Optimization of Process Parameters of Activated Tungsten Inert Gas (A-TIG) Welding for Mild Steel Plate using Taguchi Method

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Abstract— The present work is to investigates the effects of the different kinds of oxides fluxes (TiO_2, SiO_2, and Al_2O_3) used in activated TIG welding on weld bead penetration, bead reinforcement and hardness of mild steel. The flux coated tungsten inert gas welding mainly focus on reducing hardness, bead reinforcement and increasing depth of penetration of weld. The major influencing A-TIG welding process parameters, such as welding current, gas flow rate and arc travel speed are used to optimized and get desirable of best result of weld i.e. hardness, weld penetration and reinforcement. Hence this parameters are optimized by L_9 orthogonal array as tool of Taguchi method.

Key words: Activated TIG Welding, Depth of Penetration and Reinforcement, Light Optical Microscope, Mild Steel, Taguchi Method

I. INTRODUCTION

In today's manufacturing, quality is more importance. Quality can be defined as the degree of customer's satisfaction as provided by the procured product. The product quality depends on the desired requirements gained in the product that it's functional requirements in various areas of application. In the field of welding, weld quality mainly depends on mechanical properties of the weld metal, which influence by metallurgical characteristics and chemical compositions of the weld. Moreover, these mechanical-metallurgical features of the weldments depend on bead geometry, which are directly related to welding process parameters. A-TIG is the application of a reactive flux (Active-Flux) applied on the surface of the work piece for welding. It makes the welding arc contract, thus arc energy concentrate, thereby increased the weld penetration, and enhanced the production efficiency. Literature describes that work has been explored on various aspects of modeling, simulation and process optimization in conventional gas tungsten arc welding. Detailed analysis has been made to establish relationships between welding parameters, weld bead geometry, weld quality and productivity to select welding parameters leading to an optimal process. Various methods have been employed by previous investigators, such as Y. S. Tarng and W. H. Yang [5], who performed Taguchi method to formulate the experimental layout and analyzed the effect of each welding process parameters on the weld bead geometry as well as predicted an optimal setting for each process parameter. Saurav Datta [10], who performed Taguchi's L9 orthogonal array with three different levels of process parameters using welding current, % of slag-mix and flux basicity index to obtain bead-on-plate weld on mild steel plates for obtaining to achieve desired weld bead geometry. G. L. Datta [11], who carried out on austenitic stainless steel plates using an electron beam welding machine that made to minimize the weldments area, after satisfying the condition of maximum bead geometry. B. Senthilkumar [16] found out flux-cored arc welding process on the quality of the super duplex stainless steel using Taguchi L9 design of experiments by taking input welding voltage, wire feed rate, welding speed and nozzle-to-plate distance to achieved bead width and height of the reinforcement that optimized using genetic algorithm.

From the literature survey, It has been found that optimum parametric combination is very important in TIG welding operation to achieve the better weld quality on welded specimen. Taguchi method from the design of experiment is found to be efficient for design, analyze and optimize the process parameters in TIG welding operation. In the present work, the effect of welding current, arc travel speed and gas flow rate on weld quality in TIG welding of mild steel has been studied through experiment and analyses with the use of Taguchi method. In this research orthogonal array experimental design method with L9 is used to determine experimental plan that means to investigate 3 factors on a qualitative index with 3 levels of each factor. Totally nine experiments were conducted. For most influencing three different process parameters welding current, arc travel speed and gas flow rate are selected.

II. TAGUCHI METHOD

Taguchi method is the most important tools for designing high quality system at reduced cost which based on orthogonal array experiments; it recommends the signal to noise (S/N) ratio, which is a performance characteristic. S/N ratio is used to determine optimal conditions of experimental results. There are three S/N ratios commonly used for optimization of statistical problems i.e. nominal is better (NB), higher is better (HB) & lower is better (LB).

Taguchi's S/N Ratio (η) for nominal-the-best (NB):

$$\eta = 10ln_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Taguchi's S/N Ratio (η) for lower-the-best (LB):

$$\eta = -10ln_{10}\frac{1}{n}\sum_{i=1}^{n}y_i^2 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Taguchi's S/N Ratio (η) for higher-the-best (HB):

$$\eta = -10ln_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

III. EXPERIMENTAL WORK

The base metals used in this experiment were mild steel. The dimensions of base metal were 80*60*6 (in mm).The nominal chemical composition of mild steel is presented in table.1. For mild steel parent material a copper coated mild steel electrode wire ER70S6 was used. Wire diameter was 2mm and its chemical composition is given in Table.2. A fused flux [TiO_2, SiO_2 and Al_2O_3] of grain size 0.2 to 1.6 mm with basicity index 1.6 was used. Table 3 shows their levels and factors.

Component	C	Mn	P	S	Si	Ti	Ni	Cr	Al
Weight %	0.038	1.04	0.004	0.001	0.25	0.015	2.48	0.078	0.052

Table 1: Chemical composition of parent material (Mild steel)

Element	C	Mn	Si	P	Cr	S
MS ER70S6	0.06	1.4	0.8	0.025	0.05	0.035

Table 2: Chemical composition of MS material wire consumable

	Levels			Coded		
Process Parameters	Low	Medium	High	Low	Medium	High
Welding Current	170	180	190	1	2	3
Arc Travel Speed	2	4	6	1	2	3
Gas Flow Rate	8	10	12	1	2	3

Table 3: Levels of process parameters

Trial No.	Parameters / Factors					
	Welding Current (A)		Arc Travel Speed (Mm/sec.)		Gas Flow Rate (Lit/min.)	
	Original Value	Coded Value	Original Value	Coded Value	Original Value	Coded Value
1	170	1	2	1	8	1
2	170	1	4	2	10	2
3	170	1	6	3	12	3
4	180	2	2	1	10	2
5	180	2	4	2	12	3
6	180	2	6	3	8	1
7	190	3	2	1	12	3
8	190	3	4	2	8	1
9	190	3	6	3	10	2

Table 4: Design of experiment

A. Conduct experiment as per design

Mild Steel is used as base metal in this process. For test purpose, the sized of specimens is (80*60*6) mild steel plate. The Active – Flux is developed by the research with acetone and Active-Flux in a 1:1 volume ratio mixture. It can be welding after the acetone's evaporation.

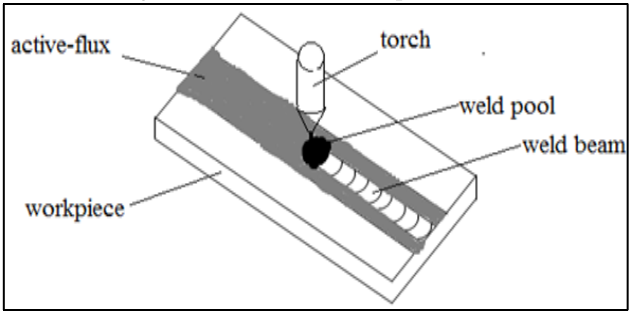

Fig. 1: Method of active-flux coating

TIG welding was carried out in MS parent metals in flat position with single pass welding. TiO_2, SiO_2, and Al_2O_3 powder was mixed in same ratio with acetone for making the paste on the different weld metals composition. A fresh MS (without flux) welding was made for the comparison. Welding was conducted in tungsten inert gas welding machine. After completion of all the welding, the welded plates were cooled in air. Then slag was removed using chipping hammer. Finally, the weld joints were cleaned by brush throughly.

Fig. 2: Photographic View of Sample after Welding of Mild Steel

Light optical microscopy (LOM) required for the inspection of the microstructure of the metals.

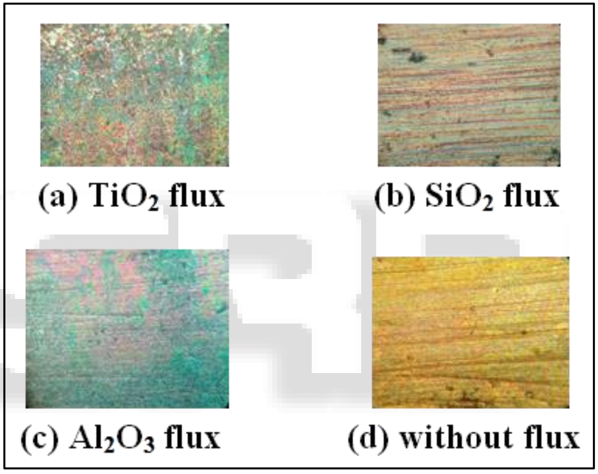
(a) TiO_2 flux
(b) SiO_2 flux
(c) Al_2O_3 flux
(d) without flux

Fig. 3: Microstructure of Weld Metals Corresponding To the Different Fluxes

For hardness measurement, samples dimension of (50x10x10) mm3 were machined of different welded plates. Then the machined samples were polished with 80, 150 and 180 emery paper and etched by 2% Nital solution. Hardness testing was carried Rockwell hardness testing machine.

Exp No.	Mild Steel		
	Hardness (HRC)	Reinforcement (R)	Penetration (P)
1	48	0.95	2.84
2	40	0.60	1.90
3	44	0.52	1.40
4	50	0.79	3.25
5	38	0.59	3.60
6	52	1.00	2.78
7	55	1.45	3.00
8	51	1.06	3.45
9	58	1.02	2.59

Table 5: Experimental data for MS

IV. RESULTS AND DISCUSSION

A. *Evaluation of SN ratio*

The Hardness, Reinforcement and depth of Penetration of specimens is calculated after testing it on Rockwell hardness testing machine and light optical microscopy. Signal to noise ratio represents the desirable and undesirable values for the output characteristics respectively. The Taguchi method uses S/N ratio to measure the quality characteristics deviating from desired values. The S/N ratio calculated from Minitab 15 software differs for different quality characteristics. In the present study Hardness, reinforcement and depth of penetration of weld specimen is response value, there For hardness, reinforcement, lower-the-better (LB) and depth of penetration a higher-the-better (HB) or larger the better (LB) criterion has been selected for analysis.

B. *Hardness*

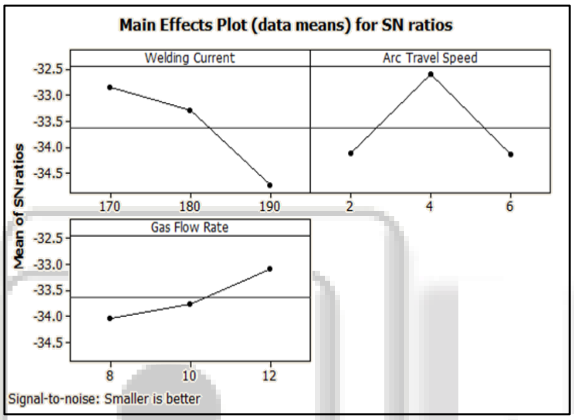

Fig. 4: Main Effects plot on hardness for SN ratio

From the main effect plot data it is observed that the S/N ratio decreases with welding current from highest value of 190 A to lowest value of 170 A. If welding arc travel speed from 2 to 6 mm/sec., the S/N ratio increase from 2 to 4 mm/sec. and then decrease from 4 to 6 mm/sec. If gas flow rate from 8 to 12 lit/min. There is smoothly an increase in S/N ratio from 8 to 12 lit/min. It is due to fact that as gas flow rate increases then oxide flux moves away from torch because of low density. It must be necessary that oxide flux will be in contact of base metal. The optimum values of process parameters to decreases the hardness of weld specimens are 190 A welding current, 2 mm/sec. travel speed, and 8 lit/min gas flow rate.

C. *Reinforcement of weld metal*

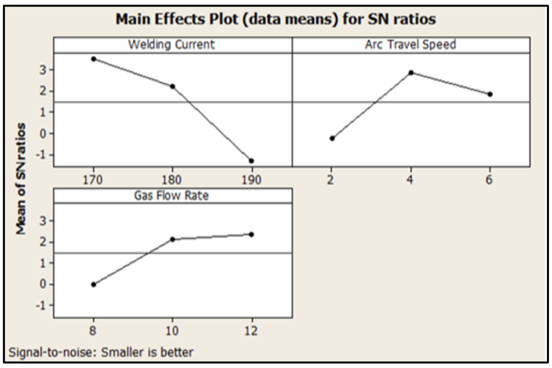

Fig. 5: Main Effects plot on reinforcement for SN ratio

From the main effect plot data it is observed that the S/N ratio increase with welding current from highest value of 190 A to lowest value of 170 A. If welding arc travel speed from 2 to 6 mm/sec., the S/N ratio increase from 2 to 4 mm/sec. and then decrease from 4 to 6 mm/sec. If gas flow rate from 8 to 12 lit/min, there is smoothly increase in S/N ratio from 8 to 12 lit/min. It is due to fact that as gas flow rate increases then oxide flux moves away from torch because of low density. It must be necessary that oxide flux will be in contact of base metal. The optimum values of process parameters to decreases the hardness of weld specimens are 190 A welding current, 2 mm/sec. travel speed, and 8 lit/min gas flow rate., it can be observed reinforcement (R) increases initially and then decreases with increase of welding current due to the fact that the deposited metal gets distributed along the width resulting in decreasing in reinforcement. As the arc travel speed increases, decreases reinforcement height. It causes reduced heat input per unit length of weld bead and less filler metal is applied per unit length of the weld. The reinforcement decreases initially with the increase gas flow rate and reinforcement increases with the further increase gas flow rate. The optimum values of process parameters to decreases the reinforcement of weld specimens are 190 A welding current, 2 mm/sec. arc travel speed, and 8 lit/min gas flow rate.

D. *Penetration of weld metal*

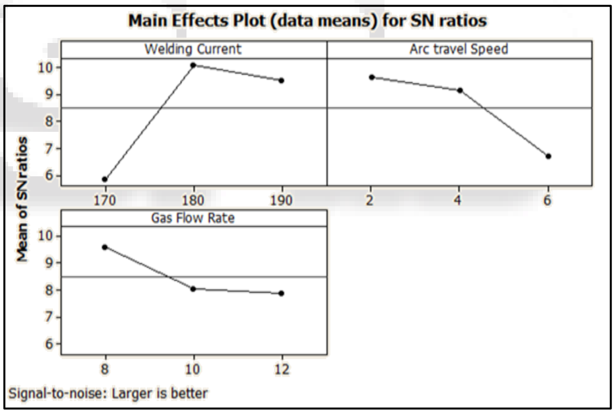

Fig. 6: Main Effects plot on penetration for SN ratio

From the main effect plot data it is observed that the S/N ratio increases with welding current from 170 A to 180 A and then decreases from 180 A to 190 A. With increases in current, heat input per unit time and deposited per unit time increases. Therefore the size of the weld pool increases. Hence penetration increases. If welding arc travel speed from 2 to 6 mm/sec., the S/N ratio decreases from 2 to 6 mm/sec. When arc travel speed is less than the optimum value the depth of penetration is decrease as reducing the heat input per unit length of the weld. If gas flow rate from 8 to 12 lit/min there is smoothly decreases in S/N ratio from 8 to 12 lit/min. Shielding gas produces a narrow penetration profile. The penetration was directly proportional to gas flow rate. Penetration increase with increase in gas flow rate during which the arc force is allowed to penetrate into the material’s surface decreases. The optimum values of process parameters to the increases penetration of weld specimens are 180 A welding current, 2 mm/sec. arc travel speed, and 8 lit/min gas flow rate.

V. CONCLUSION

From the experiment of TIG welding of Mild Steel plate following conclusion can be made with the activated welding system.

- Hardness and weld bead geometry (Reinforcement & Penetration) of the weld depends on the welding parameters like welding current, gas flow rate and welding speed.
- The optimum values of process parameters to decreases the hardness & reinforcement of weld specimens are 190 A welding current, 2 mm/sec. arc travel speed, and 8 lit/min. gas flow rate.
- With increase in current, hardness of the weld bead increases.
- Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
- The optimum values of process parameters to the increases penetration of weld specimens are 180 A welding current, 2 mm/sec. arc travel speed, and 8 lit/min gas flow rate.

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