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EFFECT OF PROCESS PARAMETERS OF WELD JOINT ON SUBMERGED ARC WELDING

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Abstract- Submerged arc welding (SAW) is one of the oldest automatic welding processes used to provide high quality of weld. In this study, influences of the welding process parameters on the Submerged Arc welding were investigated. The Welding Arc Voltage, Welding Current and Electrode stick-out are chosen as welding process parameters. The aim of the present work was to study the effect of various process parameters i.e. current, voltage and electrode stick-out on changes in tensile strength, toughness and hardness of ASTM A516 low carbon steel. With the help of above welding process parameter we analyzed the optimum value of tensile strength, toughness and hardness for SAW. This paper has been analyzed in Minitab 18 software and application of Taguchi technique is used for determining the optimal process parameters for SAW process. Mathematical models were developed for the submerged arc welding of structural steel plate's thickness of 16 mm. Accordingly, a suitable orthogonal array was selected and experiments were conducted in Minitab 18 software. After conducting the experiments the Signal to Noise ratio(S/N) was calculated for each parameter. Finally conformation was conducted by ANOVA with MINITAB18 software to check accuracy of optimized results.

Keywords— ASTM A516, Anova, Minitab 18, Optimization, Saw, S/N Ratio, Taguchi method

I. INTRODUCTION

Welding is a process of joining two or more different materials. Submerged Arc Welding is one of the oldest automatic welding processes which introduced in 1930s for providing high quality of weld. SAW is more economical and is a much faster process compared to both casting and riveting. The quality of weld in Submerge Arc Welding is majorly influenced by various factors such as welding current, welding speed, welding arc voltage, electrode extension etc. Submerged arc welding process is very important component in many industrial organizations. The submerged arc welding parameters are the most important factors affecting quality, productivity and cost of welding joint. Submerged arc welding can be employed for an extremely wide range of work pieces. The method is suitable for butt welding and fillet welding of such applications as structural members in ships, manufacture of pressure vessels, bridge beams, massive water pipes, thin sheet shells and so on. In addition, the process is particularly effective for cladding applications, e.g. when surfacing mild carbon steel with stainless steel materials, or when depositing hard materials on a softer substrate. [1]

II. LITERATURE REVIEW

Over the past several years a lot of research has been done in the area of submerged arc welding and many interesting results have been brought up on the various aspects of Submerged Arc Welding (SAW) and MILD Steel.

Patnaik *et al.* [2] studied the SAW process and found wide industrial application due to its easy applicability, high current density and ability to deposit a large amount of weld metal using more than one wire at the same time. It was

highly emphasized in manufacturing especially because of its ability to restore worn parts. SAW was characterized by a large number of process parameters influencing the performance outputs such as deposition rate, dilution and hardness, which subsequently affect weld quality. The relationship between control factors and performance outputs was established by means of nonlinear regression analysis, resulting in a valid mathematical model.

Elsayed & Chen [3] introduced that parameter design, based on the Taguchi method, can optimize the performance characteristic through the setting of process parameters and can reduce the sensitivity of the system performance to sources of variation.

Prasad & Dwivedi [4] investigated the influence of the SAW process parameters (welding current and welding speed) on the microstructure, hardness, and toughness of HSLA steel weld joints. Attempts were made to analyze the results on the basis of the heat input. The SAW process was used for the welding of 16 mm thick HSLA steel plates. The weld joints were prepared using comparatively high heat input (3.0 to 6.3 KJ/mm) by varying welding current (500–700 A) and welding speed (200–300 mm/min). Results showed that the increase in heat input coarsens the

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grain structure both in the weld metal and heat affected zone. The hardness was found to vary from the weld centre line to base metal and peak hardness was found in the HAZ. The hardness reduced with the increase in welding current and reduction in welding speed while the toughness showed mixed trend.

Rameen Datta et al. [5] carried out the tensile test on torr (torsteg) steel joined by Shielded Metal Arc Welding (SMAW) and the transverse tensile strength observed was 524 MPa while that of parent material was 523 MPa. It was found that the tensile strength obtained was higher than the minimum specified tensile strength.

M. Erglu *et al.* [6] did a research on low carbon steel plate (SAE 1020 steel) to see the effect of coarse initial grain size and heat input on microstructure using heat input for welding as 0.5, 1 and 2 kJ/mm and concluded that lower heat input (0.5 KJ/mm) resulted in maximum hardness due to formation of martensite.

Myers & Montgomery [7] studied that, in submerged arc welding process parameters interact in a complicated manner that influences various features of quality characteristics of the weld bead. Quadratic response surface methodology was an efficient approach to represent these relationships through mathematical equations.

Chandel et al. [8] observed that many variants of SAW such as twin arc, tandem arc, multiple wire, strip electrodes, etc., are widely used for specific applications. With the use of proper parameters and SAW variant, it is now possible to achieve deposition rates in excess of 50 kg/hr. The increase in deposition rate in most cases was achieved by increasing welding current and hence the heat input.

III. EXPERIMENTAL PROCEDURE AND DESIGN OF EXPERIMENT

The literature review showed that any change in the parameter of submerged arc welding affect the properties of welding. So, in this study it is proposed to find out the effect of changing different welding parameters on tensile strength, toughness and hardness. The ASTM A516 low carbon steel of dimensions of 150 x 80 x 16 mm was used as a work material. The experiments have been conducted on Submerged Arc Welding Machine i.e. ATE SA-1200 welding tractor (Make: ATE Pvt. Ltd., Pune) available at Production Workshop, B.I.T Mesra, Ranchi.

FIGURE 1- SAW Machine
(Courtesy: Production Workshop, B.I.T Mesra, Ranchi)

TABLE 1 Main technical parameters of welding tractor

Travel Speed	25-55 m/hr
Wire feeding rate	0.8m/min - 2.5 m/min
Wire diameter	2.4 mm -5 mm
Rated current	700 A
Rated voltage	100 V

A. Selection of Contributing Factors Affecting Welding

The determination of contributing factors which needs to be investigated depends on the responses of interest.. There are three factors to be identified through pilot study that affect tensile strength, toughness and hardness of work piece. These are - 1) Welding current 2) Voltage 3) Electrode stick-out. In the present experimental setup, there are three factors varied at 3-level were chosen through pilot study. Taguchi design has been used for the design of experiments, because it reduces the number of iterations and used to optimize the known parameters. The values of the input process parameters and there levels for the SAW are as given below in Table 2.

TABLE 2: MAIN PARAMETERS AND THEIR VALUES AT DIFFERENT LEVEL

Welding Parameters	Level 1	Level 2	Level 3	DOF
Current (A)	350	400	450	2
Voltage (V)	28	30	32	2
Electrode stick-out (mm)	20	28	35	2

B. Design of Experiment

As stated earlier Taguchi L9 array has been selected for the experimentation. The experimental design was completed using the Taguchi's fractional factorial experiments (FFEs). Welding current, Voltage, Electrode stick-out has been chosen as the factors of interest. L9 array with actual factors level is shown in Table 3. Chemical composition is listed in table 4.

Table 3 Orthogonal Array (L_9) and Control Parameters

Exp. Trial No.	Current (A)	Voltage(V)	Electrode stick-out (mm)
1	350	28	20
2	350	30	28
3	350	32	35
4	400	28	28
5	400	30	35
6	400	32	20
7	450	28	35
8	450	30	20
9	450	32	28

TABLE 4: CHEMICAL COMPOSITION OF ASTM A516

C	Mn	Si	S	P
0.13	1.03	0.12	0.021	0.024

C. Cutting of Steel Plates

The steel plates available for the study were of size 1000 x 500 x 16 mm. These were firstly cut in to strip of size 1000 x 80 x 16 mm through oxy-acetylene gas cutting as shown

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in Figure 5.2. Then these steel strips were cut to the required size of 150 x 80x 16 mm with the help of power hacksaw.

D. Method of preparation of steel plate specimen

9 plates were cut to size of dimension 150 x 80 x 16` mm for experiment. The edge preparation of 60^o was made on 80 mm side as shown in Figure 2. Edge preparation was done on shaper as shown in Figure 3. Groove between two plates is shown in Figure 4.

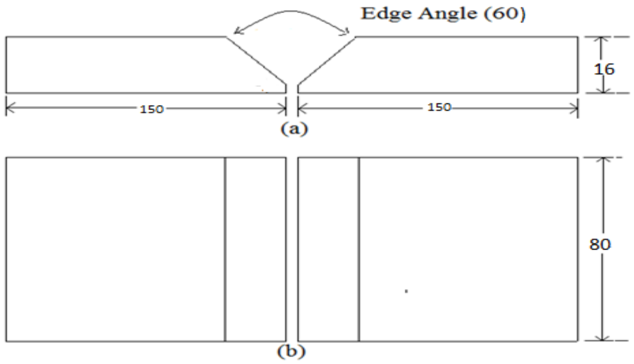
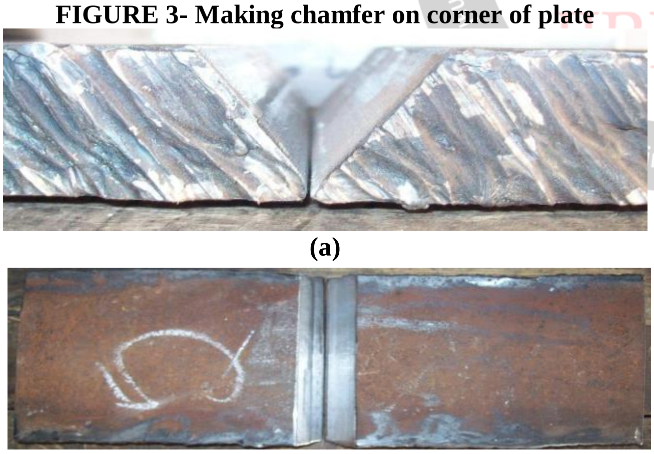


FIGURE 2- Groove geometry (a) front view and (b) top view

FIGURE 3- Making chamfer on corner of plate



(a)

(b)

FIGURE 4-Groove between two plates (a) front view (b) top view

Plates were placed under the electrode for welding and clamped with base plate using 'C' clampers. The welding was completed on each part as shown in Figures 5.

(a) **(b)**

FIGURE 5-Groove between two plates (a) Submerged arc welding of plates (b) Joints of plate after welding

After welding the parts were cut to size as per the requirement for tensile test, toughness and hardness in wire cut EDM machine.

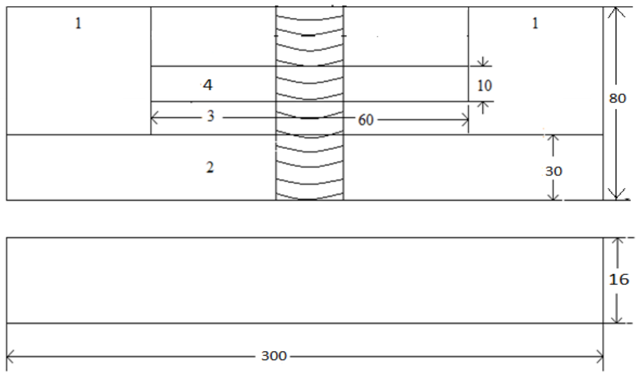


FIGURE 6- Cutting of plates after welding

Orientation of cutting of specimens after welding is shown in Figure 6, (1) represents waste material, (2) represents tensile test specimen, (3) represents toughness test specimen, (4) represents hardness test specimen.

IV. MEASUREMENT OF TENSILE STRENGTH

One measurement for each run was made for Tensile Strength using Manual Universal Testing Machine. The observed values of the responses are given in Table 2. Since a good result is obtained by the higher Tensile Strength hence higher is better S/N ratio is selected.

TABLE 2 Result of Tensile Strength with S/N ratio

Exp. Trial No.	Current (A)	Voltage (V)	Electrode stick-out (mm)	Tensile Strength (MPa)	S/N Ratio
1	350	28	20	460	53.255
2	350	30	28	510	54.151
3	350	32	35	490	53.803
4	400	28	28	524	54.386
5	400	30	35	514	54.219
6	400	32	20	521	54.336
7	450	28	35	594	55.475
8	450	30	20	570	55.117
9	450	32	28	623	55.889

A. ANOVA for Tensile Strength

The results of tensile strength are shown in table no. 3. The table consist values of tensile strength for the nine trials. ANOVA table for means is given in table 3. ANOVA table indicates that p value for current is at minimum level when tensile strength is taken as response. P value for current is 0.015, which is lesser than 0.05. F value for current is also at maximum level, which indicates that is a significant factor contributing to the response, which includes the ranks of contributing factors. In the present study current is most significant factor. Main effect plot showing the variation in the tensile strength with change in input factors have been shown table no. 3. and clearly shows that tensile strength increases almost linearly with increase in current.

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TABLE 3 ANOVA for Tensile-Strength

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	18746.0	87.30%	18746.0	9373.0	64.05	**0.015**
Voltage	2	554.7	2.58%	554.7	277.3	1.90	0.345
Electrode stick-out	2	1880.7	8.76%	1880.7	940.3	6.43	0.135
Error	2	292.7	1.36%	292.7	146.3		
Total	8	21474.0	100.00%				

B. Analysis of S/N Ratio for Tensile Strength

Lower Tensile-Strength is an undesirable property of weld bed joint, because it does not provide strength to the weld joint. So, higher the better option is chosen for signal to noise ratio calculations. Main effect plots are shown in table 4 and graph 1.

TABLE 4 Response table for S/N ratio of tensile strength

Level	Current	Voltage	Electrode stick-out
1	53.74	54.37	54.24
2	54.31	54.50	54.81
3	55.49	54.68	54.50
Delta	1.76	0.30	0.57
Rank	1	3	2

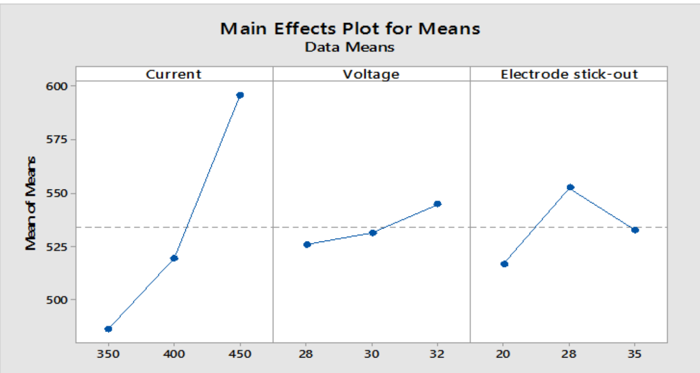

FIGURE 7 - Main effect plot for tensile strength

From Table optimal parameters setting for higher tensile strength are at 450 A current, 32 V Voltage and 28 mm electrode stick-out. Figure 7 shows main effect plot for S/N ratio.

C. Effect of welding parameters:

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	773.2	20.82%	773.2	386.62	7.48	0.118
Voltage	2	468.2	12.60%	468.2	234.09	4.53	0.181
Electrode stick-out	2	2369.8	63.80%	2369.8	1184.89	22.91	**0.042**
Error	2	103.4	2.78%	103.4	51.71		
Total	8	3714.6	100.00%				

On examination of S/N ratio of tensile strength it was found from Delta values, welding current is found to be most significant factor, next is electrode stick-out, and lastly the voltage. From figure it is observed that the optimum condition for maximum hardness is A3B3C2 (i.e. current =450 ampere, voltage=32 volts, electrode stick-out =28 mm).

For parameter optimization following formula based upon Taguchi design has been used for tensile strength:

$$\eta opt = m + (mA3 - m) + (mB3 - m) + (mC2 - m)$$

Where 'm' is the overall mean of S/N data, mA3 is the mean of S/N data for welding current at level 3 and mB3 is the mean of S/N data for welding voltage at level 3 and mC2 is the mean of S/N data for electrode stick-out at level 2.

Calculation, overall mean of SN ratio (m) was taken from Minitab software. m= 54.515

Therefore, ηopt = 54.515+ (55.4943-54.515)+ (54.6768-54.515)+(54.8093-54.515)=55.9504

$(Yopt)^2$= (10) ^ (ηopt / 10) for properties, higher is better

$(Yopt)^2$= (10) ^ (55.9504/10) = 393586.3244

Yopt= 627.364

So, Optimum value of tensile strength = 627.364 MPa

V. MEASUREMENT OF TOUGHNESS

One measurement for each run was made for Toughness using Charpy Toughness Test Machine. The observed values of the responses are given in Table 5. Since a good result is obtained by the higher Toughness hence higher is better S/N ratio is selected.

TABLE 5 Result of Toughness with S/N ratio

Exp. Trial No.	Current (A)	Voltage (V)	Electrode stick-out (mm)	Toughness (J)	S/N Ratio
1	350	28	20	181	45.1536
2	350	30	28	230	47.2346
3	350	32	35	235	47.4214
4	400	28	28	187	45.4368
5	400	30	35	211	46.4856
6	400	32	20	176	44.9103
7	450	28	35	220	46.8485
8	450	30	20	195	45.8007
9	450	32	28	200	46.0206

A. ANOVA for Toughness

The results of toughness are shown in table no. 6. The table consists of values of toughness for the nine trials. ANOVA table for means is given in table 6. ANOVA table indicates that p value for electrode stick-out is at minimum level when toughness is taken as response. P value for electrode stick-out is 0.042, which is lesser than 0.05. F value for electrode stick-out is also at maximum level, which indicates that is a significant factor contributing to the response, which includes the ranks of contributing factors. In the present study electrode stick-out is most significant factor. Main effect plot showing the variation in the toughness with change in input factors have been shown table. It is clear from table that toughness increases almost linearly with increase in electrode stick-out. Main effect

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plot showing the variation in the toughness with change in input factors have been shown in table no 6.

TABLE 6 ANOVA for Toughness

B. Analysis of S/N Ratio for Toughness

Lower Toughness is an undesirable property of weld bed joint, because it does not provide strength to the weld joint. So, higher the better option is chosen for signal to noise ratio calculations. Main effect plots are shown in table 7 and graph 2.

Level	Current	Voltage	Electrode stick-out
1	46.60	45.81	45.29
2	45.61	46.51	46.23
3	46.22	46.12	46.92
Delta	0.99	0.69	1.63
Rank	2	3	1

TABLE 7 Response table for S/N ratio of toughness

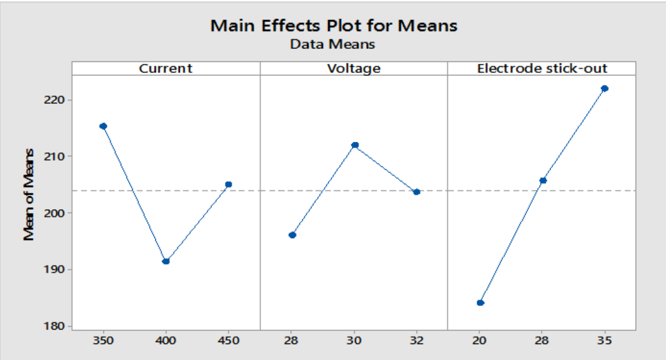

FIGURE 8 - Main effect plot for toughness

From Table optimal parameters setting for higher toughness are at 400 A current, 30 V Voltage and 35 mm electrode stick-out. Figure 8 shows main effect plot for S/N ratio.

C. Effect of welding parameters:

On examination of S/N ratio of toughness it was found from Delta values, electrode stick-out is found to be most significant factor, next is current, and lastly the voltage. From figure it is observed that the optimum condition for maximum toughness is A2B2C3 (i.e. current =400 ampere, voltage=30 volts, electrode stick-out =35 mm).

For parameter optimization following formula based upon Taguchi design has been used for toughness:

$$\eta_{opt} = m + (mA2 - m) + (mB2 - m) + (mC3 - m)$$

Where 'm' is the overall mean of S/N data, mA2 is the mean of S/N data for welding current at level 2 and mB2 is the mean of S/N data for welding voltage at level 2 and mC3 is the mean of S/N data for electrode stick-out at level 3.

Calculation, overall mean of SN ratio (m) was taken from Minitab software. m= 46.146

Therefore, η_{opt} = 46.146+ (46.6032-46.146) + (46.507-46.146) + (46.9185-46.146) =47.7367

Level	Current	Voltage	Electrode stick-out
1	54.57	62.50	64.16
2	58.62	62.74	56.24
3	67.87	55.82	60.65
Delta	13.30	6.92	7.92
Rank	1	3	2

$(Y_{opt})^2 = (10)$ ^ $(\eta_{opt} / 10)$ for properties, higher is better

$(Y_{opt})^2 = (10)$ ^ $(47.7367/10) = 59384.07554$

$Y_{opt} = 243.688$

So, Optimum value of toughness = 243.688 J

VI. MEASUREMENT OF HARDNESS

One measurement for each run was made for Hardness using Brinell Hardness Machine. The observed values of the responses are given in Table 8. Since a good result is obtained by the higher Hardness hence higher is better S/N ratio is selected.

TABLE 8 Result of Toughness with S/N ratio

Exp. Trial No.	Current (A)	Voltage (V)	Electrode stick-out (mm)	Hardness (BHN)	S/N Ratio
1	350	28	20	60.90	35.692
2	350	30	28	52.24	34.360
3	350	32	35	50.57	34.077
4	400	28	28	56.88	35.099
5	400	30	35	61.68	35.802
6	400	32	20	57.29	35.161
7	450	28	35	69.71	35.865
8	450	30	20	74.29	37.418
9	450	32	28	59.60	35.504

A. ANOVA for Hardness

The results of hardness are shown in table no. 9. The table consists of values of hardness for the nine trials. ANOVA table for means is given in table 9. ANOVA table indicates that p value for current is at minimum level when hardness is taken as response. P value for current is 0.006, which is lesser than 0.05. F value for current is also at maximum level, which indicates that is a significant factor contributing to the response, which includes the ranks of contributing factors. In the present study current is most significant factor. Main effect plot showing the variation in the hardness with change in input factors have been shown table. It is clear from table that hardness increases almost linearly with increase in current. Main effect plot showing the variation in the hardness with change in input factors have been shown in table no 9.

TABLE 9 ANOVA for Hardness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	278.739	59.64%	278.739	139.370	166.28	**0.006**
Voltage	2	92.476	19.79%	92.476	46.238	55.16	**0.018**
Electrode stick-out	2	94.501	20.22%	94.501	47.250	56.37	**0.017**
Error	2	1.676	0.36%	1.676	0.838		
Total	8	467.392	100.00%				

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B. Analysis of S/N Ratio for Hardness

Lower Hardness is an undesirable property of weld bed joint, because it does not provide strength to the weld joint. So, higher the better option is chosen for signal to noise ratio calculations. Main effect plots are shown in table 10 and graph 3.

TABLE 10 Response table for S/N ratio of hardness

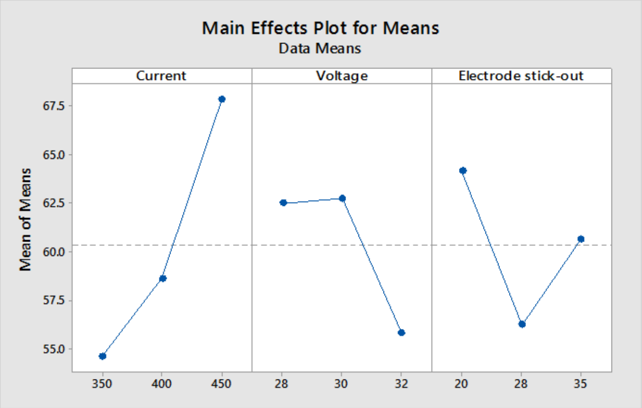

FIGURE 9 - Main effect plot for hardness

From Table optimal parameters setting for higher hardness are at 450 A current, 28 V Voltage and 20 mm electrode stick-out. Figure 9 shows main effect plot for S/N ratio.

C. Effect of welding parameters:

On examination of S/N ratio of hardness it was found from Delta values, current is found to be most significant factor, next is electrode stick-out, and lastly the voltage From figure it is observed that the optimum condition for maximum hardness is A3B1C1 (i.e. current =450 ampere, voltage=28 volts, electrode stick-out =20 mm).

For parameter optimization following formula based upon Taguchi design has been used for hardness:

$$\eta opt = m+ (mA3–m) + (mB1–m) + (mC1–m)$$

Where 'm' is the overall mean of S/N data, mA3 is the mean of S/N data for welding current at level 3 and mB1 is the mean of S/N data for welding voltage at level 1 and mC1 is the mean of S/N data for electrode stick-out at level 1.

Calculation, overall mean of SN ratio (m) was taken from Minitab software. m= 35.554

Therefore, ηopt = 35.554+ (36.5965-35.554) + (35.8858-35.554) + (36.0908-35.554)=37.4651

$(Yopt)^2$= (10) ^ (ηopt / 10) for properties, higher is better

$(Yopt)^2$= (10) ^ (37.4651/10) = 5578.404

Yopt= 74.688

So, Optimum value of hardness = 74.688 BHN

VII. RESULTS

The effect of three input factors was studied on the tensile strength, toughness and hardness using the L9 Taguchi experimental design. Tensile strength, toughness and hardness were measured as the response parameters. ANOVA was completed for all the responses to analyze the significance of the input factors. Main effect plots for mean values has been developed and analyzed.

- Welding current and travel speed was found as the most significant factor with p value of 0.015. Voltage and electrode stick-out did not show any significant effect on tensile strength.

- The mean tensile strength using the optimal condition would be maximum with welding current should be 450 Ampere, voltage should be 32 V and electrode stick-out should be 28mm.

- Electrode stick-out was found as the most significant factor with p value of 0.042.
Welding current shows moderate significant effect on toughness at room temperature, while voltage does not shows any effect on toughness.

- The mean toughness at room temperature using the optimal condition would be maximum with welding current should be 350 Ampere, voltage should be 30V, and electrode stick-out should be 35mm.

- Current was found as the most significant factors with p value of 0.006. Although the p values of voltage and electrode stick-out which was 0.018 and 0.017 respectively shows that voltage and electrode stick-out does also affect the hardness.

- The mean hardness using the optimal condition would be maximum with welding current should be 450 Ampere, voltage should be 30V, electrode stick-out should be 20mm.

VIII. CONFIRMATORY TEST

Confirmatory test was conducted at optimum combination of process parameters to check the validity of optimal parameters of welding. The conformation experiment done to validates the initial experiment results obtained and the conclusion of experiment. In this case the improvement of the performance characteristics of the welding process parameter are predicted and verified. The predicted S/N ratio using the optimal levels of the welding parameters can be calculated by using:

$$\eta_{opt} = n_m + \sum_{i=j}^{n} (n_j - n_m)$$

Where nm is total mean of S/N ratio, ni is the mean of S/N ratio at the optimal level, and n is the number of main welding parameters that significantly affect the performance. This equation is used for obtain the results of experiment, using optimal welding input parameters and comparing it with existing/initial process. The validation of the proposed optimization methodology is also confirmed by the output of confirmatory test.

Table 11 Confirmatory Test Results

Optimum parametric condition obtained by Taguchi method		**Maximum tensile strength obtained by confirmatory test**
Current	450 amperes	648 MPa
Voltage	32 volts	
Electrode stick-out	28 mm	
Optimum parametric condition obtained by Taguchi method		**Maximum toughness obtained by confirmatory test**
Current	400 amperes	

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Voltage	30 volts	264 J
Electrode stick-out	35 mm	
Optimum parametric condition obtained by Taguchi method		**Maximum hardness obtained by confirmatory test**
Current	450 amperes	84 BHN
Voltage	28 volts	
Electrode stick-out	20 mm	

IX. CONCLUSIONS

The present study was carried out to study the effect of process parameters on weld joint quality during submerged arc welding of MILD steel. The process parameters that have been considered for changing are current, voltage and electrode stick-out, were varied at different levels. The following conclusions have been drawn from the study-

• Welding current was found to be the most significant factor that affects the tensile strength, toughness and hardness.

• Electrode stick-out was found to be most significant factor that affects toughness and was the second most influencing parameters after current.

• Voltage has least significant effect on tensile strength and toughness at room temperature, but has a little affect on hardness and was the least influencing parameter.

X. FUTURE SCOPE

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In addition to the present work further work can be done in following directions:

• There are lot of parameters (Current, voltage, travel speed, electrode diameter, flux composition, electrode stick-out, preheating of flux, edge including angle and preheating of work piece) which can be varied individually to see their individual effects and combining these parameters to see their combine effect by experimental study & Taguchi method.
• Different flux can be made with different composition and study their effect on mechanical properties.
• Modeling of submerged arc welding process can be carried out by using finite element packages.

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