Investigations for Statistically Controlled TIG Welding Solution of 304 SS

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Abstract - The purpose of the present investigations is to study statistically controlled solution (from sensitization point of view) for 304 stainless steel (ss) joints using tungsten inert gas welding (tig) process. starting from the parametric optimization of tig welding process parameters (based upon taguchi design), welded joints were produced for functional validation. the output parameters selected for controlling the sensitization were selected as hardness and tensile strength of welded joints. the results are supported by sem analysis. further the study suggests that the tig welding process was found to be under statistical control (at optimized settings suggested by taguchi design) as regard to sensitization of welded joint is concerned.

Keywords: TIG welding, statistically controlled, sensitization, hardness, tensile strength.

I. INTRODUCTION

In TIG welding process workpiece are joined by the heat obtained from an electric arc struck between a non-consumable electrode and work piece in the presence of inert gas atmosphere [Natrajan and Kumaresh, 2006]. For industrial applications 304SS is mostly welded by this process and the joints prepared are susceptible to a phenomenon known as sensitization at elevated temperatures between 400°C -850°C [Mousavi and Misersmaeilli, 2008, Qinglei et al., 2010]. Sensitization is a major problem in welding of S.S that affects the alloys durability [Yan et al., 2010]. The literature review reveals that lot of work has been reported on the optimization of physical/mechanical properties of welded joints and reduction of sensitization during welding of 304 S.S by different techniques [Kumar and Shahi, 2011, Traidia and Roger, 2011, Yuri et al., 2000]. But hitherto no work has been reported on statistically controlled TIG welding solution of 304SS from sensitization point of view. So, in the present work effort has been made to investigate statistically controlled TIG welding solution of 304 SS (based upon Taguchi model) with focus on sensitization. Table1 and 2 respectively shows chemical composition of workpiece material and input parameters (namely: welding current, pulse frequency and gas flow (GF) rate and their levels based upon Taguchi L9 OA) for investigation of sensitization phenomenon in 304 S.S. The output parameters set for study are hardness and tensile strength.

TABLE 1 CHEMICAL COMPOSITION OF 304 S.S (%WT)

Element	**C**	**Mn**	**Si**	**Cr**	**Ni**	**Mo**
SS	0.035	1.08	0.388	18.47	9	0.561

TABLE 2 INPUT PARAMETER AND THEIR LEVELS

S. No.	**Current (A)**	**Pulse frequency(Hz)**	**GF rate (lt/min)**
1	40	3	5
2	40	5	8
3	40	7	10
4	60	3	8
5	60	5	10
6	60	7	5
7	80	3	10
8	80	5	5
9	80	7	8

II. EXPERIMENTATION

Based upon Table2, Table3 shows observations (with three repetitions) for hardness (H1, H2 and H3) and tensile strength (T1, T2 and T3) of welded joints with TIG welding process.

TABLE 3 OBSERVATIONS FOR HARDNESS AND TENSILE STRENGTH OF WELDED JOINTS

Hardness (HRC)			**Tensile strength ×10^3kgf**		
H1	H2	H3	T1	T2	T3
60	59	57	5.8	5.4	5.32
70	68	66	5.8	5.62	5.75
82	81	80	6.1	5.84	5.9
63	60	62	5.9	5.82	5.7
79	77	76	6.8	6.72	6.65
76	74	72	5.35	5.22	5.3
81	80	78	6.92	6.75	6.9
83	80	82	8.0	7.9	7.85
83	81	79	7.1	6.8	6.9

Further based upon Table 2 and 3, Table 4 shows signal to noise (S/N) ratios for hardness and tensile strength. The analysis has been made on the basis of maximum the better type case. Now based upon Table 4, Figure1 shows percentage contribution of input parameters for outputs.

TABLE 4 S/N RATIOS FOR OUTPUT PARAMETERS

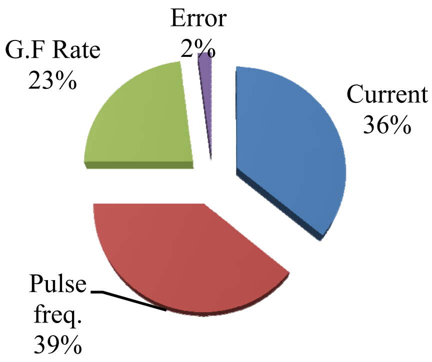
S/N for Hardness (HRC)	S/N for Tensile strength ×10^3kgf
35.36187	74.70595
36.64266	75.15067
38.16838	75.48098
35.79562	75.27592
37.76397	76.55061
37.37829	74.46777
38.02231	76.72065
38.23783	77.97004
38.1996	76.81466

As observed from Figure 1 contribution of input parameters for hardness and tensile strength of welded joints is: current (36% and 68%), pulse frequency (39% and 18%) and GF rate (23% and 5%) respectively.

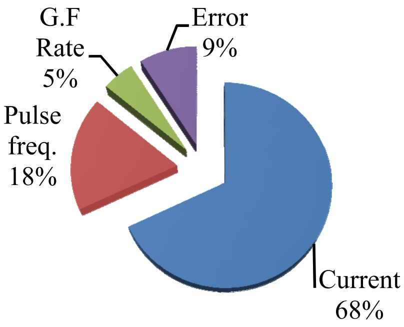
The optimized settings of input parameters for welded joints are as follows:

- For maximum hardness: current (80A), pulse freq (7Hz) and gas flow rate (10ltr/min)
- For maximum tensile strength: current (80A), Pulse freq.(5Hz),G.F Rate (10ltr/min)

The confirmatory experiments were conducted at these optimized settings and percentage improvement in hardness and tensile strength is 6% and 0.6% respectively. Figure 2 shows SEM images of welded joints at optimized settings.

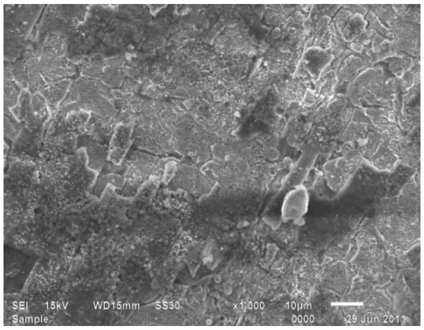


a.) Hardness of welds

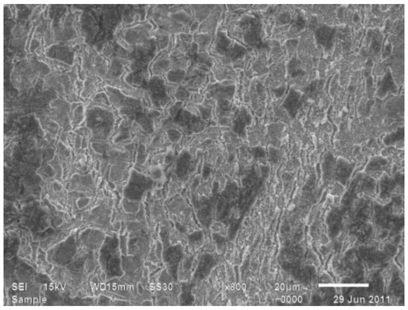


b.) Tensile strength of welds

Fig. 1 Percentage contribution of input parameters for outputs



SEM of work piece joint obtained at optimized settings for hardness (88HRC)



SEM of work piece joint obtained at optimized settings for tensile strength (8.05×10^3kgf)

Fig. 2 SEM of welded joints at optimized settings

As observed from Figure 2 sensitization has occurred over the surface on welded joints but level of sensitization is less at optimized settings (as per Taguchi design) as evidenced from improved hardness and tensile strength.

III. ANALYSIS AND DISCUSSION

Further based upon optimized settings suggested by Taguchi design, to understand whether the process is statistically controlled (06+06=12) welded joint samples were prepared for maximum hardness (with input parameter setting as current 80A, pulse freq 7Hz and GF rate 10ltr/min) and for maximum tensile strength at current 80A, pulse freq.5Hz,G.F rate 10ltr/min. On measurement of hardness and tensile strength observations are shown in Table5 and 6 respectively. Based upon Table5 and 6, Figure3 and 4 respectively shows run-chart of the observed values of hardness and tensile strength.

Now if the mean and standard of population that is having normal distribution is μ and σ respectively then for variable data X the standard normal deviate Z is defined as:

$$Z = \frac{(\mathrm{Xi} - \mu)}{\sigma}$$

Where X_i is the variable data obtained, μ is the mean of data and σ is the standard deviation [Singh and Singh, 2009, Singh, 2012].

TABLE 5 OBSERVED VALUE OF HARDNESS (HRC) AT OPTIMIZED SETTINGS

S. No.	Observation	Above or Below Mean	Up or Down
1	84.69	B	
2	84.75	B	U
3	84.79	B	U
4	84.86	A	U
5	84.84	A	D
6	84.89	A	U
MEAN	84.803	$E_{AB=1}$	$E_{UD=2}$

TABLE 6 OBSERVED VALUE OF TENSILE TRENGTH×10^3KGF AT OPTIMIZED SETTINGS

S.No.	OBSERVATION	ABOVE OR BELOW MEAN	UP OR DOWN
1	7.6	B	
2	7.59	B	D
3	7.67	B	U
4	7.74	A	U
5	7.83	A	U
6	7.819	A	D
MEAN	7.708167	$E_{AB=1}$	$E_{UD=2}$

A=above the mean, B=below the mean, U=Up from previous reading, D=Down from previous reading

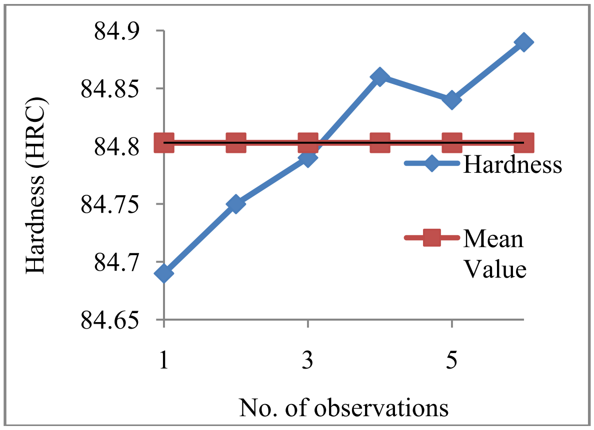


Fig. 3 Run-chart of the observed values of hardness

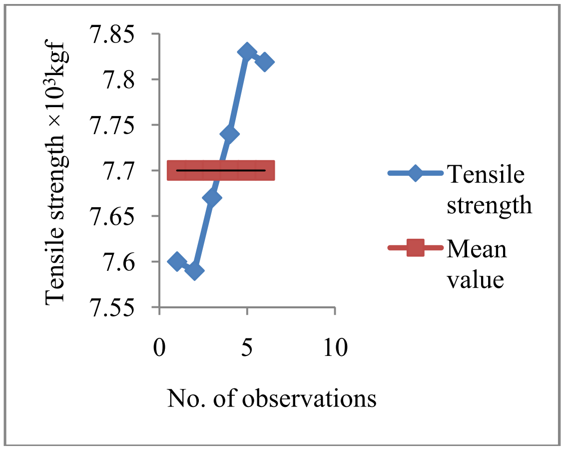


Fig. 4 Run-chart of the observed values of tensile strength

Calculation for Z (standard normal deviate) above and below:

$$E\,(\text{run})_{AB} = \left(\frac{N}{2} + 1\right)$$

Where N is the number of observations and E $(\text{run})_{AB}$ is the expected number of run above and below

$$E\,(\text{run})_{AB} = \left(\frac{6}{2} + 1\right) = 4$$

$$\sigma_{AB} = \sqrt{(N - \tfrac{1}{4})}$$

Where σ_{AB} is the standard deviation of above and below

$$\sigma_{AB} = \sqrt{(6 - \tfrac{1}{4})} = 1.118$$

$$Z_{AB} = \{RUN_{AB} - E(\text{run})_{AB}\} / \sigma_{AB}$$

Where RUN_{AB} is the actual number of run obtained above and below

$$Z_{AB} = \frac{(1-4)}{1.118} = -2.6834$$

P_{AB} = NORMSDIST(Z) when the value of Z is negative (using microsoft excel software)

P = 0.003645

For up and down calculations:

$$E\,(\text{run})_{UD} = 2N - \frac{1}{3}$$

Where N is the number of observations and E $(\text{run})_{UD}$ is the expected number of run up and down.

$$E\,(\text{run})_{UD} = 2 \times 6 - \frac{1}{3} = 3.667$$

$$\sigma_{UD} = \sqrt{(16N - 29/90)}$$

Where σ_{UD} is the standard deviation for up and down

$$\sigma_{UD} = \sqrt{(16\,X\,6 - 29/90)}$$

$$\sigma_{UD} = 0.8628$$

$$Z_{UD} = \{RUN_{UD} - E(\text{run})_{UD}\} / \sigma_{UD}$$

$$Z_{UD} = (2-3.667)/0.8628$$

$$Z_{UD} = -1.5840$$

P_{UD} = NORMSDIST(Z) when the value of z is negative (using microsoft formula)

P_{UD} = 0.056597

Normally decision making is done with certain margin of error ‘α’ & taken as equal to 0.005 that is there can 5% chances in arriving at wrong conclusion.

Decision making:

If $P_{AB} < \alpha$ OR /& $P_{UD} < \alpha$ then non-random pattern exist.

In the present case $P_{AB} < \alpha$ indicates existence of non random pattern

Now exercise of predicting various statistical or drawing conclusions should not be undertaken unless the normality of distribution has been verified. Even if one has a large data, superimposing of normal curve on the histogram it is more difficult task than it to be imagined. For histogram one require minimum of 50 observations, however more the better and for assessing whether the underlying distribution is normal or not becomes more difficult when the number of observations is fewer. For cumulative probability plot (Pi):

Pi = (S.N-0.5)/N

Where S.N is serial number of data observation arranged in ascending order, N is total number of observations in the data set. If the standard normal deviate follows normal distribution that has mean μ =0 and standard deviation σ =1, then:

$$f(Z) = 1/\sqrt{(2\Pi\, e^{\frac{z^2}{2}})}$$

The equation above follows normal probability curve and any date close to it also follows normal probability curve. The values of standard normal deviate were calculated using cumulative probability and dimensional values were arranged in ascending order as shown in Table7.

TABLE 7 STANDARD NORMAL DEVIATE AND OUTER DIAMETER IN ASCENDING ORDER

S. No.	Pi (Cumulative Probability)	Std. Nor. Deviate Z	Observed hardness (HRC)	Observed tensile strength $\times 10^3$kgf
1	0.08333	-1.382	84.69	7.6
2	0.25	-0.674	84.75	7.59
3	0.416667	-0.210	84.79	7.67
4	0.58333	0.210	84.86	7.74
5	0.75	0.674	84.84	7.83
6	0.91667	1.3829	84.89	7.819

Based on Table7 normal probability curve was drawn to predict the probability as shown in Figure 5 and 6. As observed in Figure 5 and 6, the aforesaid data follows non random pattern and is under normal probability curve. So, there are very strong chances that the process is under statistical control however X-bar chart and R-bar chart cannot be drawn due to less number of observational data. The co-efficient of determination (R^2) having value 0.91 and 0.86 states that the hardness and tensile strength observational values lies in normal probability curve.

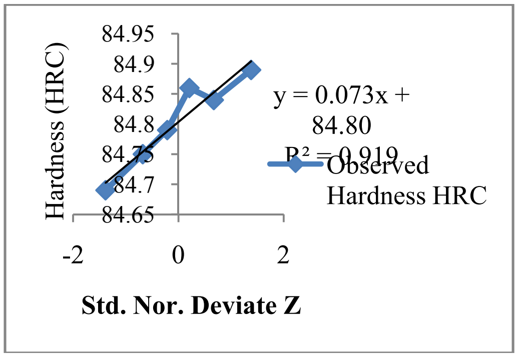


Fig. 5 Normal probability curve (for hardness at optimized settings)

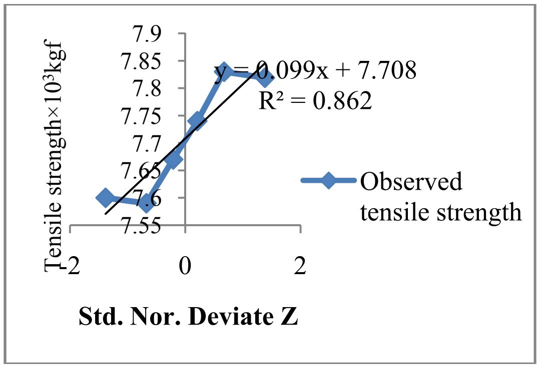


Fig. 6 Normal probability curve (for tensile strenth at optimized settings)

IV. CONCLUSIONS

On the basis of experimental observations made on welded joints of 304SS during TIG welding following conclusions can be drawn.

The results of study highlights the statistically controlled solution for hardness and tensile strength of weld joints are concerned (within the range of selected input parameters) as regards to sensitization in TIG welding process. The adopted procedure is better for proof of concept. Strong possibilities are observed for the process under statistical control at optimized settings suggested by Taguchi design. Hence the process can be used for mass production at proposed settings with controlled sensitization.

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