Optimizing ATIG welding of hot rolled steel using Taguchi Methodology

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Abstract - **The application of activated TIG welding in making butt joint in 8 mm thick hot rolled steel is investigated. Three different fluxes based on proportions of combination of TiO2 and SiO2 is used on the square butt joint of hot rolled steel. Five weld parameters which include welding current, weld ding voltage, gas flow rate, root gap and type of flux is optimized using Taguchi L27 orthogonal array. The ultimate tensile strength of joint is the chosen as the quality characteristic of weld joint in order to optimize the weld parameters. Welding current and voltage comes out to be the most influencing welding parameter and gas flow rate do not affect the quality of the joint.**

keywords - **Activated TIG welding, Taguchi Method, Ultimate tensile strength, flux.**

Introduction

Activated TIG welding is a derivative of TIG welding which produces superior quality weld and enhances productivity compared to its latter. Activated TIG welding was first proposed by the E.O. Paton Institute of Electric Welding in 1960s (Zamkovet al.[1], Anderson and Richard et al [2], Huang et al. [3]). A-TIG welding uses the flux compounds such as oxides, chlorides and fluorides to produce weld joints of large depth to width ratio using a single-pass operation without any edge preparation (Leconte et al. [4]).The penetration of A-TIG welding is greatly increased due to constriction of the electric arc caused by the presence of some components (Oxygen and fluorine) of the flux in the arc (Zamkov et al.[5] and Kazakov, [6]). This effect would increase the anode current density and the arc force acting on the welding pool increasing the penetration of the welding bead. Simple oxide flux can greatly increase the penetration of the weld bead and also increase its mechanical properties.

The application of the activated fluxes resulted in reduction of edge preparation requirements, minimizing welding filler wire consumption, and reduced weld shrinkage and distortions. An increase in productivity is attributed to the reduction in the number of weld passes needed to weld the joint. Furthermore, activating fluxes has brought about significant improvement in the TIG process, welding characteristics such as higher welding speed, appreciable depth of penetration, and reduced sensitivity to variation of cast to cast material. The application of A-TIG welding not only reduces time required to prepare the edge but also minimize filler wire use, in addition to enhancing the penetrating power within the weld pool. Thus, it is possible to achieve single pass weld that have higher weld speed.

The weld jointobtained between dissimilar steel alloys of 6 mm thickness has been analysed by Badhekaet al.[7] Three different joints using powders of TiO2, ZnO and MnO were compared to find that the joint obtained by TiO2 has highest depth to width ratio. Mechanical properties, joint efficiency produced by Activated Flux-Tungsten Inert Gas Welds are higher than normal Tungsten Inert Gas Welds. Rishi Pamnani1, et al. [8] developed an activated flux for joining of DMR-249A steel of thickness10 mm. A-TIG welding using developed flux and optimized process parameters employing double side welding for the square butt joint was done. The strengths, ductility and impact toughness of the joints were found to be comparable with that of the base metal.Sanjib Jaypuria et al.[9] obtained an optimized mixture of MnO2, SiO2 and TiO2 to be effective for enhancement of penetration. Content of MnO2 and beam current have significantly contributed for enhancement of penetration and width of bead, respectively.R.S. Vidyarthy et al. [10] compared the weld joint produced by TIG and A-TIG based on their microstructure and mechanical behavior to find that more efficient joint was produced by the latter. NaishadhP.Patel et al. [11] studied the application of activated flux with laser beam welding to find an improvement in penetration, weld quality, weld efficiency and significant reduced cost. Use of activation flux concentrates electron beam which creates a narrow and deep fusion zone due to keyhole mechanism. Xu et al. [12] investigated the effect of quantity of flux, to find that increase of active flux on the weld bead tends to increase the penetration of the weld pool at first and then decreases steeply. Magudeeswaran et al. [13] optimized parameters of A-TIG welding like electrode gap, travel speed, current and voltage for aspect ratio of ASTM/UNS S32205 DSS welds by using Taguchi Orthogonal Array (OA) experimental design and other statistical tools such as ANOVA and Pooled ANOVA techniques.Sanket C. Bodkhea et al [14] used central composite design of response surface methodology to optimize parameters of A-TIG welding of stainless steel (SS) alloy 304L. Input parameters selected for experiments were current, welding speed and arc gap from which welding current have been selected as the most significant parameter.

It has been found that very few literatures have investigated the A-TIG welding of hot rolled steel and there is no research based on parametric optimization of hot rolled steel weld joints with thickness of plate more than 6mm. So the present work is based on ATIG welding of 8mm thick hot rolled steel and analyzing the effect of weld current, weld voltage, gas flow rate, root gap and the type of flux on the quality of weld joint obtained.

Materials and Methods

The ASTM C1010 Hot rolled steel (grade IS 5986;ISH360S) were used in this investigation. The chemical composition & properties of Hot rolled steel (grade IS 5986; ISH360S) is listed in Table 1 and Table 2.

Table 1: Chemical Composition of the Hot rolled steel (grade IS 5986; ISH360S)

Elements	C	Si	Mn	N	S
(Wt %)	0.1000	0.200	0.700	120 (PPM)	0.030
Elements	Ti	Al	Nb	P	V
(Wt %)	0.0450	0.0200(min)	0.0550	0.030	0.0950

Table 2: Properties of Work piece Materials

Material Designation	Properties			
	Tensile Strength N/mm^2	Yield Strength N/mm^2	Hardness	Elongation
ASTM C1010 (IS5986;ISH360S)	330-440N/mm^2	205 N/mm^2 ,min	100-140HV	18% to 28%

The work pieces were cut in plate form of size 100 mm x 40 mm x8mm by EDM wire cut machine has been used as base material for this study. The welding machine TRITON 220 AC/DC with 3.5 mm diameter Tungsten electrode (2% Thoriated) has been used in welding of samples. The shielding gas comprised of a mixture of Argon and Helium at a constant arc length of 2.5 mm was used during welding. Fig 1 shows the schematic diagram of A-TIG welding process while preparing a joint.

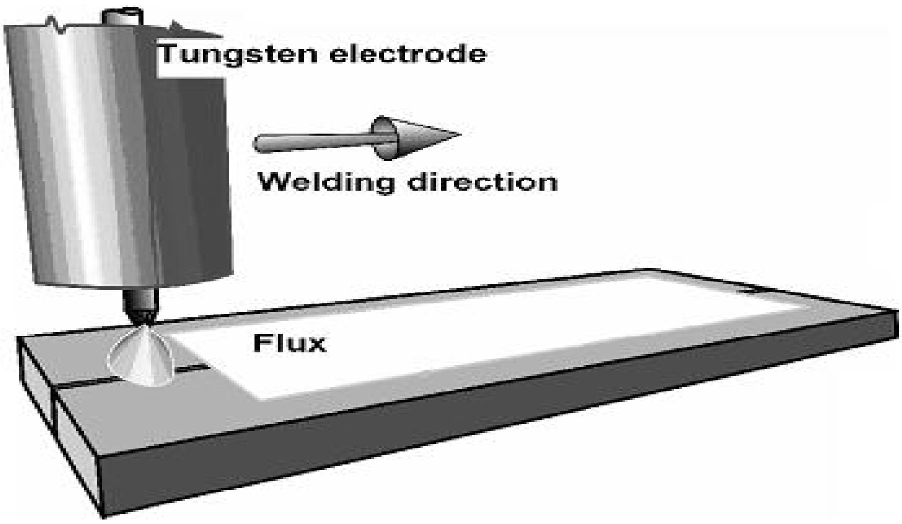

Fig. 1: Schematic Diagram A-TIG Welding Process [15]

Selection of various parameters affecting ATIGW

The determination of contributing parameters which needs to be investigated depends on the responses of interest. After doing theoretical studies, review of literature and a number of trial runs with different combinations of welding process parameters as depicted in the cause and effect diagram shown in Fig.2, five parameters which significantly affected the quality of the joint were chosen for further analysis. The five weld parameters and their rangesare welding voltage (22-30 volts), welding current (190-195 Ampere), Gas flow rate (12-15 Lit/min), Root gap (2.0-5.0 mm), Flux used [(60-80%) TiO_2 + (20-40%)SiO_2].The L_{27}Taguchi orthogonal array (OA)formed with the selected process parameters as shown in Table 3 has been used for conducting the experimentation. The tensile strength is the output response which is used to characterize the weld joint.

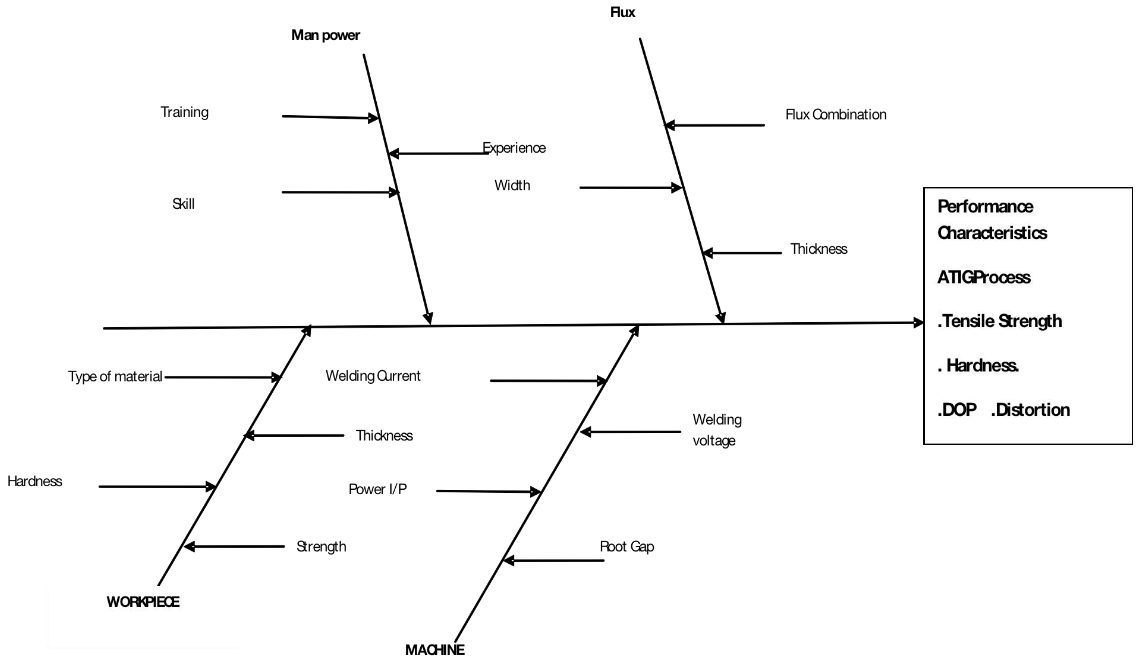

Fig 2: Cause and Effect diagram describing various characteristics affecting the quality of weld joint.

Table 3: Process Parameters and Their Values at Different Levels

Process Parameters Symbols	Process Parameter	Unit	Level 1	Level 2	Level 3
A	Welding current	Amps	190	195	198
B	Welding voltage	Volts	22	25	28
C	Gas flow rate	Lit//min	13	14	15
D	Root gap	mm	2	4	5
E	Flux	-	Flux 1	Flux 2	Flux 3

Flux 1 = 80% TiO_2+ 20% SiO_2
Flux 2 = 70% TiO_2+ 30% SiO_2
Flux 3 = 60% TiO_2+ 40% SiO_2

The experiment has been conducted based on the obtained L27 Taguchi OA. Fig 3 shows the joint prepared accordingly where the Fig 3 (A) shows the square butt joint been applied with flux and Fig 3 (B) shows the final joint obtained after welding.

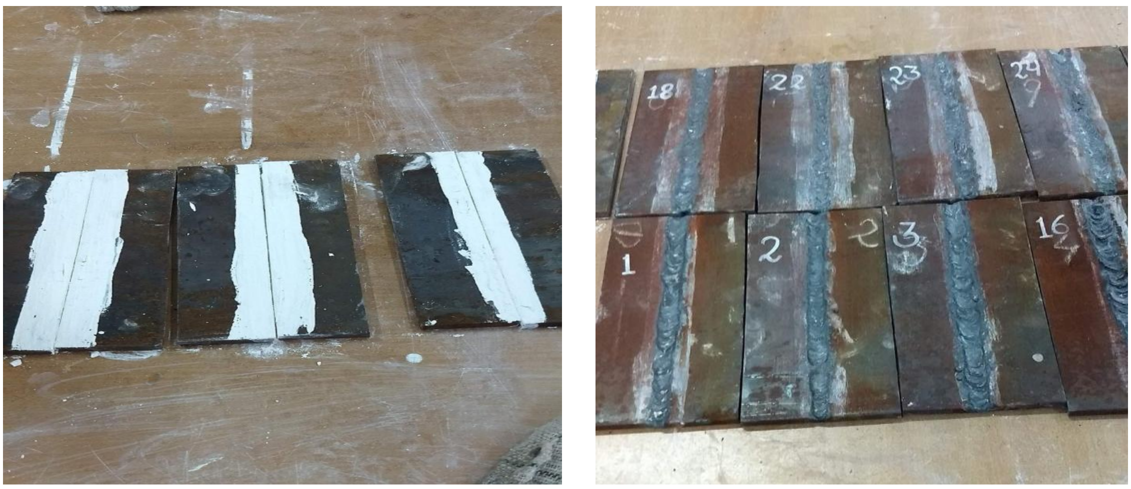

Fig. 3: (A) Sample with flux coating on the square butt joint (B) Welded samples

Specimen is prepared as per the ASTM standard as shown in Fig 4 for conducting UTS at the given set of weld parameters.

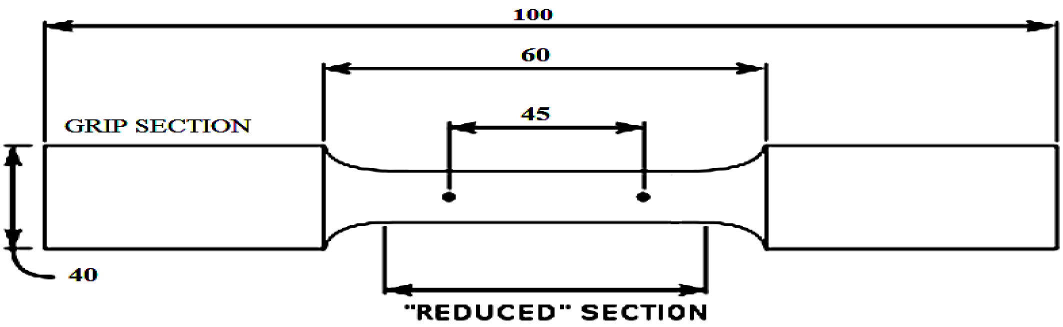

Fig. 4 : UTM speciemen

Results and Discussion

The ultimate tensile strength (UTS) is a quality characteristic of a higher-the-better (HB) type for the process. The S/N ratio is chosen accordingly and the method of calculation is given as follows:

$$(S/N)_{HB} = -10\log\left(\frac{1}{R}\sum_{j=1}^{R}\frac{1}{y_j^2}\right) \quad (1)$$

where y_j = value of the characteristic in an observation j, here it is UTS
R= number of trials in a row

TheUTS of weld joint is measured for each set of parameters according to design of experiment (DOE) developed as shown in Table 4, and from the obtained results average mean and S/N ratio is calculated. Higher mean and higher S/N ratio are indicators of the best set of parameters which is A2-B3-C1-D2-E3. Based on the value of delta from Table 5, it can be predicted that the maximum effect on the variation of UTS of weld joint is due to weld current followed by welding voltage and then root gap and flux used. Gas flow rate has minimum effect on the variation of UTS of the weld joint. It can also be predicted from the main effect plot for means in Fig 3 that there is always a increase in value of value of UTS with the increase in weld current, weld voltage from 190- 198 Amperes and 22-26 Volts respectively. But increase in root gap beyond 4 mm tends to decrease the UTS of the joint. The gas flow rate does not have any significant effect and flux 3 give the best quality joint in terms of UTS.The different input parameters used in the experimentation can be ranked "the higher current and voltage there should be higher the root gap, gas flow rate and welding speed to melt the wire coming out continuously at higher speed. So that the basically for the tensile strength the heat is required to melt the wire hence according to H=I2RT (H= Heat, I=Current) and the current and the heat are directly proportional to welding speed. Similarly voltage and current are also related to the each other according tothe equation V=IR. So it can be said that the each control factors is related to the eachother partially or directly influencing the tensile strength. Fig 3, also predicts the best set of welding parameters which is A3-B3-C3-D2-E3.

Table 4: Experimental results and S/N ratios for UTS

No. of EXP.	WELDING CURRENT (A)	WELDING VOLTAGE (B)	GAS FLOW RATE ©	ROOT GAP(D)	FLUX USED (E)	Responses: Ultimate tensile strength at weld zone			AVER ($\bar{y}$)= (R1+R2+R3)/3	S/N RATIO
						R1	R2	R3		
1	190	22	13	2	Flux 1	323.847	337.689	326.534	329.356	50.349
2	190	22	13	2	Flux 2	333.847	347.683	376.534	352.688	50.915
3	190	22	13	2	Flux 3	373.847	397.689	346.537	372.691	51.385
4	190	24	14	4	Flux 1	364.845	345.653	369.987	360.161	51.118
5	190	24	14	4	Flux 2	364.845	395.653	382.987	381.161	51.607
6	190	24	14	4	Flux 3	366.845	379.653	377.987	374.828	51.473
7	190	26	15	5	Flux 1	398.356	406.119	367.864	390.779	51.814
8	190	26	15	5	Flux 2	408.356	386.119	377.864	390.779	51.824

9	190	26	15	5	Flux 3	395.356	355.119	373.864	374.779	51.450
10	195	22	14	5	Flux 1	352.161	408.845	363.674	374.893	51.425
11	195	22	14	5	Flux 2	360.161	338.845	399.674	366.226	51.214
12	195	22	14	5	Flux 3	388.161	367.845	389.674	381.893	51.629
13	195	24	15	2	Flux 1	377.545	370.598	385.065	377.736	51.540
14	195	24	15	2	Flux 2	379.545	385.598	409.065	391.402	51.839
15	195	24	15	2	Flux 3	373.545	379.598	388.065	380.402	51.601
16	195	26	13	4	Flux 1	404.544	400.321	395.021	399.962	52.039
17	195	26	13	4	Flux 2	395.544	387.321	375.021	385.962	51.724
18	195	26	13	4	Flux 3	398.544	417.321	415.628	410.497	52.260
19	198	22	15	4	Flux 1	395.553	369.983	413.564	393.033	51.861
20	198	22	15	4	Flux 2	393.553	379.983	388.564	387.366	51.759
21	198	22	15	4	Flux 3	387.563	369.983	393.564	383.703	51.670
22	198	24	13	5	Flux 1	385.643	397.326	396.098	393.022	51.885
23	198	24	13	5	Flux 2	368.643	424.326	427.098	406.689	52.124
24	198	24	13	5	Flux 3	375.643	398.326	400.098	391.355	51.840
25	198	26	14	2	Flux 1	393.363	429.567	387.951	403.627	52.093
26	198	26	14	2	Flux 2	409.363	389.567	404.951	401.293	52.063
27	198	26	14	2	Flux 3	421.363	404.567	398.951	408.293	52.212
Average(μ T)									383.873	51.656
MAX						421.363	429.567	427.098	410.497	52.260
MIN						323.847	337.689	326.534	329.356	50.349

Table 5: Raw or mean data response for UTS on ATIG Process

Response Table for Mean					
Level	WELDING CURRENT (A)	WELDING VOLTAGE (B)	GAS FLOW RATE (C)	ROOT GAP (D)	FLUX USED (E)
1	369.7	371.3	382.5	379.7	380.3
2	385.4	384.1	383.6	386.3	384.8
3	396.5	396.2	385.6	385.6	386.5
Delta	26.8	24.9	3.1	6.6	6.2
Rank	1	2	5	3	4

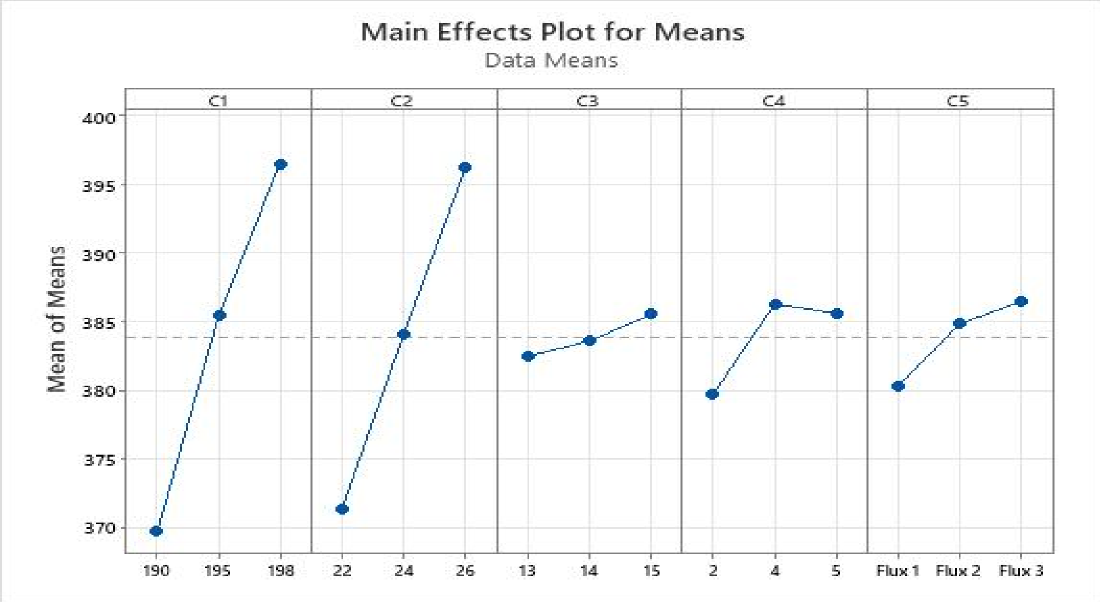

Fig. 3: Main effects plot of mean data for UTS on ATIGW process

Conclusion

As a result of the above discussion, it is possible to conclude that ATIGW can be used to join steel of up to 8 mm thickness when the optimum input parameters are selected for hot rolled steel.

1. The corresponding variables are considered statistically significant when the P-value is less than 0.05. It is found for ATIGW, UTS is affected by current, voltage, and root gap.
2. The percentage contribution of welding current to ultimate tensile strength during ATIGW is approximately 38.77%. Variables such as welding voltage, gas flow rate, and root gap have less effect on the total variation in ultimate tensile strength.
3. According to Taguchi's optimization method, the optimal parameters for ATIGW are A3B3C3D2E3.

Future Scope

The optimum process parameters here are for tensile strength, impact strength and hardness. New research findings and new studies can be derived from the results generated here. No matter how small the study is, it will contribute to the science of manufacturing. In order to analyze the whole work with new parameters and dimensions, various objects can be used.

1. To improve the properties of weld metal further study can be done post-heat treatment
2. In order to obtain an understanding of the transverse tensile properties of a parent material, the parent material can be welded with two or more different filler metals.
3. Various techniques, such as Artificial Neural Networks and Genetic Algorithms, can be used to compare the results obtained from the Taguchi approach.
4. In order to further study these zones, different loading types can be used for compressive and tensile tests.

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