Optimization of Mechanical Properties of AISI 1040 Steel in Submerged Arc Welding Process

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Abstract: In Submerged arc welding (SAW), Process parameter and composition of welding flux plays a crucial role by influencing the mechanical and metallurgical properties of the weld bead to determine the quality of the weld. The main objective of present work is to optimize the parameters effecting the weld quality. Generally, “SiO_2-Al_2O_3-CaO” flux system is used in SAW process. In this work with a target to improve the efficiency of the weld and to attain better mechanical properties. Nickel oxide (NiO) and chromium oxide (Cr_2O_3) powders are used in the flux by mixing in three different proportions, and various experiments are conducted. Taguchi technique is used for the design of experiments. Optimization of the parameter is done using the analysis of variance (ANOVA), regression models are developed using Minitab. It was found that the weld bead exhibited superior mechanical properties with the aforementioned additives. Improvement in weld bead efficiency is recorded.
Keywords: SAW; welding flux; Taguchi technique; ANOVA; regression analysis.

1 Introduction

Welding is a one of the major fabrication techniques which is extensively used to obtain good quality weld joint for various structural works. Among them Submerged arc welding is a high productivity and mostly used in heavy duty works. The SAW is a common arc welding process the first patent on the SAW process was taken 1935 and covered an electric arc beneath a bed of granulated flux .originally developed and patent “Jones, Kennedy, and Rothermund. The process requires a continuously fed consumable solid electrode. The popular areas of application are ship building, thick structural work, and Power system, chemical and nuclear industries, in all above of industries a strong weld is a must is a which should be resistant to corrosion. In SAW quality of weld bead depends upon the selection of process parameter and flux composition. Increase in the percentage of SiO_2 in the flux increases the arc stability, better slag detachability with good quality weld penetration [1]. Strength of weld joint depending upon the composition of flux and electrode [2]. Due to high deposition rate and excellent surface appearance submerged are welding process is widely used in the fabrication of shipbuilding, joining of pipe and offshore structures [3]. Three kind of oxide fluxes Fe_2O_3, SiO_2 and MgO were used to investigate the effect of activating flux aided gas metal arc welding on weld bead geometry, mechanical properties in AISI 1020 carbon steel [4].Optimal levels of NiO, MnO and MgO were selected using S/N analysis. The voltage as a noise factor affected the impact strength most [5]. Weld produced using low basicity index flux gives the structure having higher micro hardness as compared to that produced using high basicity index flux [6]. Taguchi method and regression analysis were applied to determine the process parameters of submerged arc welding process [7] the welding process has a significant effect on the microstructures and mechanical properties of weld metal because different welding process parameters result in different cooling rates of weld metals after welding. Therefore to obtain weld metals with high strength and toughness, it is necessary to develop welding wires with optimal alloying contents according to different welding process parameters [8] Slag can be recycled and used in submerged arc welding gives acceptable bead geometry, arc stability and slag detachability [9, 10] the effect of chemical composition of fluxes for submerged arc welding is well explained by using X-RD and DTA technology [11]. By varying MnO, MgO, NiO and Fe-Cr content in flux a desired hardness limit can be achieved in the weld metal [12] welding parameter combined with welding flux also effect weld bead geometry [13]. The effect of wire/flux combination on chemical composition, tensile strength and impact strength of weld metal were investigated and interpreted in terms of element transfer between the slag and weld metal [14]. Present investigation mainly highlighted for UTS, Impact strength and hardness of the joint. K.Maish Kumar [15] reported A brief review on the recent developments on metallurgical an mechanical properties in submerged arc welding with various fluxes. Kishore et.al [16-17] reported about optimizing process parameters in arc welding AISI 1040 steel using Taguchi method. G.Kiran Kumar et.al.[18] used retrofitted lathe machine for friction welding

2. Submerged arc welding process

Submerged arc welding (SAW) is one of most occurring arc welding process. It is a fusion welding process in which heat is produced by maintaining an arc between the workpiece and electrode. It needs an electrode which may be solid or tubular, the electrode should be copper coated bare electrode is used. The process uses a flux to generate protective gas and slag, and also helps to control the composition of the deposited metal by providing the alloying element to the weld pool. The arc moves along the joint line with the arc fully submerged in flux. As the arc is completely covered by granular flux layer, heat loss is minimum. This provides a thermal efficiency as high as 95%.the flux apart from shielding the arc and the molten pool protective from atmospheric contamination plays the following roles: The stability of the arc is dependent on the flux. Flux can control chemical and mechanical properties of the weld metal. The quality of the weld may be affected by the quality and quantity of the flux used over the arc. The experimental setup is shown in fig.1

Fig. 1 Experimental setup

Table .1 chemical composition of AISI 1040 steel

Element	Fe	C	Mn	S	P
Wt (%)	98.6	0.40	0.60	0.05	0.04

Experiments were performed on 1200A submerged arc welding machine of ADOR make [WH-15 TF]. The consumable electrode and material used for carrying out experimental work is AWS ER70S-6, 3.15 mm diameter work piece material AISI is 1040 steel plate of 10mmx100mmx150mm size. The flux used is silicon based flux, Cr_2O_3, NiO for single v-joint. Research work planned, to be carried out in following manner, Selection of important process parameters and find is their upper and lower limits as shown in table 2 developing the design of experiments (DOE), L9 is considered for the present study. Each experiment was repeated twice to avoid bias and results are shown in table 3, 4, 5 and 6.

Table 2 Variation of process parameters

Input parameter	Level 1	Level 2	Level 3
Current (Amp)	200	250	300
Arc voltage (V)	50	55	60
Carriage speed (mm/min)	0.4	0.6	0.8

Table 3. Experimental results by using "SiO_2-Al_2O_3-CaO" flux system

S.NO	Current (Amp)	Arc voltage(v)	Carriage speed(mm/min)	UTS (N/mm^2)	Impact strength (J)	Rockwell hardness Rc
1	200	50	0.4	450.45	62	27.6
2	200	55	0.6	471.19	20	21.3
3	200	60	0.8	435.44	16	36.3
4	250	50	0.6	415.65	26	33.6
5	250	55	0.8	423.33	40	29
6	250	60	0.4	603.06	42	31.3
7	300	50	0.8	410.25	38	21.6
8	300	55	0.4	464.46	42	24
9	300	60	0.6	371.34	28	23.6

Table 4. Experimental results by using "10% of Iron oxide in the silicon based" flux

S.NO	Current (Amp)	Arc voltage(v)	Carriage speed(mm/min)	UTS (N/mm^2)	Impact strength(J)	Rockwell hardness Rc
1	200	50	0.4	405	32	25
2	200	55	0.6	423	18	19
3	200	60	0.8	391	14	33
4	250	50	0.6	373	23	31
5	250	55	0.8	380	36	27
6	250	60	0.4	542	38	29
7	300	50	0.8	369	34	20
8	300	55	0.4	417	37	23
9	300	60	0.6	333	25	22

Table 5. Experimental results using "10% of nickel oxide in the silicon based" flux

S.NO	Current (Amp)	Arc voltage(v)	Carriage speed(mm/min)	UTS (N/mm^2)	Impact strength(J)	Rockwell hardness Rc
1	200	50	0.4	481	36	28
2	200	55	0.6	504	22	22
3	200	60	0.8	465	17	38
4	250	50	0.6	444	26	30
5	250	55	0.8	461	30	32
6	250	60	0.4	645	44	22
7	300	50	0.8	437	40	25
8	300	55	0.4	495	420	24
9	300	60	0.6	378	32	21

Table 6. Experimental results "10% of chromium oxide in the silicon based" flux

S.NO	Current (Amp)	Arc voltage(v)	Carriage speed(mm/min)	UTS (N/mm^2)	Impact strength(J)	Rockwell hardness Rc
1	200	50	0.4	513	39	32
2	200	55	0.6	537	23	38
3	200	60	0.8	501	19	35
4	250	50	0.6	473	29	31
5	250	55	0.8	482	33	29
6	250	60	0.4	687	47	25
7	300	50	0.8	467	43	24
8	300	55	0.4	529	45	26
9	300	60	0.6	423	32	27

3. Taguchi Method

The quality engineering methods of Taguchi, employing design of experiments (DOE), is one of the most important statistical tools for designing high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only.

3.1 Signal to noise ratio

Number of repetition of experiment permits the determination of variance index. This variation of the index is called as a signal to noise ratio (S/N). The S/N ratio is used to optimize the signal value. It is basically of three type lower is better, higher is better and nominal is better. In the present study, Ultimate tensile strength (UTS), impact strength and hardness of the each experimental weld were obtained as a response. For the weld to be of good quality hardness and impact strength must be on the higher side. A higher value of S/N ratio indicates a smaller deviation in response which is desired as obtained by the following equation.

$$\frac{\mathrm{S}}{\mathrm{N}} = -10\log_{10}\left\{\frac{\sum_i^n\left(\frac{1}{y_i^2}\right)}{n}\right\}$$

The graph for S/N ratio for ultimate tensile strength, impact strength and hardness is shown in fig 2 to fig 13. Average S/N ratio is shown in the graph by a straight line. From these figures, optimal level for each combination is selected and optimal value for each combination was calculated.

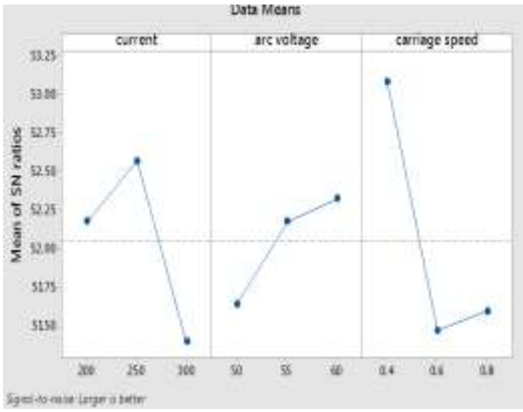


Fig. 2 Variation of UTS for input Fe_2O_3 flux

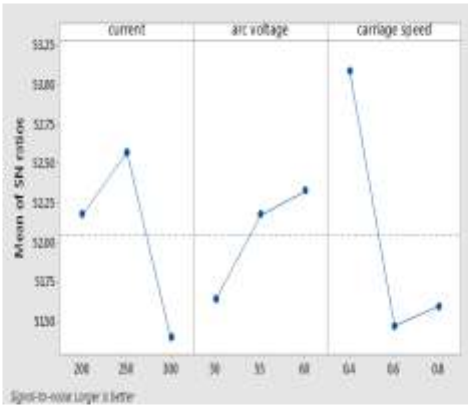


Fig. 3 Variation of impact strength parameter, Fe_2O_3 flux

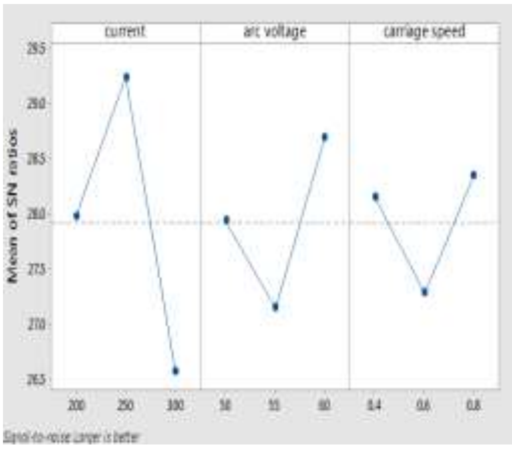


Fig. 4 Variation of hardness for input Fe_2O_3 flux

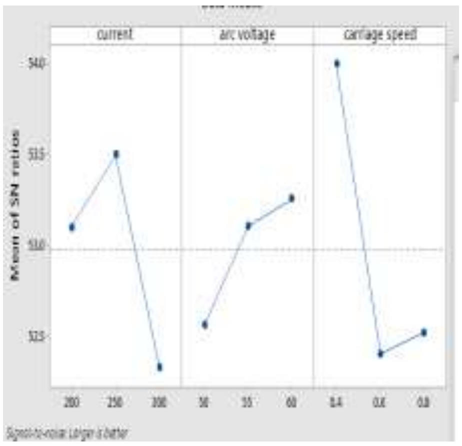


Fig. 5 Variation of UTS for input (SiO) flux.

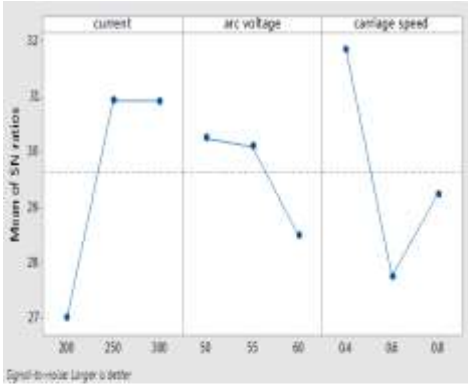
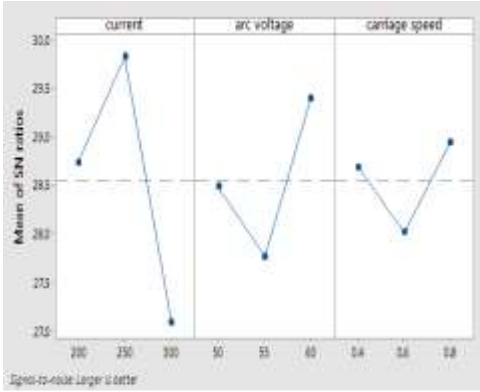


Fig. 6 Variation of Impact strength for input (Si O) flux



F**ig. 7** Variation of Rockwell hardness for (SiO) flux.

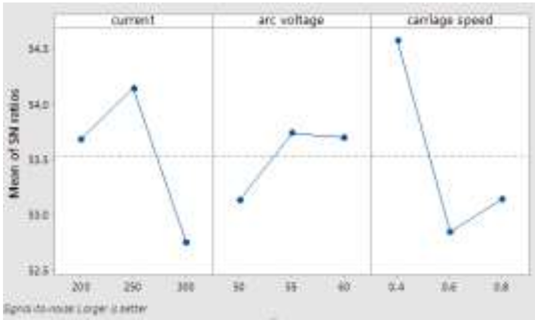


Fig.8 Variation of UTS for input (NiO) flux.

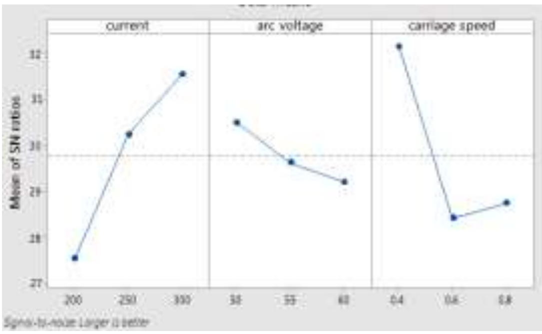


Fig.9 Variation of Impact strength for input (NiO) flux.

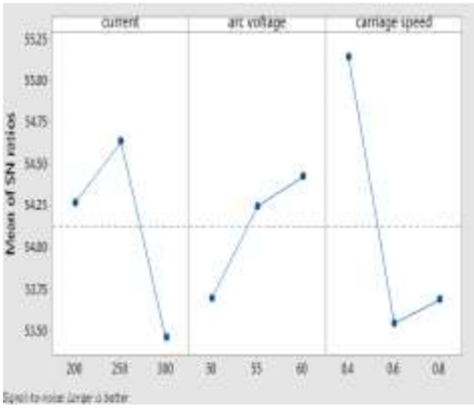


Fig.10 Variation of Rockwell hardness for input (NiO) flux.

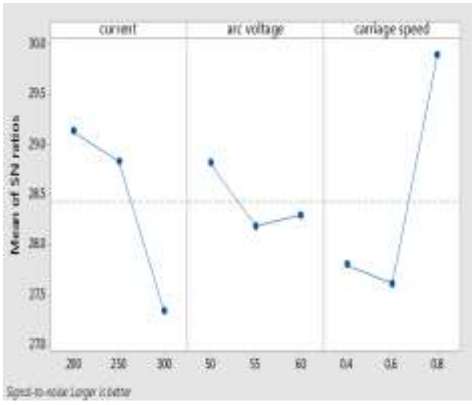
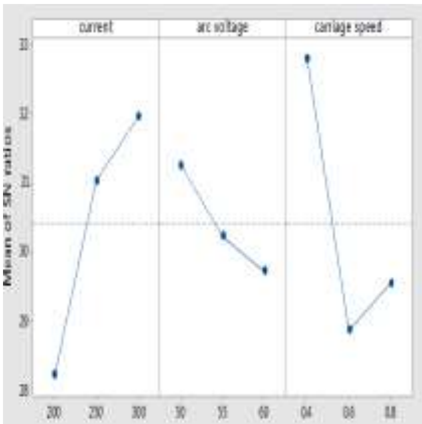


Fig.11 Variation of UTS for input Cr_2O_3 flux.,



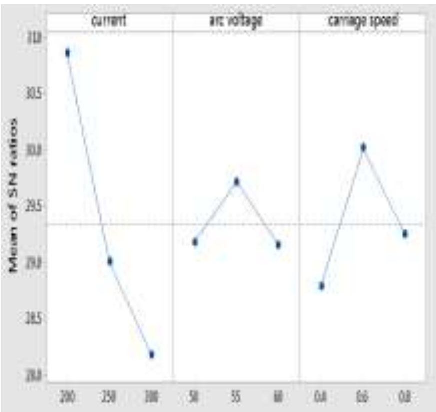


Fig.12 Variation of impact strength for input Cr_2O_3 flux. , **Fig.13** Variation of Rockwell hardness for Cr_2O_3 flux.

3.2 Analysis of variance

The purpose of the ANOVA test is to research the importance of the process parameters which influence the ultimate tensile strength (UTS), Hardness and Impact energy of SAW joints. The F- test is being carried out to study the significance of process parameters. The higher F value indicates that is highly significant in affecting the response of the process. In our investigation, for the material AISI 1040 steel the carriage speed is a highly significant factor and plays a major role in affecting the ultimate tensile strength and impact strength of the weld joint. Current is also a significant factor and plays a major role in affecting the Hardness of the weld joint.

Table 7 ANOVA for UTS by using silicon based flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	6440	3220	0.63	0.612	18.90
Arc voltage	2	3050	1525	0.30	0.769	8.95
CS	2	14414	7207	1.42	0.413	42.32
Error	2	10156	5078			29.81
Total	8	34059				100

Table 8 ANOVA for Impact strength by using silicon based flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	296.22	148.11	3.82	0.207	39.94
Arc voltage	2	44.22	22.11	0.57	0.637	5.963
CS	2	323.56	161.78	4.17	0.193	43.63
Error	2	77.56	38.78			10.45
Total	8	741.56				100

Table 9 ANOVA for hardness by using silicon based flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	106.89	53.44	1.52	0.396	45.76
Arc voltage	2	42.89	21.44	0.61	0.621	18.36
CS	2	13.56	6.77	0.19	0.838	5.80
Error	2	70.22	35.11			30.06
Total	8	233.56				100

Table 10 ANOVA for UTS by using Nickel oxide flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	9689	4844	0.79	0.560	22.98
Arc voltage	2	2918	1459	0.24	0.809	6.92
CS	2	17218	8609	1.40	0.417	40.84
Error	2	12326	6163			29.24
Total	8	42151				100

Table 11 ANOVA for Impact strength by using Nickel oxide flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	260.22	130.111	3.47	0.223	37.72
Arc voltage	2	16.22	8.111	0.22	0.822	2.38
CS	2	337.56	168.778	4.51	0.182	49.00
Error	2	74.89	37.444			10.87
Total	8	688.89				100

Table 12 ANOVA for hardness by using Nickel oxide flux

Input	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	52.66	26.333	0.59	0.627	21.58
Arc voltage	2	4.66	2.333	0.05	0.950	1.91
CS	2	98.00	49.00	1.11	0.475	40.16
Error	2	88.66	44.333			36.33
Total	8	244.00				100

Table 13 ANOVA for UTS by using Chromium oxide flux

Input parameters	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	8382	4191	0.64	0.608	19.03
Arc voltage	2	4218	2109	0.32	0.755	9.58
CS	2	18416	9208	1.42	0.414	41.82
Error	2	13011	6505			29.55
Total	8	44026				100

Table 14 ANOVA for Impact strength by using Chromium oxide flux

Input parameters	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	269.56	134.78	4.03	0.199	34.99
Arc voltage	2	30.89	15.42	0.46	0.684	4.01
CS	2	402.89	201.44	6.02	0.142	52.30
Error	2	66.89	33.44			8.68
Total	8	770.22				100

Table 15 ANOVA for hardness by using Chromium oxide flux

Input parameters	DF	Adj SS	Adj MS	F- Value	P-Value	% of contribution
Current	2	138.667	69.333	29.71	0.033	77.03
Arc voltage	2	8.00	4.00	1.71	0.368	4.44
CS	2	28.667	14.333	6.14	0.140	15.92
Error	2	4.667	2.333			2.59
Total	8	180.00				100

4. Results and discussion

Deviation of the signal from this average value is the indicator for noise. From the graph of S/N ratio, it is clearly visible that each factor has a clear effect on response. Higher is the value of Ultimate tensile strength, hardness and impact strength, better is the performance of submerged arc welded joint. So S/N ratio was selected on the basis of ‘Larger is Better’ to maximize the response variables. Because of orthogonal design, the effect of each flux constituents on S/N ratio can be seen separately in fig 3, 4, 5, 6. These diagrams indicate that all three flux constituents have a significant effect on the value of the response. For the higher value of the Ultimate tensile strength, impact strength and hardness of weld I2V3CS1 are the optimal levels. ANOVA result (table 7-9) the percentage of contribution of SAW process parameters was evaluated. It was observed that the weld speed has a major contribution for UTS and impact strength, current has more influence on hardness of welded joints by using silicon flux. It was observed from tables 10-12 carriage speed is predominantly effecting all three parameters for nickel oxide flux. It was observed from table 13-15 carriage speed is highly influencing for UTS and impact strength and current has more influence on hardness. Optimal values for UTS in iron oxide, NiO, SiO and Cr_2O_3 are I2, V3 and CS1.optimal values for impact strength is I2, V1 and CS1. Optimal values for hardness is I2, V3 and CS1.

Conclusion

1. Submerged arc welding is effective welding process for AISI 1040 steel plate of 10 mm thickness.
2. The obtained joint efficiency is 97% when Cr_2O_3, Fe_2O_3 and NiO are added in the silicon-based flux.
3. When 10% Cr_2O_3 is added in the silicon-based flux, has improved the tensile strength by 15%.
4. When 10%NiO added in the silicon-based flux has improved the tensile strength by 7%. Similarly, CrO_3added in the flux impact strength has improved by 13%.
5. Similarly, NiO added in the flux impact strength has improved by 6%.
6. Cr_2O_3 is more effective when compared to with NiO.

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