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Optimization of Process Parameters of Submerged Arc Welding

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Abstract - *Submerged arc welding is one of the arc welding processes to provide high quality of weld. The quality of weld in SAW is mainly influenced by independent variable such as welding current, arc voltage, welding speed, electrode stick out. The prediction of process parameters involved in SAW is very complex process. Researches attempts to predict the process parameters of SAW to get smooth quality of weld. .Experimentation was planned as per Taguchi L9 Orthogonal array. In this paper experiments have been conducted using welding current, arc voltage, welding speed, electrode stick out as input parameters for evaluating responses namely bead width and bead hardness. The optimum values were analyzed by means of signal to noise ratio. The optimum values for smaller bead width and higher bead hardness are weld current at low level[16.88A],arc voltage at low level[21.3V] ,welding speed at low level[22.72mm/min] and electrode stick out at low level[22.44mm] .Finally conformation has conducted by ANOVA.with MINITAB17 Software to check accuracy of optimized results.*

***Key Words*: SAW, Taguchi method, Optimization, S/N ratio, ANOVA.**

1. INTRODUCTION

Welding is a process of joining the materials. It is more economical process compared to both casting and riveting. SAW is one of the arc welding processes introduced in 1930

A SAW involves formation of arc between a continuously-fed bare wire electrode and the work piece. The process uses a flux to generate protective gas and slag and also helps to control the composition of deposited metal by providing alloying elements to the weld pool. Prior to welding a thin layer of flux powder is placed on the workpiece.The arc moves along the line with the arc fully submerged in the flux As the arc is completely covered by the flux ,heat loss is minimum. This provides a thermal efficiency as high as95%.It provides no visible arc light, welding is spatter free and there is no need for fume extraction. .In this process flux plays following roles.

1-The stability of the arc dependant on the flux.

2-Chemical and thus the mechanical properties of the weld metal can be controlled by flux.

3-The quality of the weld may be affected by the quality and quantity of the flux used over the arc.

4-All fluxes react with weld pool to produce the weld metal chemical combination and mechanical properties.

5-The flux in a solid is non conductor of electricity but in molten state becomes a highly conducting medium.

6-The process uses a flux to generate protective gas and slag and also helps to control the composition of deposited metal by providing alloying elements to the weld pool.

7-When molten the flux becomes conductive and provides a current conducting path between electrode and w/p.The current used for the arc welding was relatively high which leads to produce a heavy arc and spatter conversely decreases the weld quality and weld strength as the exact penetration of weld joint is not achieved which leads to poor welding strength of the joints.

To overcome all the problems the SAW was introduced. The process includes continuously feeding electrodes. The molten weld and Arc zone was prevented by atmosphere by being submerged under the cover of granular fusible flux. The atmospheric oxygen and nitrogen comes in contact with the weld pool which causes the brittleness of the weld joints and porus joints. SAW is preferred method for welding thick sections in the industry because of its several advantages which include high production rates, good weld quality, ease of automation and minimum operator skill requirement.

After continuous innovation SAW introduced which protects weld pool and arc submerged by granular flux.

SAW is mainly influenced by independent variable such as welding current, arc voltage, welding speed, electrode stick out.

Welding current is a major factor that influences the penetration. Arc voltage and welding speed are also factors that influence the penetration. Weld width increases with increase voltage, current, wire feed rate and decreases with increase in speed and electrode stick out.

To get optimum results it is most important to know the effect of above parameters on weld bead geometry and how to select them and control their effect on deposited shape .most important parameters that affect on weld bead geometry are following. The heat input rate is directly proportional to current and voltage and inversely proportional to speed.

A- Welding current-As current increases temp. of the droplets increases. Increases in current reduces the size but increases the momentum of the droplets on striking the weld pool causes deeper penetration or indentation. Welding current directly influences the depth of penetration and extent of base metal fusion.

B- Welding speed-Increase in welding speed causes decreases in heat input per unit length of the weld and decreases electrode burn rate and reinforcement. Welding speed has pronounced effect on weld bead size and penetration for a given combination of welding voltage and current.

C -Welding Voltage- Raising the voltage increases arc length, in turn voltage increases the bead width and Welding voltage has directly influence the shape of weld bead and external bead appearance.

D -Electrode stick out- By increasing electrode stick out increases deposition rate and reduces penetration.

2. OPERATING VARIABLE

Qualities of weld deposited are determined by following parameters

Welding current

Welding arc voltage

Electrodes stick out

Grade of wire

Travel speed

Size of electrode

Flux layer depth

Wire feed rate

As per below formula, the present work is carried out by selecting following parameters. As per following formula,

HIR=VXA/S

Heat input rate is directly proportional to voltage with current and inversely proportional to speed

As per these formula, the present work is carried out by selecting following parameters that is

-Welding current

-Welding arc voltage

-Electrodes stick out

- Travel speed

3 WELDING PARAMETER AND ITS LEVEL

Table Shows factors (parameters) with their levels. Experiment has conducted using three level and four parameters

Table 1 Welding Parameter And Its Level

sr.no.	parameter	L1	L2	L3
1	**welding current A**	350	425	475
2	**welding voltage V**	28	30	34
3	**welding speed MM/MIN**	250	275	300
4	**electrode stick out MM**	20	21	22

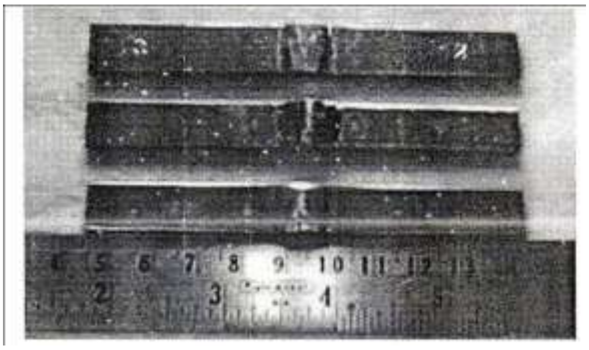

Figure1. Typical Photographic View Of Weld Samples

4 EXPERIMENTAL SET-UP

Experiment was conducted at Metal Fab High Tech. at Nagpur India. Machine has a rectifier/type with 1200A capacity was used to join the mild steel plates.

WELDING RECORDS

Welding process: SAW

Welding Position: 1G

Material: S355J0

Electrode Flux: EM12K+7A5

Diameter: 4.00mm

Size of test plate: 20 X 300 X 500

SAW welding, keeping the electrode positive and perpendicular to the plate. Samples of 10 mm cut from test piece and were polished, etched and the bead geometries were measured. The hardness was test by Rockwell hardness testing machine. Careful attention is necessary to select the welding process parameters to obtain the desirable weld quality. Though many and indirect parameters affect the quality of weld in SAW the major key process parameters affecting the bead geometry are arc voltage, welding current, welding speed and electrode stick out. In the present study three levels of factors (four process parameters) that is arc voltage, welding current, welding speed, electrode stick out are observed. The values of the welding process parameter are listed in table.

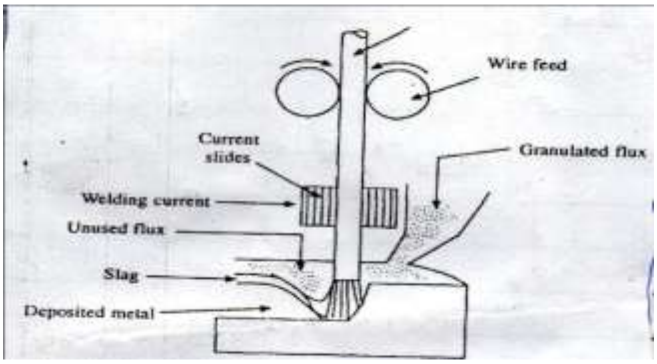

Figure 2 Schematic Dig. Of Saw Machine.

The Experiment was conducted at Metal Fab High Tech. at Nagpur India. Machine has a rectifier/type with 1200A capacity was used to join the mild steel plates of material S355JO of size 20(height)x300(width)x500(length).Copper coated electrodesEM12K,4mm diameter, of coil from ESAB brand and basic –fluoride-type(7A5)granular flux was used. Hardness test has done by Rockwell hardness tester machine.

Table 2 Observation table

EXPERIMENT VALUE						
Layers	Electrode	Volt (Volts)	Current (Amps.)	Travel speed mm/min	Heat input KJ/MM	Pre-Heat Temp. 0C
1ST SIDE WELDING						
Run-1	EM12K	28	350	300	1.960	20
Run-2	EM12K	30	400	275	2.618	100
Run-3	EM12K	30	425	275	2.782	100
Run-4	EM12K	32	450	300	2.880	150
Run-5	EM12K	34	450	300	3.060	200
2ND SIDE WELDING AFTER BACK GRINDING						
Run-1	EM12K	30	425	300	2.550	18
Run-2	EM12K	34	425	275	3.153	100
Run-3	EM12K	34	450	300	3.060	100
Run-4	EM12K	34	475	300	3.230	150

Figure 3 Measurement of weld bead width and hardness by Rockwell hardness Tester

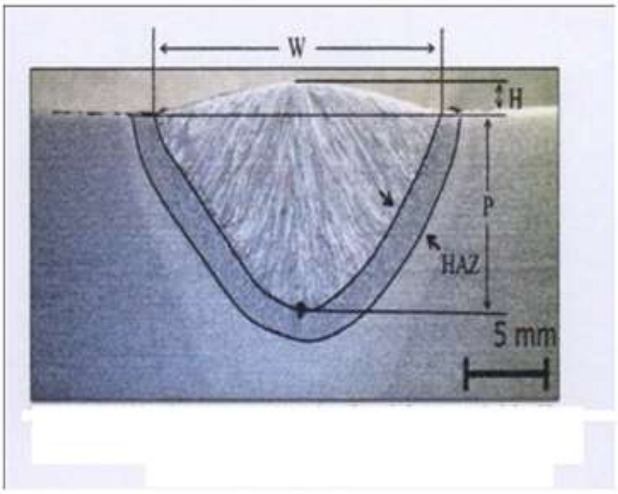

Figure 4 H-Reinforcement, p-penetration, HAZ-Heat affected zone-width

4.1 ORTHOGONAL ARRAY EXPERIMENT:-

To select an appropriate orthogonal array for

Experiments, total degree of freedom are computed. Experiments using L9 orthogonal array for three levels and four process parameters were computed and S/N ratio for bead width, hardness and penetration were calculated.

Below table shows all the observations made on Experimentation.

Table 2 Measured values from the test specimen as per L9Orthogonal array

MEASURED VALUE							
RUN	WELDING CURRENT	VOLTAGE	SPEED	STD	BEAD WIDTH	PENETRA TION	HARDN ESS
1	350	28	250	20	15	3	63
2	350	30	275	21	18	4	66
3	350	34	300	22	20	6	65
4	425	28	275	22	19	9	56
5	425	30	300	20	20	12	61
6	425	34	250	21	24	15	67
7	475	28	300	21	20	17	71
8	475	30	250	22	21	18	68
9	475	34	275	20	24	20	68

Analysis was based on orthogonal array, in this study an L9 orthogonal array with 5 columns and 9 rows were selected. This array has 8 degrees of freedom and it can handle 3 level process parameters

The degree of freedom is defined as the no. of constraints between process parameters that must be made to determine which level is better and specifically how much better it is. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for the two process parameters in the present study; interaction between the welding parameters is neglected. Once the degree of freedom is known, the next step is to select an orthogonal array to fit the specific task. The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study an L9 orthogonal array with 5 columns and 9 rows. This array has 8 degrees of freedom and it can handle 3 level process parameters. Each welding parameter is assigned to a column and 9 welding welding parameters combination are available. Therefore only 9 nine experiments are required to study the entire welding parameters using L9 Orthogonal array.

Table 3 S/N ratio for bead width, penetration, hardness.

Orthogonal Array experiment								
Run	current	voltage	Speed	Stick out	penetration	Hardness	bead width	SNRA1
1	350	28	250	20	3	63	15	14.4528
2	350	30	275	21	4	66.30	18	16.5880
3	350	34	300	22	6	64.65	20	19.9258
4	425	28	275	22	9	55.80	19	22.8856
5	425	30	300	20	12	61.27	20	24.8987
6	425	34	250	21	15	67.25	24	26.7083
7	475	28	300	21	17	71.23	20	26.8773
8	475	30	250	22	18	68.21	21	27.3135
9	475	34	275	20	20	67.55	24	28.2825

4.2 OVER ALL LOSS FUNCTION AND S/N RATIO:-

The control factors that may contribute to reduce variation (improved quality) can be quickly identified by looking at the amount of variation present as a response. The bead with, depth of penetration of the weld bead geometries and weld bead hardness belong to higher-the-better quality characteristic. The loss function of the higher-the –better quality characteristic can be expressed higher is better

$$L_{ij} = \left(\frac{1}{r} \sum_{i=1}^{r} \frac{1}{y_{ijk}{}^2} \right) \cdot$$

Where Lij is the loss function of the ith quality characteristic in the jth experiment, r is the no. of test.andyijk the experimental value of ith quality characteristic in the jth experiment at the kth test. As a result four quality characteristic corresponding to the bead width, hardness, penetration of the weld bead geometry are obtained using above equation

The overall loss function is further transformed into the signal-to-noise (S/N) ratio. In the Taguchi method, the S/N ratio is used to determine the deviation of the quality characteristic form the desired value. The S/N ratio n_j in the J^{th} experiment can be expressed as:

$$n_j = -10\log(L_{ij})$$

The S/N ratio corresponding to the overall loss function is shown in Table.

Similarly signal to noise ratios for bead width, depth of penetration, weld bead hardness were found separately. The largest signal-to-noise ratio (average) is the optimum level, because a high value of signal-to-noise ratio indicates that the signal is much higher than the random effects of the noise factors. Table shows the calculation of the average S/N ratios for welding current, arc voltage, welding speed and weld bead hardness.

Table 4 Average values for bead width, hardness, penetration

Weld parameters	Levels	S/N ratio
Weld current	1(350)	16.88(opt)
	2(425)	24.83
	3(475)	27.4911
Weld Speed	1(28)	21.30(opt)
	2(30)	22.9334

	3(34)	24.9722
Weld Voltage	1(250)	22.679
	2(275)	22.72(opt)
	3(300)	24.369
Electrode stick out	1(20)	22.44(opt)
	2(21)	23.39
	3(22)	23.374

The largest S/N_{avg} for parameter is indicated by (opt) and the effect is shown in the fig. . The welding process parameter performance levels are shown in fig. . From Table 4the optimal bead width and high hardness were obtained.

The largest S/Navg for parameter is indicated by optimum. The welding process parameter performance levels shown in above table. The optimum bead width, hardness, penetration has obtained by welding current350A, arc voltage28v, weld speed250mm/electrode stick out20mm

From the above equations,values of bead width, hardness,penetration can be predicated for any given values of process parameters.

4.3RESPONSE TABLE FOR SIGNAL TO NOISE RATIO

Larger is better

Table 5 Response table for means

Level	current	voltage	speed	Electrode stick out
1	16.88	21.3	22.72	22.44
2	24.83	22.93	22.59	23.39
3	27.49	24.97	23.9	23.37
Delta	10.61	3.67	1.32	0.95
Rank	1	2	3	4

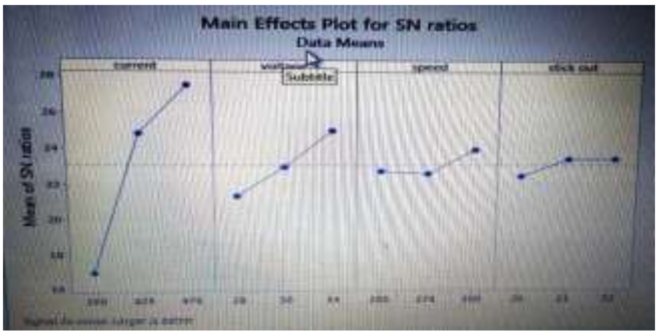

Figure 4 Effect of controllable factor [bead width] on S/N ratio

Welding current has a major effect on weld bead width, hardness and the electrode stick out has minor effect on weld bead. Welding speed and welding current have major influence on depth of penetration of bead whereas arc voltage has a little effect on it. Electrode stick out has very little influence on weld parameters.

5 ANALYSIS OF VARIANCE

Analysis of variance is done using MINITAB Software. The ANOVA table for weld bead width, hardness and penetration are shown in Table. Analysis of bead width, hardness and penetration through ANOVA shows that welding current and arc voltage are the significant welding process parameters that affect the width, hardness and penetration of weld bead. Similarly ANOVA is carried out for are within 95% confidence level.

Analysis of variance is done using MINITAB Software. The ANOVA table for weld bead width, hardness and penetration is shown in Table. Analysis of bead width through ANOVA shows that welding current and arc voltage are the significant welding process parameters that affect the width of weld bead, hardness and penetration Similarly ANOVA is carried out for other weld parameters, which shows that welding current has a major effect on weld bead width, hardness, and the electrode stick out has minor effect on weld bead width, hardness. Welding speed and welding current have major influence on depth of penetration of bead whereas arc voltage has a little effect on it. Electrode stick out has very little influence on weld parameters. Confirmation of experiment showed that the experimental observations are within 95% confidence level other weld parameters, which shows that welding current has a major effect on weld bead hardness ,bead width and the electrode stick out has minor effect on weld bead width. Welding speed and welding current have major influence on depth of penetration of bead whereas arc voltage has a little effect on it. Electrode stick out has very little influence on weld parameters.

TABLE—Analysis of Variance

Table 6 Analysis of Variance

Analysis of variance							
Source	DF	Seq. SS	Contribution	Adj SS	Adj. MS	F-Value	P-Value
Current	1	27.5556	43.82%	27..5556	13.778	124.00	0.008
Voltage	1	33.5556	53.36%	33..5556	16.778	151.00	0.007
Stick out	1	1.5556	2.12%	1.5556	0.7778	7.00	0.127
Speed	1	0.2222	0.35%	0.2222	0.1111	0.01	0.989
Error	4	62.6667	0.35%	62.6667	10.444		
Total	8	62.8889	100.00%				

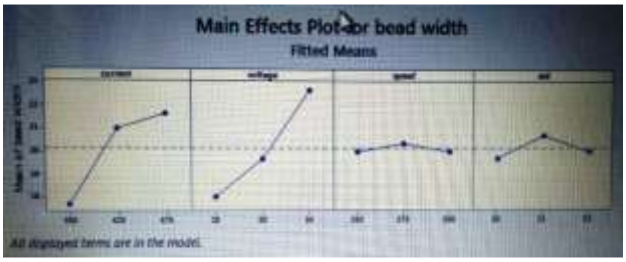

Figure 5 Main effect plot or bead width

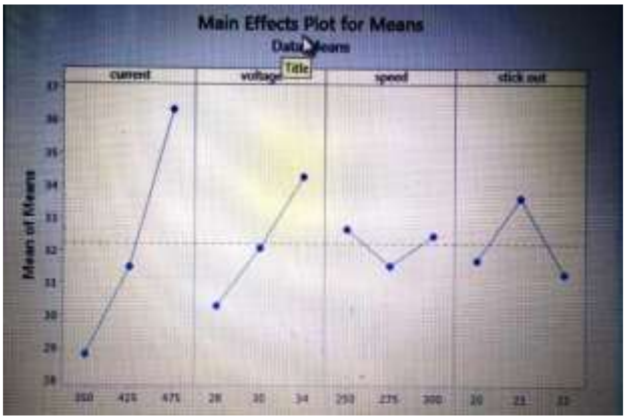

Figure6 Main effect plot for means

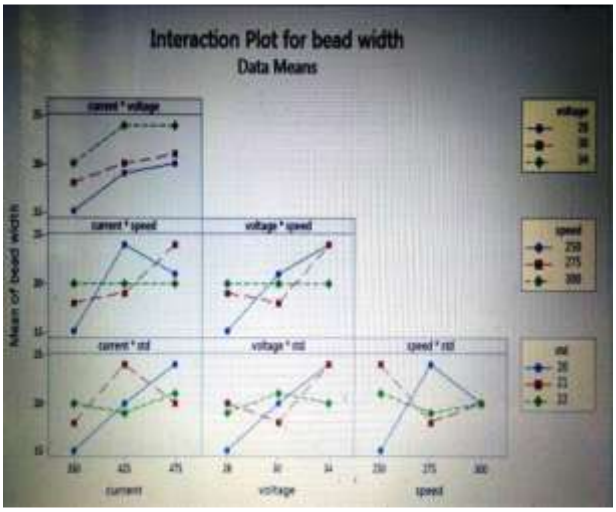

Figure 7 Interaction plot for bead width

6 RESULTS AND DISCUSSION

Economical layout of welding experiments is optimized by Taguchi method on design of experiments. The results from ANOVA indicate that welding current and arc voltage are the significant welding process parameters that affect weld bead width bead hardness. The output results are calculated for bead width, hardness, penetration from MINITAB17 with input variables.

7 CONCLUSION-

The present study concludes the following

1 The optimum parameter for minimum bead width is current at low level(16.88A),Voltage at low level(21.3v), Speed at low level(22.72mm/s),Electrode stick out at low level(22.44mm)

2 The optimum parameter for maximum hardness is current at low level (16.88A), Voltage at low level(21.3v), Speed at low level(22.72mm/s),Electrode stick out at low level(22.44mm)

3 Main and interaction effects of process variables on maximum penetration is current at low level(16.88A),Voltage at low level(21.3v), Speed at low level(22.72mm/s),Electrode stick out at low level(22.44mm)

4 Conformation test validated the use of multi objective taguchi method for enhancing welding performance and optimizing welding parameters

In future study can be extended by developing and analysing various technique like Genetic algoritham,influence of flux density,study of HAZ, Microstructure can be appliedfor optimization of process parameters.

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