Asian Journal of Engineering and Applied Technology
ISSN: 2249-068X (P) Vol. 2 No. 2, 2013, pp.78-83

DOI: https://doi.org/10.51983/ajeat-2013.2.2.661

Optimisation of High Frequency Seam Welding Parameters By Taguchi Method

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Abstract - **Seam welding is a versatile and most widely used method of fabrication in pipe and tube industries. A seam weld is a series of overlapping resistance spot welds made progressively along a joint by rotating circular electrodes. With the operating conditions becoming more and more stringent and the increased use of seam welded pipe joints in Industrial and domestic pipelines, the improvement in mechanical properties have become increasingly important. In this study, process parameters viz. Welding current, frequency of current, Roll Pressure and weld speed of Therma Tool welding machine were studied at three levels in a reputed company of Northern India by using $L_9(3)^4$ orthogonal arrays of Taguchi method to study tensile strength of electric resistance welding of pipes of 15 mm diameter of Class B. "Welding speed" was found to be contributing the most i.e. 45.43% in variation of Tensile strength followed by "roll pressure" which is contributing 22.93%. The parameter "Welding Current" contributing 20.92% and "Weld current frequency" is affecting least to variation being 10.58% of total variation of process. Lower levels of weld speed and Roll pressure, medium level of welding current and higher level of current frequency resulted in improvement in Tensile strength of pipes by 11.8%.**

Keywords: **Self High Frequency Pipe welding, Welding current and frequency, Tensile strength, Taguchi Method.**

I. Introduction

High Frequency pipe welding are joining processes in which coalescence of metals is obtained by application of heat induced from electrical resistance of work to high frequency currents combined with application of Forge pressure to produce seamless welds.

The process is classified further to High frequency resistance welding with physical electrical contact known as High frequency resistance welding (HFRW) and Non contact High frequency Induction welding (HFIW).The shielding or fluxing is not required generally is most of metals except for some Reactive metals like Titanium and certain stainless steels. The process is available only for automation due to low volume of metal heating at bead area only with high efficiency at higher welding speeds.

Robert K. Nichols [1] presented High Frequency Welding as undoubtedly the fastest and most efficient method of making pipe and tube. However, it can also present the operator with a bewildering variety of weld defects. The paper objectively discusses most common defects, their causes and how they can be prevented. G. T. Quickel *et al***.** [2] reviewed common pipeline welding types and provides several case histories in which failure analysis techniques were used to determine a metallurgical cause of failure. There are more than 2.5 million miles of oil and gas pipelines in the United States. These pipelines typically contain longitudinal seam welds in each pipe joint and girth welds that connect the individual joints to form the pipeline. Both types of welds are prone to failure from time independent and/or time dependent failure mechanisms.

Wu Xiaomeng [3] presented a method for detection of Weld Line Defect for Oil-gas Pipeline based on X-rays Image Processing. The optimal threshold method is used for the x-ray welding image segmentation. The quality of welds is judged by determining whether there has air bubble or not in the weld image. Processed by x-ray real-time imaging detection system for the weld image of a oil pipe factory, the results shows that the proposed method can be carried out in identification of weld quality successfully.

Choong Myeong Kim *et al.* [4] presented during high-frequency electric resistance welding (HF-ERW), the electromagnetic force induced by the high-frequency electric current was studied to improve the understanding of penetrator formation mechanism. ERW melting zone behavior is investigated by the cinematography and the three-dimensional numerical analysis of electromagnetic field around molten metal bridge. Based on the results, the penetrator formation is mainly influenced by the narrow gap shape, the variation of electromagnetic forces along the narrow gap, the molten metal bridge traveling speed, and the second bridge formation frequency. Electromagnetic force acting on the molten metal bridge is rapidly decreasing as the bridge is traveling away from the apex point. The 'comet' shape narrow gap produced by the variation of Lorentz forces makes the bridge pushing pressure decrease. Due to the decrease of electromagnetic force and pushing pressure, the sweeping speed of molten metal bridge slows down until the bridge reaches the welding point. Previous molten metal bridge traveling is arrested when the next bridge is formed before the previous bridge arrives at the welding point. Thus, the molten metal and oxide are refilled into the narrow gap due to the capillary force and then remained as a penetrator. According to the analysis of penetrator formation mechanism, the new penetrator formation model is proposed. Khalid Ali Babakri [5] described areas of improvement in the acceptance criteria to the flattening test in the pipe line international standards (API 5L and ISO 3183) are discussed. The aim is to make the flattening test acceptance criteria for the high frequency induction welded (HFIW) steel pipe clearly stated and defined so that there will be no argument about its interpretation. Recommendations for improving the mill set up to enhance the flattening test performance are also presented based on practical implementation in Saudi Steel Pipe Company. The process capability index is also used as quantitative tool to measure and monitor the performance of the flattening test using the height of the first weld crack as a basis of measurement.

P.C.Chung *et al***.** [6] performed two post-weld heat treatment cycles of one-step normalizing and two-step quenching and tempering by Gleeble, a thermo-mechanical simulator, to improve the toughness of fine-grained electric resistance welded pipe welds. Comparison was made to API X65 grade steel, which is widely used for pipeline parts. Micro structural evolution was investigated by optical microscopy and transmission electron microscopy. Vickers hardness and Charpy V-notch impact toughness tests were used to evaluate the mechanical properties. While the mechanical properties of one-step normalizing heat treatment satisfied the API specification, the two-step quenching and tempering heat treatments were conditional upon tempering temperature for X65 grade and fine-grained steels. As a result, a one-step normalizing heat treatment was more effective for both steel pipes.

Zongyue Bi *et al***.** [7] investigated the characteristics of grooving corrosion of oil coiled tubes by electric resistance welding were investigated by using electrochemical polarization tests and an immersed corrosion test. The welded tube exhibited severe localized corrosion in the welding zone. The post-weld heat treatments reduced the sensitivity of grooving corrosion. A corrosion groove occurred at the fusion line. The local heat treatment for the welding zone at 930°C adding the whole heat treatment for tubes at 690°C was beneficial to improve the resistance to the grooving corrosion. The reasons of the grooving corrosion were discussed from the microstructures and chemical compositions of the weld.

II. Methodology

The objective of this paper is on optimizing the process parameters of High Frequency induction welding process to find optimum levels and the experimental study has been carried in one of reputed company in Northern India. The Taguchi method has been used by planning eight experimental steps that can be grouped into three major categories as follows [8]:

(a) ***Planning the experiment***

(1) Identify the main function of welding process.

(2) Identify the quality characteristic to be observed and the objective function to be optimized.

(3) Identify the control factors and their alternate levels.

(4) Identify noise factors and the testing conditions of the process.

(5) Design the matrix experiment and define the data analysis procedure.

(b) ***Performing the Experiment***

(6) Conduct the matrix experiment.

(c) ***Analyzing and verifying the experimental results***

(7) Analyzing the data, determining the optimum levels for the control factors, and predicting performance under these levels. (8) Conducting the verification experiment.

A. Selection of Process Parameters Levels

In the present work, the performance quality characteristic of the electric resistance welding of pipe was tensile strength. Taguchi technique has been used to study the entire process parameters and select their levels with minimum number of experiments. Welding current; Current frequency; Roll pressure and welding speed were selected as main process parameters to control the quality of weld. The experiments were conducted at three levels as shown in Table I. Degree of freedom requires for experimental work is 2×4= 8. Taguchi's OA are selected on the basis of the condition that the total DOF of a selected OA must be greater than or equal to the total DOF required for the experiments [9]. $L_9\,(^{.}3^4)$ orthogonal arrays has nine number of rows or 8 Degree of freedom and is therefore selected.

Table I Process Parameters and Their Levels

	Parameters	Level-1	Level-2	Level-3
A	Welding Current	150A	200A	250A
B	Current Frequency	200KHz	300KHz	400KHz
C	Roll Pressure	200 kN	225 kN	250 kN
D	Welding Speed	100fpm	130fpm	160fpm

III. Experiments and Analysis of Data

Total 9 experiments were conducted as per standard array shown against each trial in Table II and tensile Strength and Signal to noise ratio are shown against

$$SN_{HB} = -10\log\left(\frac{1}{r}\sum_{i=1}^{r} 1/Y_i^{\,2}\right)$$

The experimental data for tensile strength shows that in trial no. 6 tensile strength is highest (453 MPa) while it is lowest (395 MPa) in trial number 7 with a overall variation of 58 MPa.

The average main and SN Response shown in Table III has been calculated by using MINITAB software (Release 16.1.1), which shows average Tensile strength at given parameter level. The average Tensile strength and S/N ratio is found out to be decreasing continuously with increasing in parameter C and parameter D, whereas these were found out to be increasing continuously with increasing in parameter B (Current Frequency). The average Tensile strength and Signal to Noise ratio is found out to be increase slightly at second level where as it reduce sharply at Highest Level in case each row. In this work, the characteristic measure was Tensile strength which must be as higher as possible. The S/N ratio for higher the better is given by [11] of parameter A (Welding current).The response graph for average Tensile strength and SN ratio has been plotted using MINITAB Software release 16.1.1 and are shown in figure 1 and figure2.

Table II Experimental Data

Exp No.	Welding Current (Amp)	Current Frequency (kHz)	Roll Pressure (kN)	Welding Speed (Feet/Min)	Tensile Strength (MPa)	S/N Ratio (dB)
1	150	200	200	100	445	52.97
2	150	300	225	130	416	52.38
3	150	400	250	160	405	52.15
4	200	200	225	160	403	52.11
5	200	300	250	100	432	52.71
6	200	400	200	130	453	53.12
7	250	200	250	130	395	51.93
8	250	300	200	160	400	52.04
9	250	400	225	100	428	52.63

Table III Raw Data Average and S/N Response for Main Factors (Tensile Strength)

Designation / Levels	Control Factor	Average (MPa)			S/N (dB)		
		1	2	3	1	2	3
A	Welding Current	422	429.33	407.67	52.50	52.65	52.20
B	Current Frequency	414.33	416	428.67	52.34	52.38	52.63
C	Roll Pressure	432.67	415.67	410.67	52.71	52.37	52.26
D	Welding Speed	435	421.33	402.67	52.77	52.48	52.10

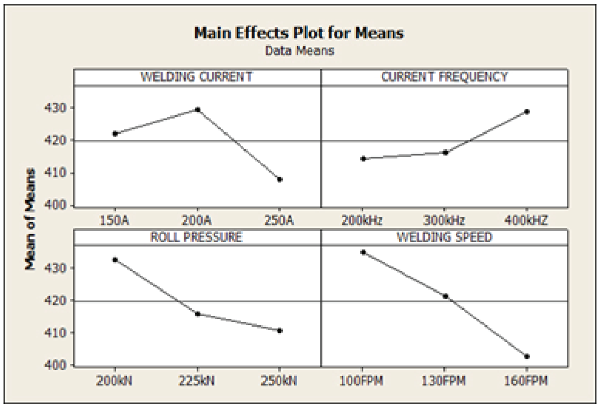

Fig. 1 Response graphs for average Tensile strength.

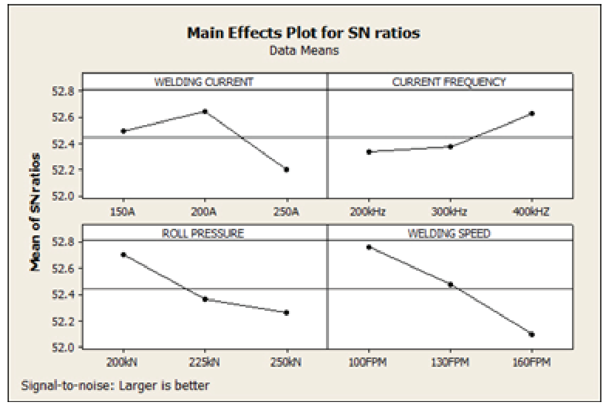

Fig. 2 Response graphs for tensile strength S/N ratios

Table IV Raw Data Anovas (Tensile Strength)

Source	SS	DOF	V	F Ratio	P%
A	728.67	2	364.34	700.49***	20.92
B	368.67	2	184.33	354.90***	10.58
C	798	2	399.00	767.60***	22.93
D	1580.66	2	790.33	1520.09***	45.43
SST	3476	8	---	---	100

*Note: 1) *** At least significant at 99%confidence,* $F_{0.99\,(2\&8)}$ *=9.37*
*2) ** At least significant at 95%confidence,* $F_{0.95\,(2\&8)}$ *=19.4*
3) At least significant at 90%confidence,* $F_{0.90\,(2\&8)}$ *=99.4*

Table IV shows analysis of variance of different parameters for complete experimental design to calculate its significance to tensile strength. The asterisk (*) marks shown below the Table 4 are from F tables in order of 99%, 95% and 90% respectively.

These values are compared with calculated F values column of ANOVA table. It shows that all factors are significant as their F ratios are significant at 99% confidence interval to their tabulated value. From Table IV and Table V of raw and S/N data, it can be concluded that all the parameters are significant and affect both mean and variability of the process. So the optimum parameter levels were selected from the response graphs as shown in Fig.1. Higher values were selected for all parameters as shown in Table VI.

Table V S/N Anova Summary (Tensile Strength)

SOURCE	SS	DOF	V	F RATIO	F* RATIO	P%
A	0.309	2	0.155	10.53*	154***	21.06
B	0.156	2	0.078	5.32**	78**	10.63
C	0.325	2	0.163	11.08*	163***	22.15
D	0.677	2	0.338	23.08***	338***	46.16
SST	1.467	8	---	---	---	100

Table VI Summary of Optimum Levels

Parameters	Optimum Level	Value
Welding Current	A_2	200A
Current Frequency	B_3	400 KHz
Roll Pressure	C_1	200 kN
Welding Speed	D_1	100fpm

Tensile strength was found to be reducing with increase of weld speed and Low welding speed of 100 f/min was enough to produce weld bead with best metallurgical properties. The current of 200 Amp. Combined with High frequency of 400 KHz produced optimum melting temperature at edges of pipes due to best skin effect. The minimum roll pressure of 200 kN produced the desired weld bead with minimum scarf.

A. Estimation of Optimum Tensile Strength

The averages of the level of factor A, B, C and D are:

$$\overline{A_1} = 422 \quad \overline{B_1} = 414.33 \quad \overline{C_1} = 432.67$$
$$\overline{D_1} = 435 \quad \overline{T} = 419.67$$

$$\overline{A_2} = 429.33 \quad \overline{B_2} = 416 \quad \overline{C_2} = 415{,}67$$
$$\overline{D_2} = 421.33$$

$$\overline{A_3} = 407.67 \quad \overline{B_3} = 428.67 \quad \overline{C_3} = 410.67$$
$$\overline{D_3} = 402.67$$

So, optimum levels are:

$$\overline{A_2} = 429.33 \quad \overline{B_3} = 428.67 \quad \overline{C_1} = 432.67$$
$$\overline{D_1} = 435$$

The estimated average results, when the control factors are at their better level is:

$$\mu_{A2,\ B3,\ C1\ \&\ D1} = A_2 + B_3 + C_1 + D_1 - 3\ T \qquad \ldots\ (1)$$
$$= 429.33+428.67+432.67+435-3(419.67)$$
$$= 468.5\ \text{MPa}$$

The 99% confidence interval (C.I.) for the population and the confirmation experiments of 5 parts is calculated as:

(a) For population:

$$CI_{pop} = \pm\sqrt{\frac{F_{\alpha(fi\ \&\ fe)} \times V_e}{n_{eff}}} \qquad (2)$$

(b) For confirmation experiment:

$$CI_{CE} = \pm\sqrt{F_{\alpha(fi\ \&\ fe)} \times V_e \times \frac{1}{neff} + \frac{1}{r}} \qquad (3)$$

Where,

$$n_{eff.} = \frac{= \text{ Total number of observations}}{1+ (\text{Total degree of freedom associated with items used in estimating } \mu)}$$

By substituting the following: $F_{0.99\ (2\&\ 8)} = 99.4$; $V_e = 34.76$; $n_{eff.} = 9/5$; $r = 5$, Confidence Interval. is calculated to be ± 5.5 MPa Therefore the 99% confidence interval should be given by

$$463\ \text{MPa.} < \mu_{CE} < 474\ \text{MPa.} \qquad (4)$$

1. Confirmation Experiments

The validation experiments were conducted on optimum parameters i.e. A_2 (Welding Current. of 200 Amp.), B_3 (current frequency 400 kHz), C_1 (200kN Roll pressure) and D_1 (Welding speed 100feet/min) and five number of pipe were welded on the same set up. The samples were evaluated following the same criteria used for the original experiments.

The Tensile Strengths of five number of pipe specimens were found and are as shown in Table VII.

Table VII Verification Trial (Tensile Strength)

S.No..	Tensile Strength	S/N ratio
1	469	53.42
2	463	53.31
3	472	53.48
4	468	53.40
5	474	53.52
Avg.	469.2 MPa	53.43 dB

The value of average Tensile Strength (469.2 MPa) and signal ratio (53.43 dB) is well within the confidence interval range of validation experiments as per equation 4 defined earlier. Thus the selected optimum parameters are validated to be used for further production.

The expected improvement in Tensile strength has been found to be 11.8%.

IV. Conclusions

The study investigated high frequency seam welding parameters by taguchi method for Tensile strength of electric resistance welding of pipes of 15 mm diameter of Class B. The results are summarized as follows:

1. The optimal parameter combination of high frequency seam welding process for best Tensile strength corresponded to A_2 (Welding Current of 200 Amp), B_3 (current frequency 400 kHz), C_1 (200kN Roll pressure) and D_1 (Welding speed 100feet/min). Therefore, $A_2B_3C_1D_1$ is recommended for achieving best Tensile strength for electric resistance welding of pipes of 15 mm diameter of Class B.

2. The predicted optimal range for the confirmation experiment of five experiments is given by 463 MPa < μ_{CE} < 474 MPa.

3. All the process parameters were found to affect the average Tensile strength and variability.

4. The welding speed was contributing the most (46.16%) of variability of process followed by Roll pressure (22.15%), and Welding current (21.06%). The current frequency is least contributing (10.63%).

5. The confirmation experiment was conducted to validate the experimental work done. It showed expected improvement of 11.8%.in average Tensile strength of the pipes.

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