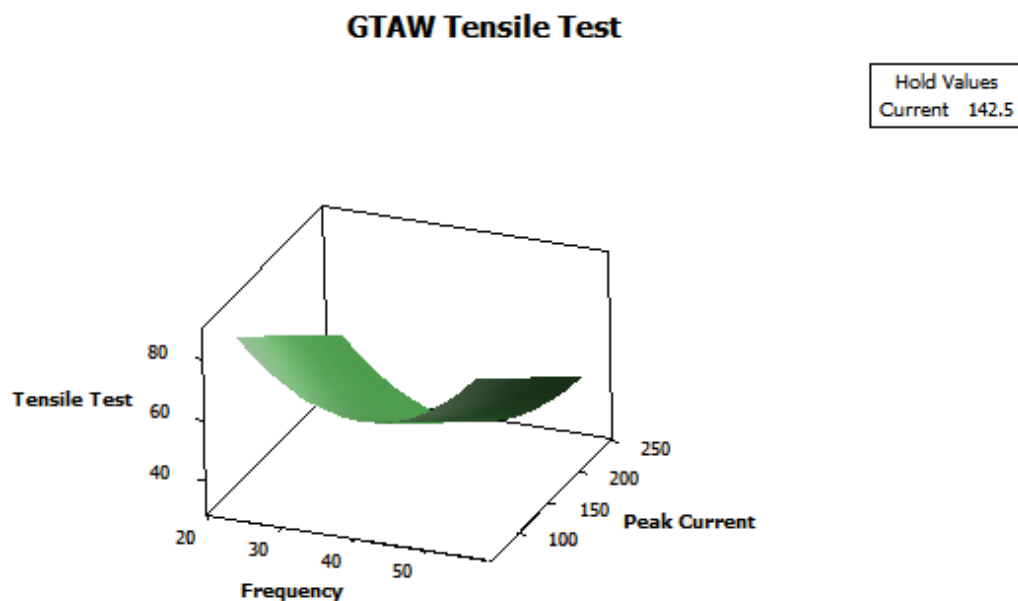


Figure.2 Surface plots for Tensile test Vs Frequency

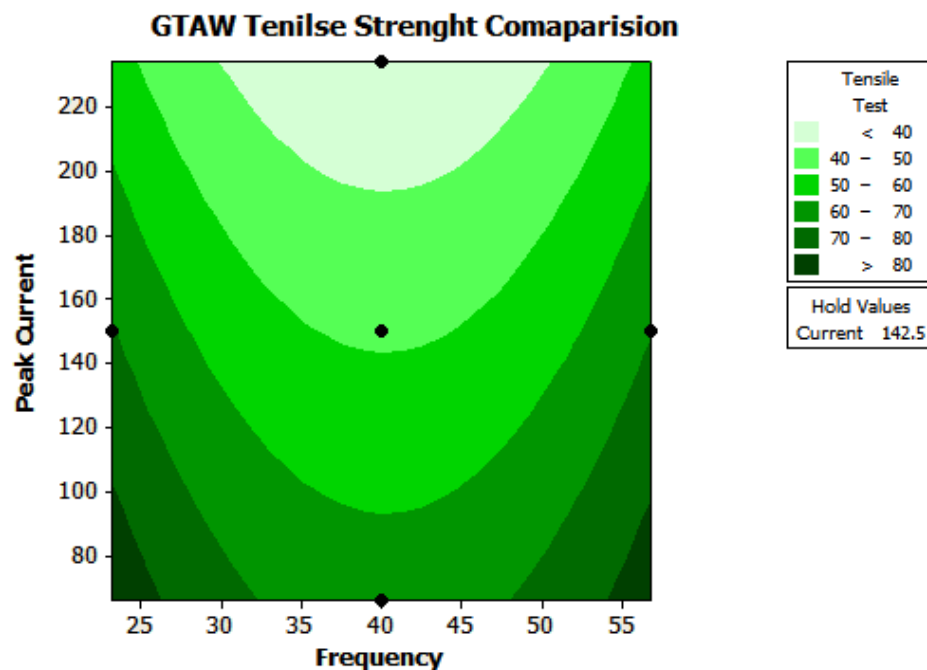


Figure.3 Contour plot for Peak current and Frequency;

Similarly the contour plots for tensile test with current and peak current is shown in the figures 4. It is observed that high tensile strength is achieved with low weld current, low peak current values. And low tensile strength is achieved with high weld current and high peak current values.

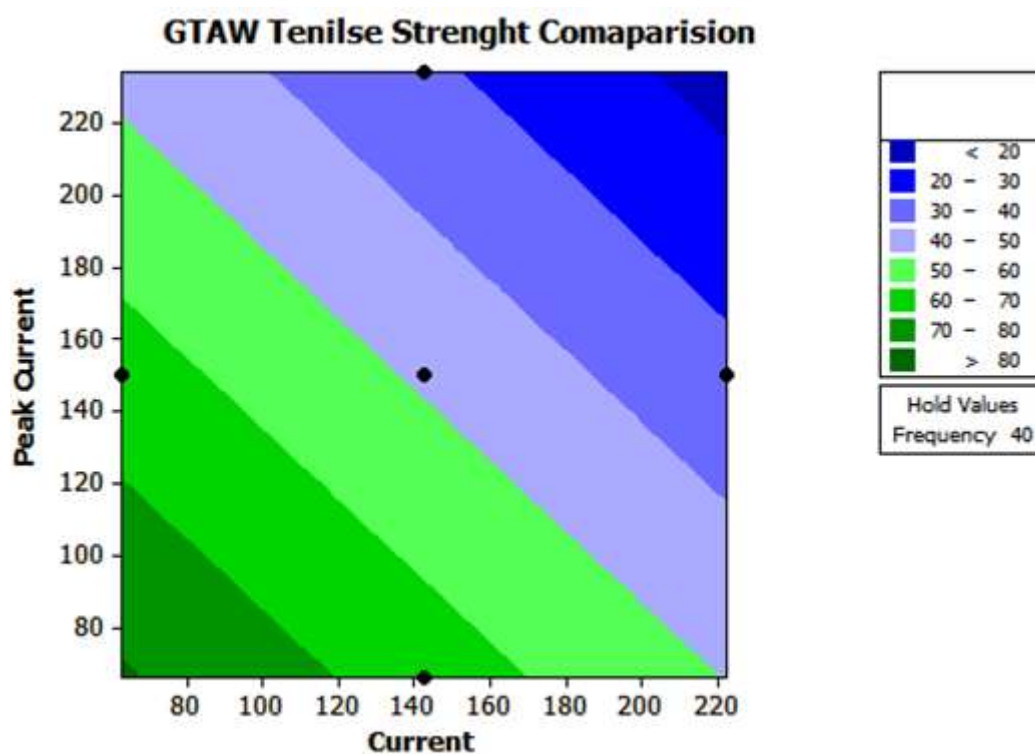


Figure.4 Contour plot for Current and Peak current

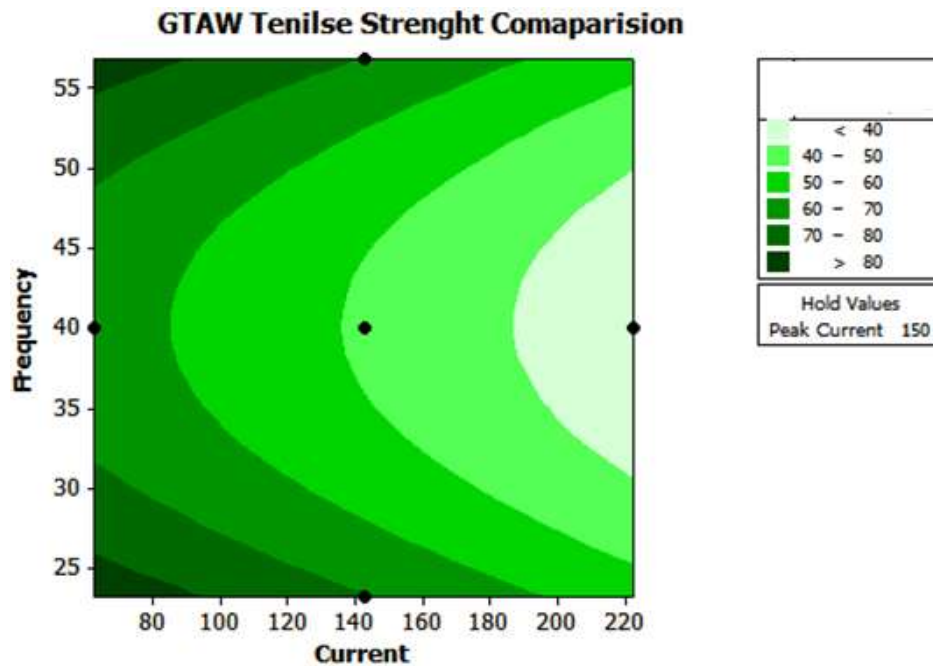


Figure.5 Contour plot for Frequency and Current;

From the figures 5 it is observed that high tensile strength is achieved with low weld current, high frequency. High tensile strength is achieved with high weld current and moderate frequency values. Using optimization in response surface methodology (RSM) for maximizing the tensile strength, with a target of 100 Kn, the optimum combination of input parameters was determined. Figure 6 shows the methodology adopted in this and also the parametric effect.

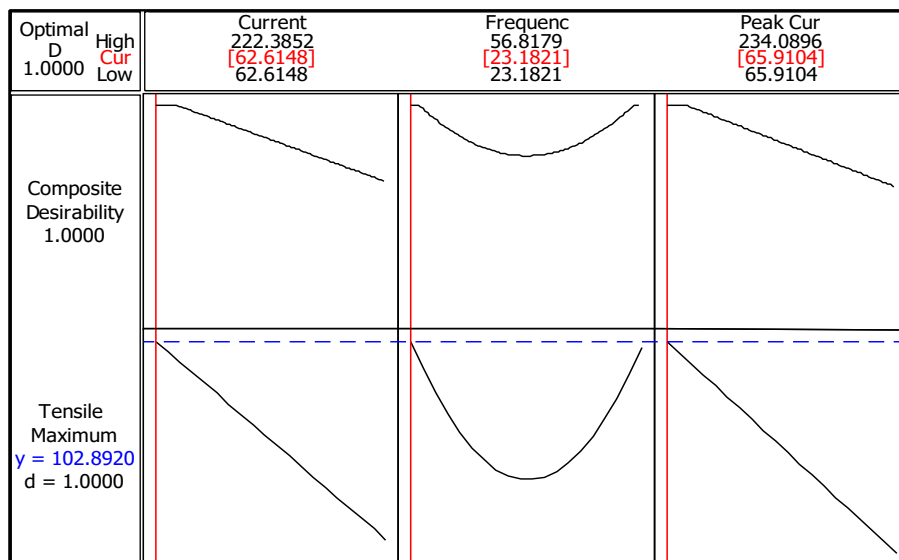


Figure 6 Optimization of weld parameters in GTAW process

3.2 Experimental Validation

To check the validity of the predicted values of tensile strength and regression equation a confirmation test was carried out for the optimal parameters predicted by RSM and regression values agree well with the experimentally confirmed results.

Input parameters	Output Response.	Target	Obtained	% Error
Weld current	Tensile strength	102.89	98.8	3.975
Frequency				
Peak current				

4. Conclusions

An experimental procedure were established to carry out the welding GTAW process for SA106 Grade B steel and also to measure the tensile strength.. A detailed analysis has been carried out to identify the influencing parameters such as weld current, frequency and peak current which affect the tensile strength of specimens after welding. Die penetrant testing was done to determine the defects in weld and tensile testing was done in UTM to obtain corresponding tensile strengths. The following conclusions were drawn from the investigation The obtained optimal parameters are weld current (62.6148 Amp), frequency (23.1821 Hz), Peak current (65.9104 Amp). Validation test was conducted and the results are in lie with the prediction.

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