Optimization Of Tig Welding Process Parameters For Welding Of Dissimilar Metals Taking Ss-304 As Base Metal

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Abstract **- In the industries, dissimilar metal joints are mostly used in the form of a structural material for different manufacturing applications because it yields high strength and corrosion resistance. However, the joining process is difficult as both the materials have different mechanical and chemical properties; optimum use of the process parameters becomes utterly important. Ultimate tensile strength was used as major parameter to perform the optimization study. Mechanical joints obtained were also compared among each other on the basis of ultimate tensile strength and hardness tests. Taguchi method was used primarily for optimising the process parameters involved in welding of dissimilar joints. Mechanical joints obtained in the form of stainless steel- mild steel, stainless steel- carbon steel and stainless steel-stainless steel were used for the study. Analysis of variance (ANOVA) method was also used for performing the optimization study and study performed by Taguchi method was validated by using ANOVA method. For welding process, gas welding process was used to create butt joint. In this project two different category of steels namely carbon steel and mild steel has been welded with stainless steel as a butt joint. Similarly, stainless steel was also welded with stainless steel of same thickness. Plate thickness was considered to be 5 mm for all the materials. All the samples created were cut into test samples according to the dimensions of the ASTM standards. Moreover, the samples were tested in universal testing machine (UTM) and vicker hardness machine in order to obtaining their tensile strength and hardness values. Current, Gas flow density and filler rod thickness were some of the most important process parameters and they were found out to affect the performance of the joint formed by dissimilar metals. Keywords: TIG Welding, Stainless Steel, ANOVA, Taguchi Method, UTM.**

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I. INTRODUCTION

TIG welding process also known as GTAW was developed during Second World War. Since its invention, welding of difficult to weld materials such as, aluminium, magnesium etc. became easier. Now-a-days with the development TIG welding process, the use of TIG has spread to a variety of metals like, stainless steel, mild steel and high tensile steels, Al alloy, Titanium alloy and many more. In the TIG welding process, the arc is formed between a tungsten electrode and the work piece in an inert atmosphere. For high quality welding, the small intense arc provided by the electrode is ideal. During TIG welding process, no input heat balance is required because of the use of non-consumable electrode. Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length as per requirement.

In dissimilar welding, for joining between two different materials, any type of welding process can be used as per suitability. In previous studies, researchers used different types of welding processes including Tungstun inert gas welding (TIG), gas tungsten arc welding (GTAW), submerged arc welding (SAW), pressure welding, fusion welding, explosion welding, friction welding, diffusion welding, brazing, and soldering. The studies explored that among the other welding processes; TIG is proven as a resourceful process that is extensively used in producing variety of dissimilar joints.

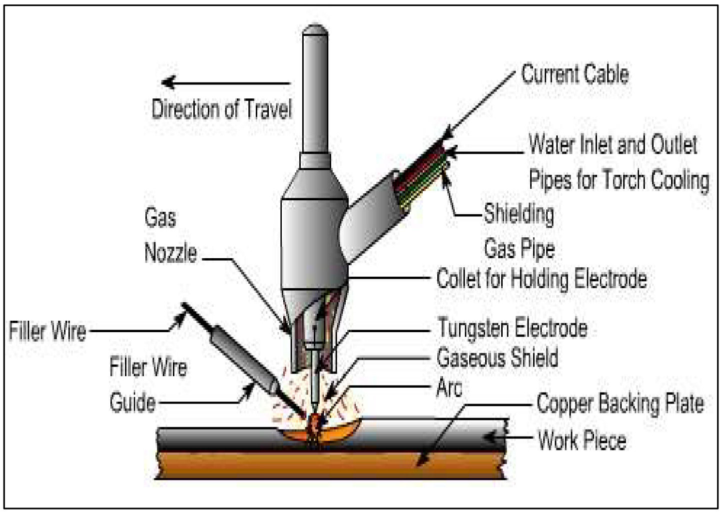

Fig. 1: Schematic Diagram of TIG Welding

II. LITERATURE REVIEW

Kohyama et al. [1] in their study investigated the Micro structural changes in welded joints of grade 316 SS. During study, effect of three different parameters was studied i.e. Current, Voltage, Flow Rate. The response was identified in conjunction with Heat affected zone (HAZ).

Durgutlu [2] studied the effect of hydrogen in argon as a shielding gas during TIG welding process. The work piece material used for the study was stainless steel of different grades. The study was done by varying percentage combination of argon with hydrogen. The study concluded that, increase in hydrogen content in the shielding gas reduces the mechanical properties.

Liu et al. [3] in their study for TIG welding, worked for microstructure characteristics on welded joint. The work piece material chosen was of Mg/Al dissimilar materials having input process parameters as welding velocity and wire feed velocity.

Esme et al. [4] in their study worked for the optimization of resistance spot welding. The material used for the experimentation was SAE 1010 steel sheets with different thicknesses. The response parameter chosen for the study was tensile shear strength. ANOVA and S/N ratio analysis was used to optimize the results.

Gadeawar et al. [5] in their study, investigated weld characteristics for a single pass TIG welding to identify the effect of process parameters such as weld current, gas flow and work piece thickness on the response parameter i.e. Bead geometry of the welded joint. The material used for the study was SS304. They observed the effect of input process parameters on the response parameters experimentally.

Mishra et al. [6] studied about TIG and MIG welding processes for welding of dissimilar joints of mild steel & stainless steel. The study was majorly focused at investigation of the tensile strength and dilution of welded joints. Through study, it was observed that while welding with MIG during dissimilar joints, the cracks were developed while the same joints can be achieved easily using TIG welding process.

Sathish et al. [7] conducted their study for optimization of dissimilar pipe joints using TIG welding. The response parameter chosen was ultimate tensile strength. The study reported that the Gas flow rate is the highly contributing factor having greater influence on the tensile strength followed by current and bevel angle. Results also showed that at higher or lower heat input reduced tensile strength is achieved. Thus, an intermediate value of heat input gave the highest tensile strength.

Patil et al. [8] in their study, worked for experimental investigation for the optimization of process parameters for TIG welding. The study was focused on enhancing welding penetration in activated flux coated TIG welding. During study, they investigated the optimum parameters for enhancing weld penetration for AISI-304 steel plate of dimensions 100mm*70mm*5mm.

Connor [9] in his book stated that controlling of weld-bead shape is highly needed because all the mechanical properties of welds are affected by the weld-bead shape. Hence, proper selection of process parameters should be done.

Raveendra and Parmar [10] also worked for weld bead geometry using mathematical modeling technique. During study they used fractional factorial technique to predict the weld-bead geometry. The base metal chosen for experimentation was a thick low-carbon structural steel plate. The input process parameters considered were arc voltage, welding current, welding speed, gun angle and nozzle to plate distance.

Kim et al. [11] used factorial design of experiment approach to correlate the TIG process parameters (such as voltage, welding speed and arc current) to three responses parameters (bead width, bead height and penetration). The study was focused on optimizing the response parameters. The material used for experimentation was plates of AS 1204 mild steel. Electrode wire having the same mechanical and physical properties of the base metal was used. The study revealed that all process parameters prejudiced the responses and the models developed are able to predict the responses with accuracy range of 0–25%.

Kurt and Samur [12] observed the microstructure and mechanical properties of material during TIG welding process. The material used for the study was 304 SS with 308 SS rod as filler metal. The study reported ultimate tensile strength of 1800 MPa, yield strength of 75 MPa, breaking strength of 150 MPa, and percentage elongation as 25% of welded joints. Optical microscopy (OM) and stereo microscopy (SM) techniques were adopted for studying the microstructure of base metal, HAZ, and weld metal.

Durgutlu [13] studied about the effect of H_2 in Ar as shielding gas for TIG welding. The material used for the study was 316L SS. The experimentations were done with varying percentage of H2-Ar mixture. The study reported that with increase in H2 content the mean grain size in weld metal is also increased along with its width and weld penetration depth.

Nayee and Badheka [14] investigated the effect of current, welding speed, joint gap and electrode diameter on weld dimension of 6 mm between the carbon steel (CS) and SS. They compared the results with activated TIG and reported that activated TIG welded joint has better mechanical properties and joint elongation than normal TIG welded joints.

III. MATERIALS AND METHODS

Present study deals with 'Dissimilar Welding' as it is most widely adopted method of welding to join two dissimilar materials and has found its use extensively in, nuclear reactors, petrochemical, power generation, electronic and chemical industries due to environmental concerns, energy saving, high performance, cost saving and many more. However, effective welding of dissimilar metals has represented a major challenge due to difference in thermal, mechanical and chemical properties of the materials to be joined under a common welding condition. This causes a steep gradient of the mechanical properties along the weld. A variety of problems come up in dissimilar welding like cracking, large weld residual stresses, migration of atoms during welding causing stress concentration on one side of the weld, compressive and tensile stresses, stress corrosion cracking etc. To overcome these causes, it is required to analyze the effect of welding process parameters effectively.

Thus, for accomplishment of the present work, the experimental setup is needed to select which involves a set of machineries, which are used for completion of the work along with the work piece material. The requirements of experimental setup are as follows:

- TIG welding machine
- Sample Work piece
- Non-consumable Electrode
- Filler rods
- Universal Testing Machine (UTM)
- Vicker hardness tester

The basic components required are also represented by line diagram of TIG welding setup as shown in figure 3.1.

Fig. 2 TIG Welding Machine

Three different work piece materials have been selected to accomplish present study. One material is chosen as a base material while other two are chosen for dissimilar welding purpose. This is highly trending in industries to make dissimilar welding joints of austenitic stainless steel with ferritic steel. These types of joints are highly adopted in various industries, such as, power generation or petrochemical industries [industries related to construction of vessel or heat exchanger and many more.

Following three materials are used for present work:

1. Stainless Steel (SS-304)
2. Carbon Steel (A-220)
3. Mild Steel (A-36)

In the present study, Stainless steel (SS) is considered as the base material because this is the austenitic grade of steel. This is one of the most abundant and easily available steel used for manufacturing of structures and machines due to its appropriately high strength and relatively lower cost. Other two materials chosen are carbon steel and mild steel, which are the ferritic grade of steel and extensively used to weld with austenitic grade of steel.

Table 1 Material Combination for Sample Preparation

S. N.	Sample	Material Combinations
1	Test Sample-1	Stainless steel (SS-304)+ Stainless steel (SS-304)
2	Test Sample-2	Stainless steel (SS-304)+ Carbon steel (A-210)
3	Test Sample-3	Stainless steel (SS-304)+ Mild steel (A-36)

Taguchi Method Taguchi method generally takes the help of a loss function in order to analyses the quality characteristics of a method. These Loss function values are further diverted into a signal to noise (S/N) ratio. 'Signal' is used as a representation of desirable value (mean) for output characteristic while 'noise' stands for representation of the undesirable value for the output characteristic. Noise parameters are mostly described as the constrains of the analysis. It is critically acclaimed upon that performance characteristics were characterized on three categories based on S/N ratio i.e., the smaller the better, and nominal the best and the larger the better. The equations indicating this category are as shown in equation 1, 2 & 3 respectively. It was keenly observed that S/N ratio is computed on process parameters at each level depending upon the S/N ratio analysis. The optimal level of the process parameters is the level having highest S/N ratio.

Smaller is better

$$\frac{S}{N}\ ratio = -10\log\sum_{i=1}^{n} y^2 \qquad (1)$$

Larger is better

$$\frac{S}{N}\ ratio = -10\log\sum_{i=1}^{n}\frac{1}{y^2} \qquad (2)$$

Nominal the best

$$\frac{S}{N}\ ratio = 10\log\sum_{i=1}^{n}\frac{y2}{s^2} \qquad (3)$$

Where:

η = Signal to Noise ratio
n = No. of repetitions of the experiment
y_i = Measured value of the quality characteristics
s = Variance

***Experimental Parameters and Responses**

Although there are number of input parameters and response parameters which can be considered for the study purpose. The present experiments involve following variables which are of utmost importance:

- Independent variables
  - i. Current (Amp.)
  - ii. Gas flow rate (mm^3/min)
  - iii. Filler rod thickness (mm)

- Response parameters
  - i. Ultimate Tensile Strength(UTS) (MP)
  - ii. Hardness(HV)

Each selected parameters are having four levels as shown in table 2.

Table 2 Factors and their Levels

Factor symbol	Input Process Parameters	Level 1	Level 2	Level 3	Level 4
A	Current (Amp.)	90	100	110	120
B	Gas flow rate (mm^3/min)	12	14	16	18
C	Filler rod thickness (mm)	1.5	2	2.5	3

IV. RESULTS

1. EXPERIMENTATION AND ANALYSIS FOR TEST SAMPLE 1 (SS & SS JOINT)

The task of obtaining signal-to-noise ratios (S/N ratios) for different response parameters is being done with the help of available statistical software. Their respective values for UTS and hardness are as for further analysis. For obtaining S/N values, in case UTS and hardness, 'Larger is better' approach was adopted.

Rank Table, ANOVA and Main Effect Plot Analysis for UTS

Furthermore, for detailed analysis of the data collected, after calculating S/N ratio, Rank table is generated using Taguchi methodology in Minitab Software for UTS as shown in Table 3. At the same time, main effect plot is also generated for the UTS as shown in figure 3.

Table 3 Rank Table for S/N with Welding Parameters for UTS (Test Sample 1)

Level	Current	Gas flow rate	Filler rod thickness
1	47.08	47.18	47.18
2	47.19	47.14	47.23
3	47.27	47.21	47.16
4	47.24	47.26	47.22
Delta	0.19	0.12	0.06
Rank	1	2	3

In order to analyze the above observations, Analysis of variance (ANOVA) was also performed for the observed data. Firstly, the ANOVA was done for UTS as shown in Table 4. While conducting analysis, UTS is taken as the response parameter while current, gas flow rate and filler rod thickness are taken as controlled factors. The complete task was accomplished using MiniTab-18 statistical software.

Table 4 ANOVA for UTS (Test Sample 1)

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value

Current	3	37.92	19.507	6.502	5.33	0.040
Gas flow rate	3	28.06	14.432	4.811	3.95	0.072
Filler rod thickness	3	19.80	10.183	3.394	2.78	0.132
Error	6	14.22	7.315	1.219		
Total	15	100	51.438			
R-Sq- 85.78%						

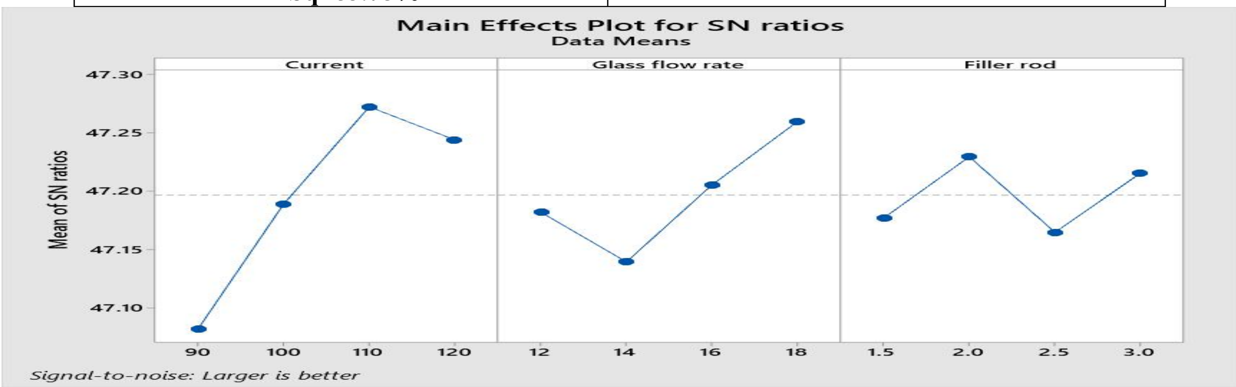

Fig. 3 Main Effect Plot for S/N Ratios Corresponding to UTS (Sample 1)

Rank Table, ANOVA and Main Effect Plot Analysis for Hardness

Further, the same analysis task was also performed for the second response parameter i.e. hardness of the welded joint. The same analysis values for Rank table and ANOVA is shown in table 5 and 6 respectively. The main effect plot for hardness is shown in figure 4.

Table 5 Rank Table for S/N with Welding Parameters for Hardness (Test Sample 1)

Level	Current	Gas flow rate	Filler rod thickness
1	52.07	52.03	52.05
2	52.08	52.04	51.96
3	52.04	52.03	52.09
4	51.97	52.05	52.05
Delta	0.11	0.02	0.13
Rank	**2**	**3**	**1**

Table 6 ANOVA for Hardness (Test Sample 1)

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	3	19.96	57.546	19.1819	0.76	0.558
Gas flow rate	3	0.98	2.821	0.9405	0.04	0.990
Filler rod thickness	3	26.23	75.608	25.2027	0.99	0.457
Error	6	52.83	152.309	25.3848		
Total	15	100.00	288.284			

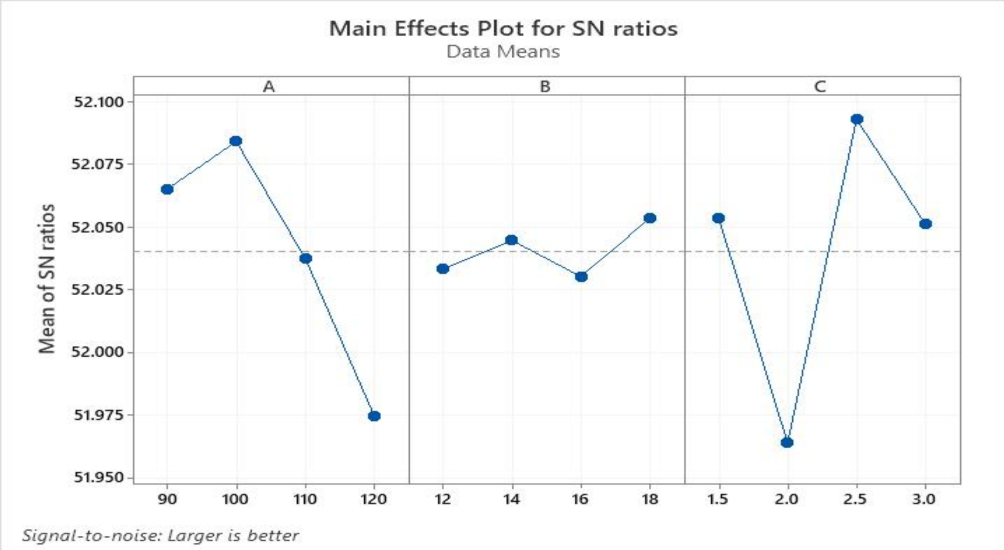

Fig. 4 Main Effect Plot for S/N Ratios Corresponding to Hardness (Sample 1)

II EXPERIMENTATION AND ANALYSIS FOR TEST SAMPLE 2 (SS & CS JOINT)

The same methodology as adopted for test sample 1 is also repeated for test sample 2, in which dissimilar welding was done between SS and CS taking SS as a base material.

\Rank Table, ANOVA and Main Effect Plot Analysis for UTS

Furthermore, Rank Table and ANOVA tables are generated for both the responses as shown in Table 7 and 8 for UTS and Table 9 and 10 for Hardness. The main effect plots are also generated for UTS and Hardness as shown in figure 5and 6 respectively.

Table 7 Rank Table for S/N with Welding Parameters for UTS (Test Sample 2)

Level	Current	Gas flow rate	Filler rod thickness
1	55.47	55.47	55.48
2	55.49	55.48	55.49
3	55.48	55.50	55.48
4	55.51	55.49	55.50
Delta	0.04	0.03	0.02
Rank	**1**	**2**	**3**

Table 8 ANOVA for UTS (Test Sample 2)

Source	DF	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Current	3	48.18	14.683	4.8942	15.70	0.003
Gas flow rate	3	31.34	9.553	3.1842	10.22	0.009
Filler rod thickness	3	14.34	4.372	1.4575	4.68	0.052
Error	6	6.14	1.870	0.3117		
Total	15	100	30.478			
R-Sq- 93.86%						

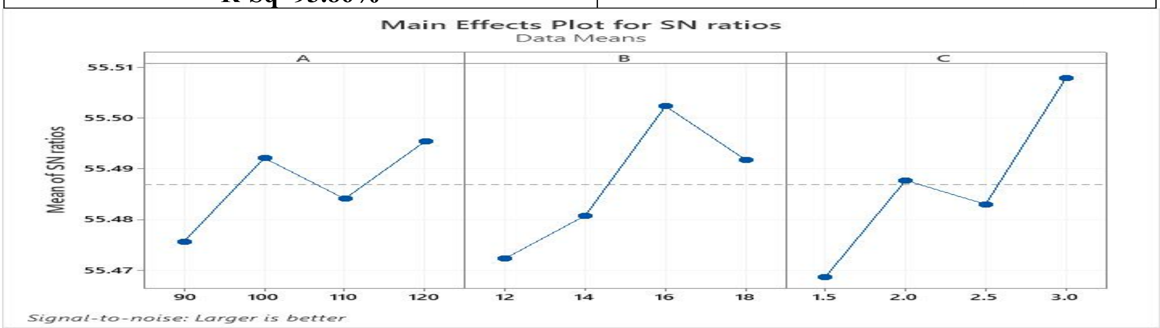

Fig. 5 Main Effect Plot for S/N Ratios Corresponding to UTS (Sample 2)

Rank Table, ANOVA and Main Effect Plot Analysis for Hardness

Table 9 Rank Table for S/N with Welding Parameters for Hardness (Test Sample 2)

Level	Current	Gas flow rate	Filler rod thickness
1	53.98	53.99	53.97
2	54.01	53.99	53.99
3	54.00	54.02	54.02

4	53.99	53.99	54.00
Delta	0.03	0.03	0.05
Rank	**2**	**3**	**1**

Table 10 ANOVA for Hardness (Test Sample 2)

Source	DF	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Current	3	7.01	6.008	2.003	0.22	0.881
Gas flow rate	3	7.77	6.661	2.220	0.24	0.865
Filler rod thickness	3	20.60	17.668	5.889	0.64	0.618
Error	6	64.62	55.410	9.235		
Total	15	100.00	85.747			

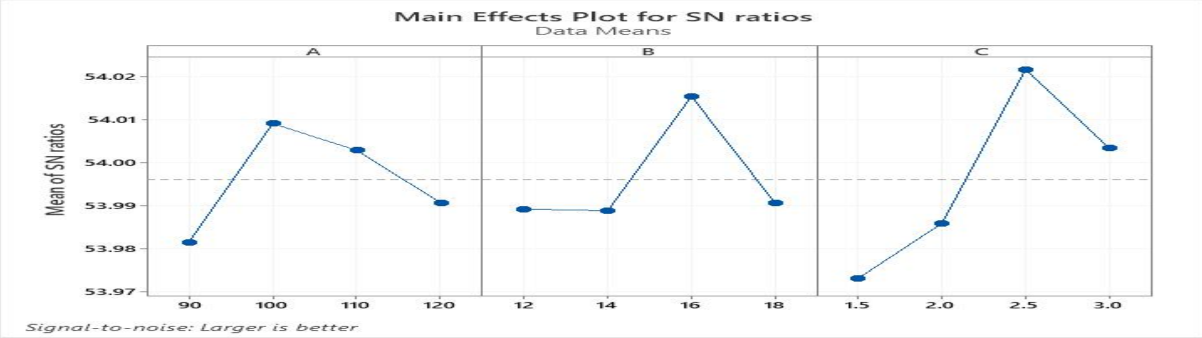

Fig. 6 Main Effect Plot for S/N Ratios Corresponding to Hardness (Sample 2)

III EXPERIMENTATION AND ANALYSIS FOR TEST SAMPLE 3 (SS & MS JOINT)

The same methodology as adopted for test sample 1 & 2 is also repeated for test sample 3, in which dissimilar welding was done between SS and MS taking SS as a base material. In the similar manner, data collection task was performed as per DOE approach and their respective data are collected as shown in and their respective values of S/N ratios are stored in table 11.

Rank Table, ANOVA and Main Effect Plot Analysis for UTS

Rank Table and ANOVA tables are generated for both the responses as shown in Table 11 and 412 for UTS and Table 13 and 14 for Hardness. The main effect plots are also generated for UTS and Hardness as shown in figure 7 and 8 respectively

Table 11 Rank Table for S/N with Welding Parameters for UTS (Test Sample 3)

Level	Current	Gas flow rate	Filler rod thickness
1	47.08	47.18	47.18
2	47.19	47.14	47.23
3	47.27	47.21	47.16
4	47.24	47.26	47.22
Delta	0.19	0.12	0.06
Rank	**1**	**2**	**3**

Table 12 ANOVA for UTS (Test Sample 3)

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	3	59.15	58.407	19.469	10.14	0.009
Gas flow rate	3	21.30	21.032	7.011	3.65	0.083
Filler rod thickness	3	7.88	7.783	2.594	1.35	0.344
Error	6	11.66	11.515	1.919		
Total	15	100.00	98.737			
R-Sq- 88.34 %						

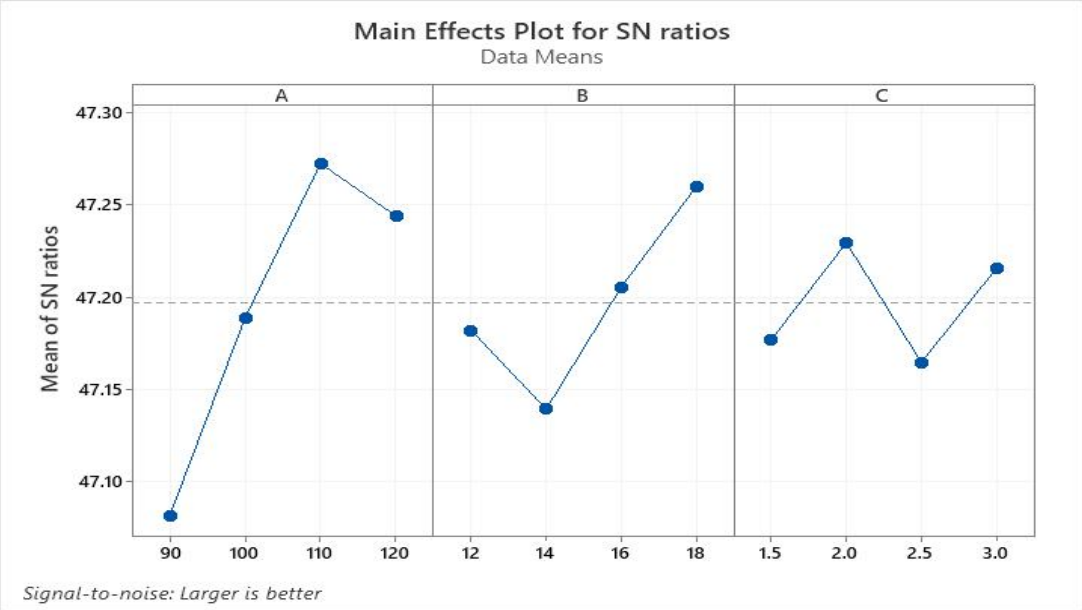

Fig. 7 Main Effect Plot for S/N Ratios Corresponding to UTS (Sample 3)

Rank Table, ANOVA and Main Effect Plot Analysis for Hardness

Table 13 Rank Table for S/N with Welding Parameters for Hardness (Test Sample 3)

Level	Current	Gas flow rate	Filler rod thickness
1	51.17	51.19	51.22
2	51.22	51.21	51.21
3	51.18	51.21	51.17
4	51.22	51.18	51.21
Delta	0.05	0.03	0.05
Rank	**1**	**3**	**2**

Table 14 ANOVA for Hardness (Test Sample 3)

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	3	21.94	14.032	4.677	0.76	0.557
Gas flow rate	3	5.81	3.717	1.239	0.20	0.892
Filler rod thickness	3	14.30	9.144	3.048	0.49	0.700
Error	6	57.95	37.063	6.177		
Total	15	100.00	63.956			

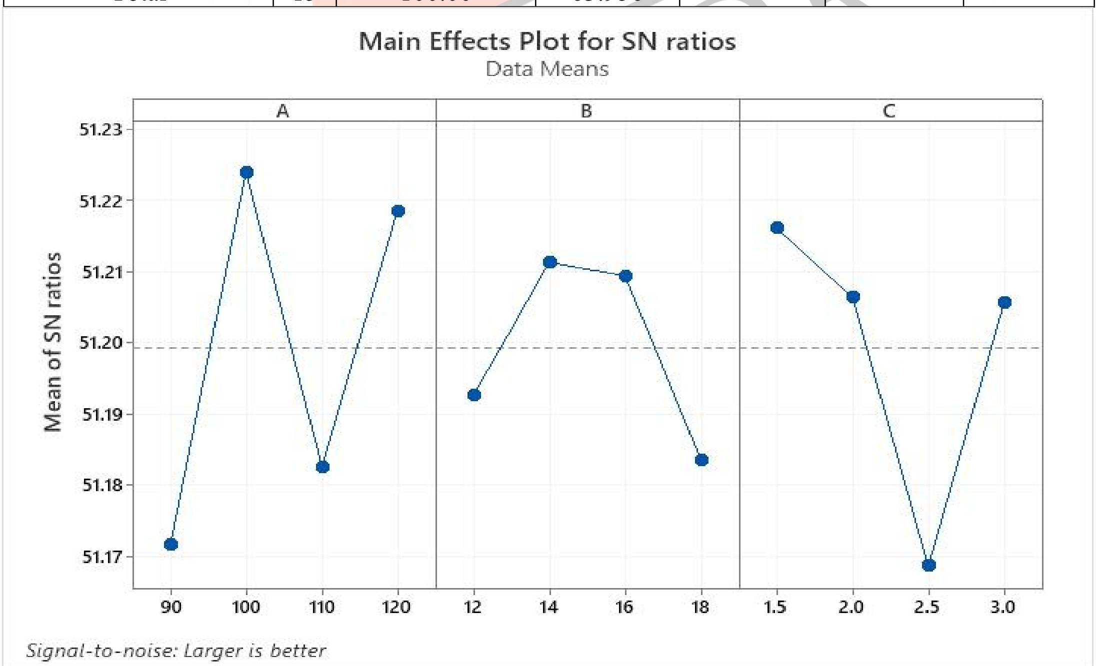

Fig. 8 Main Effect Plot for S/N Ratios Corresponding to Hardness (Sample 3)

IV. CONCLUSIONS

The present study is focused on attaining optimized values of ultimate tensile strength (UTS) and vicker's hardness during dissimilar welding for three different samples as discussed in chapter 3. Three varying or controlled parameters have been taken in account i.e. current, gas flow rate and filler rod thickness and two response parameters are considered i.e. UTS and hardness. Design of experiment approach has been adopted for completion of the work. Taguchi and ANOVA approach has been used to analyze the problem. Main effect plots, ANOVA tables, Rank tables, are used to investigate the results from the collected data.

Finally, the following conclusions may be drawn for design of experiment (DOE):

1. From the experimentations, it is found that it is impossible to achieve any desired response just by Trial and Error because of a large number of variability among the collected data. Thus, an in-depth analysis is needed to achieve the final response.
2. It is identified that, both the response parameters i.e. UTS and hardness have highly non-linear relationships with welding parameters .
3. It can be concluded from the previous literature reviewed that the design of experiment approach is proven to be a best choice for researchers because it involves all the possible combination of parameters thus resulting in accurate and exact results and response values can be obtained to close level of accuracy and precision.
4. From the results it can be concluded that Stainless steel have been successfully welded with the dissimilar metal i.e. carbon steel and mild steel with high strength and hardness value. The strngth of the welded joints shows that the dissimilar metal welds with stainless steel as base metal can produce perfect joint at low cost.
5. From the previous results it can be concluded that the sample 2 (Dissimilar welding of SS with CS) is identified as best joint out of all the three samples taken into consideration for the study purpose. The coefficient of determination for sample 2 (93.86 %) is also higher than remaining two samples showing good level of significance for parameter combination.
6. While analyzing UTS, current is identified as the most affecting factor and filler rod thickness is the least affecting factor for all the three samples.
7. In case of analysis for hardness, fro sample 1 and sample 2 same relationships for the parameters have been identified. For both samples filler rod thickness is identified as a most affecting parameter while gas flow rate is identified as the least affecting factor. While in case of Sample 3, current is identified as a most affecting parameter while gas flow rate is identified as the least affecting factor.

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