Effects of Shielded Metal Arc Welding Process Parameters on Mechanical Properties of S355JR Mild Steel

Kishor Purushottamrao Kolhe(✉), Fetene Teshome, and Aragaw Mulu

Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
skishor75@gmail.com, fetenet2017@gmail.com

Abstract. In this work the effect of welding parameters on mechanical properties of S355JR structural mild Steel is studied using SMAW process and E6013 as filler electrode with Taguchi orthogonal array of L9. Welding parameters like, voltage, current and speed are used as independent variables and tensile strength, hardness of weld zone and hardness of HAZ are consider as the output response in this investigation. Signal to noise (S/N) ratio and ANOVA are performed to know the significant of the parameters and the optimal welding condition using MINITAB 18 software. The maximum mechanical properties of the welded sample are obtained for optimal welding conditions. The maximum tensile strength, hardness of weld zone and hardness of heat affected zone were obtained 494.47 Mpa, 269.77 and 255.06 respectively. From the investigation, the parameters of SMAW process like voltage, current and speed noted significant influence on the mechanical properties of the base metal.

Keywords: Shielded Metal Arc Welding · Welding parameters · Mechanical properties

1 Introduction

Shielded Metal Arc Welding (SMAW) is a type of arc welding process that uses a welding power supply to create an electric arc between an electrode and the base material to be melt at the welding point [1, 2]. SMAW is a manual arc welding process that uses a consumable flux coated electrode to lay the weld [3]. However; SMAW is having many applications in the various sectors like automobile, farm machinery and general-purpose fabrication work [4]. Moreover; in manufacturing engineering, SMAW is the basic manufacturing process to produce quality and low-cost weld product. Nevertheless; there are different welding variables that barriers from achieving quality and low-cost weld product. Those variables apply their influence on the metallurgical behavior, chemical composition and mechanical property of the overall welding structure and weldments. This leads to the failures of many fabricated structures like industrial construction; erection of buildings, bridges and pressure vessels. Also, the failures of these members and structures bring hazard on human beings. Mainly the present work emphasis on

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analyzing the effect of welding parameters on hardness and tensile strength of S355JR structural mild steel joined by SMAW process. Furthermore, selection of proper welding parameters for the required job helps to get quality weld product, reduce welding defect, and save work material.

2 Experimental Procedures

The Shielded metal arc welding experimental setup is arranged at Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia as shown in Fig. 1. Mainly S355JR structural mild steel as a base metal and the electrode E6013 of diameter of 3.2 mm is used in the present study for making a weld joint. The chemical compositions for both base metal and electrode are shown in Table 1. The welding specimens are prepared by the standard British Welding Standard (BWS) guidelines. The specimen of (200 × 100 × 5) mm length, width and thickness respectively. However, the work piece surface and edge are carefully clean and edge prepared for welding using grinding machine and wire brush. Also; during experimental work the proper work holding fixtures are used to hold and position the parts to be weld in proper orientation. Moreover, after completion of welding specimen, tensile strength test, hardness of weld zone and Heat Affected Zone (HAZ) are tested using Universal tensile testing machine and Brinell hardness testing respectively. The signal to noise ratio has been calculated using MINITAB18 software for each single number of experiments in the overall study.

Table 1. Chemical composition of electrode and BM

Matl	C	Si	Mn	P	S	Cu	Ti	Cr	Mo
BM	0.24	0.5	1.6	0.04	0.05	0.55	0.24	–	–
Electrode	0.5	1	3	–	–	1.5	1	6	1.6

(a) (b)

Fig. 1. (a, b) Experimental Set up of SMAW power sources.

Design of Experiment

The optimization of the mechanical properties for the selected material is carried out by using Taguchi method using nine levels of orthogonal arrays (L9) [5, 6]. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied [7]. However, optimization of welding parameters like; current (I), voltage (V) and travel speed (S) for forming each of them into three levels are presented in Table 2.

Table 2. SMAW Process Parameters and their level

S. N	Process parameters	Unit	Levels		
			1	2	3
1	Current (I)	A	90	110	130
2	Voltage (V)	V	30	35	40
3	Speed (S)	mm/s	2	3	4

Selection of Orthogonal Array

Orthogonal arrays (OA) is a standard design by which simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a process characteristics or output response in a minimum number of tests [8]. The optimum setting of process control parameters of orthogonal array is as shown in Table 3.

Table 3. Orthogonal arrays for number of experiments

Experiments	Experimental variables		
	I	V	S
1	90	30	2
2	90	35	3
3	90	40	4
4	110	30	3
5	110	35	4
6	110	40	2
7	130	30	4
8	130	35	2
9	130	4	3

The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise) [10]. For example, to minimize defect. S/N = $-10\log(MSD_{SB})$ (1)., S/N = $10\log$ (MSD_{NB}) (2) Larger is better (LB): This type of signal to noise ratio is used when the research wants to maximize the value. S/N = $-10\log$ (MSD_{LB}) (3).,

Where,

$MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}\left(\frac{1}{Y_j^2}\right)$, $MSD_{SB} = \frac{1}{R}\sum_{j=1}^{R}(Y_j^2)$, $MSD_{NB} = \frac{1}{R}\sum_{j=1}^{R}\left(\frac{Y^2}{S^2}\right)$

MSD = mean square deviation, R = number of repetitions, Y_j = measured data, Y = mean of measured data, S = variance., S/N = Signal/Noise = Mean/Standard deviation (4).

Analysis of Variance (ANOVA)

ANOVA is used to explicate the input parameters, i.e. voltage, current and speed that mainly influence the hardness and tensile strength. This furnishes the information on weightage of each parameter on the hardness and tensile strength of the weld [9]. Taguchi recommended a logarithmic transformation of mean square deviation (S/N ratio) for the analysis of results. ANOVA separates the overall variation from the average S/N ratio into contribution by each of the parameters and the errors.

3 Results and Discussion

(1) Tensile Strength (TS)

The result of the tensile strength on different combination of parameters, recorded data and S/N ratio of each sample is presented in Table 4. Table 5 presents the response for tensile strength and average response characteristics (S/N ratio, means) for each level of variable.

Table 4. Test results of Tensile strength and S/N ratio

S. N	I	V	S	T.S (Mpa)	S/N
1	90	30	2	445	52.9672
2	90	35	3	462	53.2928
3	90	40	4	475	53.5339
4	110	30	3	462	53.2928
5	110	35	4	468	53.4049
6	110	40	2	485	53.7148
7	130	30	4	450	53.0643
8	130	35	2	459	53.2363
9	130	40	3	482	53.6609

Table 5. Response of S/N ratio for tensile strength

Level	V	I	S
1	53.26	53.11	53.31
2	53.47	53.31	53.42
3	53.32	53.64	53.33
Delta	0.21	0.53	0.11
Rank	2	1	3

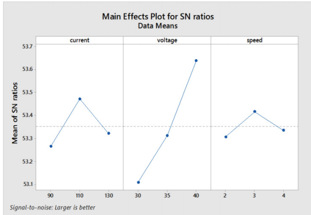

Fig. 2. Main effect plot for S/N ratio of tensile strength

Table 6. General linear model of Tensile strength verses current, voltage and speed for ANOVA

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-value	P-value	Significant
I	2	194.00	13.14	194.00	97.00	291	0.003	Less
V	2	1228.67	83.24	1228.67	614.33	184	0.001	Equal
S	2	52.67	3.57	52.67	26.333	79	0.012	Least
Error	2	0.67	0.05	0.67	0.333			
Total	8	1476.00	100					

Figure 2 depicts the voltage has a greater influence followed by current and welding speed on the signal to noise ratio. However; the level averages in the response shows that the S/N ratio and the mean are maximum, when the voltage is 40 V and the current and speed are as 110 A and 3 mm/s respectively. These values are observed for optimum welding variables on which maximum tensile strength is noted. Those are examined by using normal probability plot and plot of the residuals vs. predicted response as shown in Fig. 3. If the model is adequate, the residual points on the normal probability plot should form a straight line. On the other hand, the plot of residuals vs. predicted response should be structure less i.e. it should contain no obvious pattern. From the normal probability plot, it is found that the residuals fall on a straight line; it implies that the errors are distributed normally (Refer Fig. 4). The plot of residual vs. predicted/fitted surface roughness values reveals there is no obvious pattern and unusual structure. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption. From Table 6, it is observed that all the parameters have 'p' value less than 0.05%, which means each variable has their own influence on the tensile strength of the weld specimen using SMAW process, though their numerical value is different.

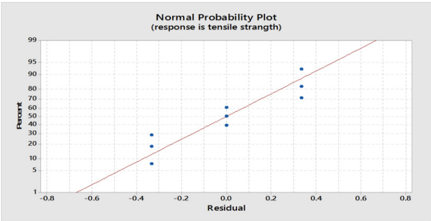

Fig. 3. Normal probability plot of residual for TS

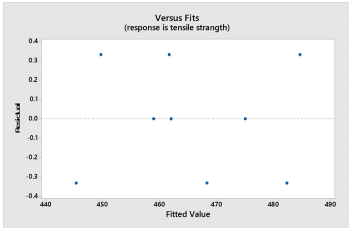

Fig. 4. Plot of residual vs. fitted tensile strength values

Similarly, current has 0.003 ‘P’ value and 291 ‘F’ value, which has second contribution for the strength. Speed has 0.012 ‘P’ value and 79 ‘F’ value which has less contribution, when compared with voltage and current. However; percentage contribution is one way to know the influence of each parameter on the tensile strength. Moreover; the parameter with high percentage of contribution has high power to change the performance of the system. In this case voltage with 83.24%; current with 13.14% and speed with 3.57% have a rank of 1 to 3 respectively by their percentage of influence.

Hardness of Weld Zone (HWZ)

The hardness result for fusion (welded) zone can be obtained by combining different parameters at a time. The observed results for hardness and S/N ratio have been recorded in Table 7 below.

Table 7. Test results of Hardness of weld zone and S/N ratio

S. NO	I	V	S	HWZ (BHN)	S/N
1	90	30	2	208.68	46.3896
2	90	35	3	217.12	46.7340
3	90	40	4	221.25	46.8977
4	110	30	3	213.93	46.6054
5	110	35	4	229.49	47.2153
6	110	40	2	229.13	47.2016
7	130	30	4	222.13	46.9321
8	130	35	2	233.63	47.3706
9	130	40	3	236.69	47.4836

Table 8. Response of signal to noise ratio for HWZ

Level	Current	Voltage	Speed
1	46.67	46.64	46.99
2	47.01	47.11	46.94
3	47.26	47.19	47.02
Delta	0.59	0.55	0.07
Rank	1	2	3

The response observed in Table 8 presents average of each response characteristics (S/N ratio, means) for each level of every variable. The table contains the rank of each variable according to the delta statistics reading, which compares the relative magnitude of each variables effect. Figure 5 presents the main effect plot for S/N ratio of the welded zone hardness. This also indicates which level of each factor provides the best result by using the level averages in the response table. From the overall analysis the current has a greater influence followed by voltage and welding speed on the signal to noise ratio. The level averages in the response shows that the S/N ratio and the mean are maximum, when the current is 130A and the voltage and speed are 40 V and 4 mm/s respectively as shown in Fig. 5.

Table 9. General linear model of Hardness of weld zone verses current, voltage and speed

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-value	P-value	Significant
I	2	345.269	49.11	345.269	172.63	39.	0.025	Equal
V	2	344.303	48.98	344.303	172.15	39.	0.026	Equal
S	2	4.672	0.66	4.672	2.336	0.5	0.652	Least
Error	2	8.753	1.25	8.753	4.377			
Total	8	702.997	100	–				

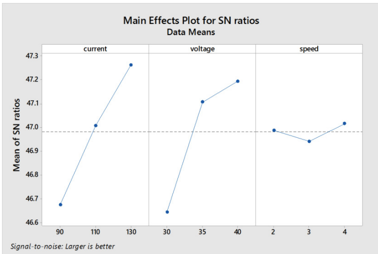

Fig. 5. Main effect plot for S/N of welded zone hardness

Therefore, this value of optimum welding variables for getting good hardness of weld zone. Figure 6 and presents the Plot of residual vs. fitted hardness and Normal probability plot of residual for hardness of WZ (Fig. 7).

Table 9 shows that the parameters like; current and voltage have ‘P’ value less than 0.05%, which means those variables have significant influence on the hardness of

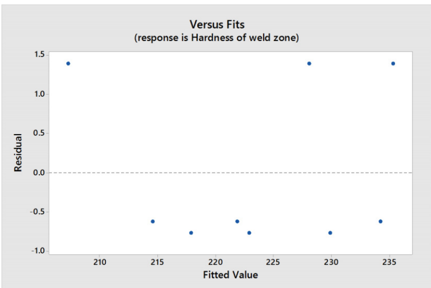

Fig. 6. Plot of residual vs. fitted hardness of WZ

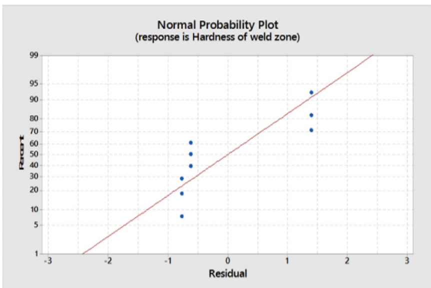

Fig. 7. Normal probability plots of residual for hardness of WZ.

weld zone of the weld sample using SMAW process. However, after arranging their numerical value, current has a greater influence with 'P' and 'F' values of 0.025 and 39.45 respectively. Similarly, voltage has 0.026 'P' value and 39.34 'F' value; which has second contribution for the hardness of weld zone.

Analysis of Variance for Weld Zone

Speed has 0.652 'P' value and 0.53 'F' value, which has no contribution since its 'P' value is greater than 0.05. In this case current with 49.11%; voltage with 48.98% and speed with 0.66% have a rank of 1 to 3 respectively by their percentage of influence with total allowable error of 1.2%.

Hardness for Heat Affected Zone (HHAZ)

The response Table 11 shows that the average of each response characteristics (S/N ratio, means) for each level of every variable. However; the above table contains the rank of each variable according to the delta statistics reading which compares the relative magnitude of each variables effect. Figure 8 depicts the current has a greater influence followed by voltage and welding speed on the signal to noise ratio. However; the level averages in the response shows that the S/N ratio and the mean are maximum, when the current is 130 A and the voltage and speed are at 35 V and 3 mm/s respectively. Table 12 depicts that current and voltage have 'P' value less than 0.05%, which means those variables have significant influence on the hardness of weld HAZ of SMAW process. However; while arranging their numerical value current has a greater influence with 'P' and 'F' value of 0.006 and 163.94 respectively. Similarly, voltage has 0.021 'P' value and 46.79 'F' value which has second contribution for the hardness. Figures 9 and 10 presents Normal probability plot of residual for hardness of HAZ and Plot of residual vs. hardness of HAZ values (Table 10).

Table 10. Hardness of Heat affected zone reading and signal to noise ratio

S	I	V	HHA (BHN)	S/N
1	9	3	200	46.02
2	9	3	225	47.06
3	9	4	215	46.68
4	1	3	225	47.06
5	1	3	235	47.43
6	1	4	225	47.06
7	1	3	235	47.43
8	1	3	245	47.78
9	1	4	245	47.79

Table 11. Response Table for signal to noise ratio of the hardness of HAZ

Level	Current	Voltage	Speed
1	46.59	46.84	46.96
2	47.19	47.43	47.31
3	47.67	47.18	47.19
Delta	1.08	0.59	0.35
Rank	1	2	3

Table 12. General linear model of hardness of HAZ versus current, voltage and speed for ANOVA

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-value	P-value	Significant
I	2	1179.16	72.13	1179.16	589.58	163	0.006	Equal
V	2	336.55	2	336.55	168.27	46.	0.021	Less
S	2	111.95	6	111.95	55.975	15.	0.060	Least
Error	2	7.19	0	7.19	3.596			
Total	8	1634.85	1					

Fig. 8. S/N ratio for hardness of HAZ

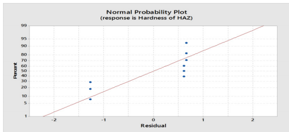

Fig. 9. Normal probability plot of residual for hardness

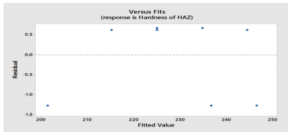

Fig. 10. Plot of residual vs. hardness of HAZ values

Analysis of Variance for Hardness of HAZ

Speed has 0.060 'P' value and 15.56 'F' value which has no contribution, since its 'P' value is greater than 0.05. In this case current with 72.13%; voltage with 20.59% and speed with 6.85% have a rank of 1 to 3 respectively by their percentage of influence with total allowable error of 0.439%. Taguchi optimization formulas for confirmatory test is as, $P_{opt} = X + (I - X) + (V - X) + (S - X)$ (5)., Where:- P_{opt} = Optimal condition., X = is the overall mean of S/N data, I = mean of S/N data for welding current at optimal level. V = mean of S/N data for welding voltage at optimal level, S = mean of S/N data for welding travel speed at optimal level.

Taguchi Optimization Formula for Tensile Strength

From Table: 5, $P_{opt} = X + (I2-X) + (V3-X) + (S2-X)$., X = is the overall mean of S/N data = 53.35., I2 = mean of S/N data for welding current at level 2 = 53.47., V3 = mean of S/N data for welding voltage at level 3 = 53.64., S2 = mean of S/N data for welding travel speed at level 2 = 53.42., Then; $P_{opt} = 53.35 + (53.47-53.35) + (53.64-53.35) + (53.42-53.35)$ $P_{opt} = 53.83$., Predicted performance strength; Y^2 for larger is better., Y^2_{opt} optimal condition = $10(P_{opt}/10)$, $Y^2 = 10(53.83/10) = 10(5.383) = 241546.08344$., $Y = \sqrt{241546.08344} = 491.47$., Therefore, the optimal value for tensile strength is 491.47.

Taguchi Optimization Formula for Hardness of Weld Zone

From Table: 8; $P_{opt} = X + (I3-X) + (V3-X) + (S3-X)$., X = is the overall mean of S/N data = 46.98., I3 = mean of S/N data for welding current at level3 = 47.26., V3 = mean of S/N data for welding voltage at level3 = 47.19., S3 = mean of S/N data for welding travel speed at level 3 = 47.02., Optimal condition for hardness of weld zone,

$$P_{opt} = X + (I3 - X) + (V3 - X) + (S3 - X)$$

$$P_{opt} = 46.98 + (47.26 - 46.98) + (47.19 - 46.98) + (47.02 - 46.98)$$

$P_{opt} = 47.51$. Predicted performance (hardness of weld zone); Y^2 for larger is better, Y^2_{opt} optimal condition $= 10^{(P_{opt}/10)}$, $Y^2 = 10^{(47.51/10)}$., $Y^2 = 10^{(4.751)} = 56363.765582$, $Y = \sqrt{56363.765582} = 237.41$., Therefore, the optimal value for hardness of weld zone becomes 237.41.

Taguchi Optimization Formula for Hardness of HAZ

From Table: 11, $P_{opt} = X + (I3-X) + (V2-X) + (S2-X)$, X = is the overall mean of S/N data = 47.15., I3 = mean of S/N data for welding current at level3 = 47.67., V2 = mean of S/N data for welding voltage at level2 = 47.43., S2 = mean of S/N data for welding travel speed at level2 = 47.31., Optimal condition for hardness of HAZ., $P_{opt} = X + (I3-X) + (V2-X) + (S2-X)$

$$P_{opt} = 47.15 + (47.67 - 47.15) + (47.43 - 47.15) + (47.31 - 47.15)$$

$$P_{opt} = 48.11\text{., Pedicted performance (hardness of HAZ); } Y^2$$

Y^2_{opt} optimal condition $= 10^{(P_{opt}/10)}$., $Y^2 = 10^{(48.11/10)}$, $Y^2 = 10(4.811) = 64714.2615748583$, $Y = \sqrt{64714.2615748583} = 254.39$. Therefore, the optimal value for hardness of HAZ becomes 245.39. Hence; the optimal value for hardness of HAZ at parameters of current 130 A, voltage, 35 V and speed 3 mm/s is 245.39.

Confirmatory Tests

The last step of the Taguchi methodology is confirmation or verification experiment verify the optimum conditions. If the predicted and observed values are close to each other, then model consider adequate for describing the effect of Parameters on quality characteristics. And if there is a large difference in observed values and predicted values then the model is not adequate.

OPCTM:-**Optimum parametric condition obtained by Taguchi method., MTSCT**:- Maximum tensile strength obtained by confirmatory test.

PPOTM: Prediction for parametric optimization by Taguchi method., **MHWZC:-** Maximum hardness of weld zone obtained by confirmatory test., **MHHZC:-** Maximum hardness of HAZ obtained by confirmatory test.

Table 13; depicts the comparison between the experimental and the theoretical values of the tensile strength, hardness of weld zone and heat affected zone of the welded specimens. The optimization is done by increasing the tensile strength, hardness of weld zone and hardness of HAZ. However; the tensile strength is increased from 491.97 Mpa to 494.47 Mpa with a minimum error of 0.508%. The hardness of weld zone has been increased from 254.39 to 269.77 and the hardness of HAZ increased from 237.41 to 255.06. The confirmatory test is done by taking the optimal parameters and the result into

Table 13. Comparison between actual (experimental value) and theoretical (expected value) of tensile strength, hardness of weld zone and hardness of HAZ

OPCTM		MTSCT	PPOTM	% Error
Current	110 A	494.47 Mpa	491.97Mpa	0.508%
Voltage	40 V			
Speed	3 mm/s			
OPCTM		**MHWZC**	**PPOTM**	
Current	130 A	269.77	254.39	6.04%
Voltage	40 V			
Speed	4 mm/s			
OPCTM		**MHHZC**	**PPOTM**	
Current	130 A	255.06	237.41	7.43%
Voltage	35 V			
speed	3 mm/s			

considerations to show that the improvement of the response variables is acceptable. The contribution of the parameters on the change of tensile strength, hardness of weld zone and hardness of heat affected zone are explained in terms of percentage. The parameter with higher percentage has a great contribution to the change and parameter with low percentage has low contribution on the performance change. Based on this principle; for tensile strength, voltage, current and speed have 83.24%, 13.14%, 3.57% percentage contribution respectively. Also for hardness of weld zone, current, voltage and speed have, 49.11%, 48.98%, 0.66% percentage contribution respectively. And for hardness of heat affected zone, current, voltage and speed have 72.13%, 20.59%, 6.85% percentage contribution for the change.

4 Conclusions

From this study following conclusions are made

1. For optimized parameter, the tensile strength is increased from 491.97 Mpa to 494.47 Mpa with a minimum error of 0.508%. Also, the hardness of weld zone has been increased from 254.39 to 269.77 and the hardness of HAZ increased from 237.41 to 255.06.
2. The parameter with higher percentage has a more contribution to the change and parameter with low percentage, has low contribution on the performance change. Based on this principle for tensile strength, voltage, current and speed have 83.24%, 13.14% 3.57% contribution respectively. For hardness of weld zone, current, voltage and speed have, 49.11%, 48.98%, 0.66% contribution respectively. And for hardness of heat affected zone, current, voltage and speed have 72.13%, 20.59%, 6.85% contribution for the change.

References

1. Kchaou, Y., Haddar, N., Hénaff, G., Pelosin, V., Elleuch, K.: Microstructural, compositional and mechanical investigation of shielded metal arc welding (smaw) welded superaustenitic uns n08028 (alloy 28) stainless steel. Mater. Des. **63**(3), 278–285 (2014)
2. Tong, L.G., Wang, L., Yin, S.W.: Influences of deposited metal material parameters on weld pool geometry during shield metal arc welding. Int. J. Heat Mass Transf. **90**(2), 968–978 (2015)
3. Kolhe, K.P.: Development and testing of tree climbing and harvesting device for mango and coconut trees. Indian Coconut J. **52**(3), 15–19 (2009). published by Ministry of Agriculture, CDB board Kochi Kerla
4. Kolhe, K.P.: Mechanized harvesting device A need of Coconut growers in India. Indian Coconut J. **73**(2), 15–19 (2010). published by Ministry of Agriculture, CDB board Kochi Kerla
5. Kolhe, K.P., Jadhav, B.B.: Testing and performance evaluation of tractor mounted hydraulic elevator for mango Orchard. Am. J. Eng. Appl. Sci. **4**(1), 179–186 (2011)
6. Kolhe, K.P., Powar, A.G., Dhakane, A.D., Mankar, S.H.: Stability and ergonomic design features of tractor mounted hydraulic elevator. Am. J. Eng. Appl. Sci. **4**(3), 380–389 (2011)
7. Kanakaraja, D., Reddy, A.K., Adinarayana, M., Vamsi, L., Reddy, K.: Optimization of CNC turning process parameters for prediction of surface roughness through Taguchi's parametric design approach. Int. J. Mech. Eng. Rob. Res. **3**(4), 708–714 (2014)
8. Jadhav, N.D., Patil, R.A.: Parametric optimization of spot welding metal by Taguchi approach. Weld. J. **3**(4), 857–860 (2015)
9. Thakur, P.P., Student, P.G.: Effect of GTAW-SMAW hybrid welding process parameters on hardness of weld. Weld. J. **10**(1), 782–786 (2017)
10. Kolhe, K.P., Datta, C.K.: Prediction of microstructure and mechanical properties of multipass SAW. J. Mater. Process. Technol. **197**(1–3), 241–249 (2007)