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Optimum welding process parameters investigation for mechanical properties of mild steel welded by GMAW

S.Gejendhiran[1], R.Titus[2], S.Subash Arunkumar[2], P.Arunkumar[2], B.Subash[2]
[1]Assistant Professor, [2]UG Students,
Department of Mechanical Engineering, Nandha Engineering College, Erode-52, Tamil Nadu, India.
[1] geja.mechanical@gmail.com, [2] titus.rts@gmail.com@gmail.com

Absract - Gas Metal Arc Welding (GMAW) process is the most widely used welding process for structural fabrication industries, owing to its high productivity and ease. This research investigates on the optimum welding process parameters for achieving better mechanical properties of weldment. In order to meet the requirement in terms of both welding efficiency and effectiveness, the Taguchi parametric design methodology and regression analysis is used. Weld Process parameters considered for this research are welding current, welding voltage, shielding gas. The process output characteristics are ultimate tensile strength, hardness and toughness of the weldment. After collection of data from the experimental work, signal to noise ratio were calculated and the optimum level of every process parameters was obtained by using Taguchi method. Subsequently by using the analysis of variance, the significant co-efficient for each input factor on the mechanical properties was determined and regression analysis is carried out for predicting the mechanical properties.In this research, the mechanical properties were obtained by welding of 10 mm Mild Steel IS 2062 thick plates in Gas Metal Arc Welding using Ar+18% CO_2, pure CO_2 and Ar+5% O_2 as the shielding gas mixtures. The optimum tensile strength was achieved in the shielding gas mixture Ar+18% CO_2 and also it provides the optimum toughness value. Pure CO_2 gives the superior hardness values when compared to other shielding gas compositions. The numerical results reveal that the shielding gas and welding current have significant effect on the mechanical properties of weldment.

Index words: Optimization, Design of Experimets, Taguchi Method, Experimental design

I. INTRODUCTION

GMAW is the very common welding process due to it speed,ease of use,ease of automation and speed of welding. GMAW is a less popular for under water welding process [1-4].High weld deposition rate, less distortion and less distortion are the other important advantages of welding process [4-9]. The important welding parameters like welding current, speed, voltage, arc gap and gas flow rate plays a major role in mechanical properties of MIG weldments.The proper shielding gas mixture is used to achieve better mechanical properties [10]. The pure carbon di oxide produces the maximum hardness values and the carbon di oxide mixes with the argon produces more tensile strength properties [10, 12, 16]. Thewelding current raises the deeperweld penetration.

And also the arc speed and welding voltage affects the deeper weld penetration. S.R.Patil et.al investigated to improve the strength of welded joints by optimization of various welding parameters [11]. The taguchi method is a statistical technique is mainly used for welding parameter optimization. Quality of weld, experiment performing and wastage of resources are reduced by using process Parameter optimization [13, 15].

II. MATERIALS AND METHODS

Mild steel is the easily available, most versatile and less cost form of steel and it provides every application which needs a bulk amount of steel. . It is softer and more easily shaped. The IS 2062 mild steel is selected as the base material for this research. The composition of chemical in IS 2062 mild steel is shown in the table-1.

TABLE 1. The composition of Chemical in IS 2062 Mild steel

GRADE	PERCENTAGE	C	Mn	Si	S	P
IS 2062	Minimum	0.23	1.5	0.045	0.40	0.045
	Maximum	0.25	1.55	0.050	0.43	0.050

From the literature review and the previous work done by researchers concluded that the below mentioned parameters are the most important process parameters which have the greater influence than other process parameters over the mechanical properties (Tensile strength, Hardness and Toughness) of the weldment.

The most important process parameters considered are, Welding Current (Amps), Welding Voltage (Volts), Gas Flow Rate (LPM) and Shielding Gas. Selection of level for the parameters depends upon the number of weld experiments were carried out and the range of MIG weld parameters.

Range of MIG welding parameter selection and their levels for the present study and the constant MIG welding parameters are shown in the Table-2 and table-3.

TABLE 2. MIGwelding parameters and the levels

S.No	welding Parameter	Unit	Level-1	Level-2	Level-3
1	Shielding Gas	-	Ar +18% CO_2 (1)	Pure CO_2 (2)	Ar+5%O_2 (3)
2	Welding Current	Amps	120	150	180
3	Welding Voltage	Volts	20	22	24

TABLE 3. Constant MIG welding parameters

S.No	MIG welding Parameter	Value
1	Electrode type	ER70S6
2	Wire diameter (mm)	1.
3	speed of welding (mm/sec)	2.2
4	feed rate of wire (m/min)	1.5
5	Metal thickness (mm)	10
6	Gas flow rate (LPM)	10

Selection of weld process parameters under the present study is three and the levels for each MIG weld parameter is three. To calculate Degrees Of Freedom (DOF) by using this formula,

Degree of freedom (DOF) = N*(n-1)

Where,N = Number of process parameters

n = Number of levels

DOF = 3*(3-1) = 6.

Hence, here orthogonal L9 array was selected. The selected orthogonal L9 array is tabulated in Table-4.

TABLE 4. Orthogonal L9 array

S. No	Shielding Gas	Welding current (A)	Welding voltage (V)
1	1	120	20
2	1	150	22
3	1	180	24
4	2	120	22
5	2	150	24
6	2	180	20
7	3	120	24
8	3	150	20
9	3	180	22

The dimensions of base material are 150 mm x 150 mm x 10 mm (breathxlengthxthick) & 50° groove angle have been prepared and the experiments are done based on orthogonal L9 array layout as tabulated in the table-4. Using acetone, the surface oxides or scales were thoroughly removed for all the samples.

III. RESULTS AND DISCUSSIONS

Tensile properties

Tensile test is to examine the plasticity,tensile characteristics and strengthand of weldments and to evaluate the involvement of defects on weldmentjoint. The UTM (universal testing machine) is used for examine the tensile properties. The tensile strength of all joints has been evaluated in transverse direction. theASTM E8M-04 standard is used for the tensile test specimen dimension and shape. The Tensile strengthof MIG weldments is tabulated in Table-5.

TABLE 5. Tensile strength of MIG welded specimen

Welding current (A)	Welding voltage (V)	Shielding Gas	Tensile strength (N/mm^2)
120	20	Ar+18%CO_2	392
150	22	Ar+18%CO_2	386
180	24	Ar+18%CO_2	388
120	22	Pure CO_2	387
150	24	Pure CO_2	384
180	20	Pure CO_2	379
120	24	Ar+5%O_2	381
150	20	Ar+5%O_2	378
180	22	Ar+5%O_2	375

The results are clearly noted that the supply shielding gas of argon+18 % carbon dioxide, which provides the best tensile properties than other, protecting gas supply in GMAW process.

Hardness properties

This test is evaluated to determine the weld metal hardness value. The hardness test was evaluated on the transverse direction of the MIG Welding region using the applied load 187.5 kgf, for the time span of 20 s. The test is performed on the Brinell hardness testing machine. The hardness value of welded specimen is shown in the Table 6.

TABLE 6. Hardness value of the welded specimen

Welding current (A)	Welding voltage (V)	Shielding Gas	Weld metal hardness
120	20	Ar+18%CO_2	178
150	22	Ar+18%CO_2	176
180	24	Ar+18%CO_2	174
120	22	Pure CO_2	180
150	24	Pure CO_2	177
180	20	Pure CO_2	172
120	24	Ar+5%O_2	175
150	20	Ar+5%O_2	172
180	22	Ar+5%O_2	170

The results are clearly noted that the supply shielding gas of pure carbon dioxide will provides the good hardness properties provides than other, protecting gas supply in GMAW process.

Impact properties

The test is evaluated to calculate the impact energy of weld metal and also check the values of results.

The impact test was performed on the transverse cross-section onMIG Welding region. Impact test is performed on Charpy impact testing machine. Toughness value from impact test of MIG weldments are tabulated in the Table-7.

TABLE 7. Toughness value of the welded specimen

Welding current (A)	Welding voltage (V)	Shielding Gas	Toughness Joules
120	20	Ar+18%CO_2	78
150	22	Ar+18%CO_2	80
180	24	Ar+18%CO_2	84
120	22	Pure CO_2	76
150	24	Pure CO_2	79
180	20	Pure CO_2	77
120	24	Ar+5%O_2	73
150	20	Ar+5%O_2	71
180	22	Ar+5%O_2	76

The results are clearly noted that the supply shielding gas of argon+18% carbon dioxide provides the best toughness properties than other, protecting gas supply in GMAW process.

Find optimum point for mechanical properties

In Taguchi method, Signal/Noise ratio, signal shows the advisable output characteristics value and the noise shows the unadvisable output characteristics values. The Signal/Noise ratio takes intoaccount on both the differences in response data and also the degree closeness of the response averages to the target value. Normally the ultimate tensile strength, toughnessand thehardness value of the welded specimen are in the category of larger the better quality features. All the three levels of three process parameters are equally represented in 9 experiments. Then evaluate the signal to noise ratio for all retaliationin the experiments. The signal/noise ratio for the tensile strength values are tabulated in the Table-8.

TABLE 8. Signal/Noise ratio for tensile strength

S. No	S/N ratio	S. No	S/N ratio	S. No	S/N ratio
1	51.865	4	51.754	7	51.618
2	51.731	5	51.686	8	51.549
3	51.776	6	51.572	9	51.480

To determine the optimum point for each parameter, the mean value of signal/noise ratio has been determined. The mean value of signal/noise ratio of every factor in everylevel for tensile strength is tabulated in the Table-9 and Figure-1.

TABLE 9. mean value of the Signal/Noise ratio for tensile strength

Process Parameter	Level 1	Level 2	Level 3
Welding Current	51.75	51.66	51.61
Welding Voltage	51.66	51.66	51.69
Shielding gas	51.59	51.67	51.55

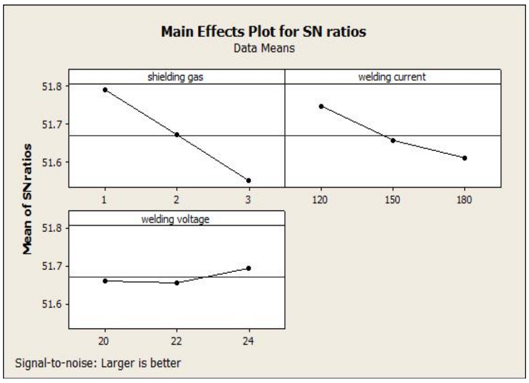

Fig. 1 influence of weld parameters on Signal/Noiseratio for Tensile Strength

The Table-9 and Figure-1shows the results of the mean value of S/N ratio for tensile strength of welded specimen, and then the optimum value for tensile strength is found it.

The optimum point is at a process parameter of welding current 120 Amps, welding voltage 24 Volts, shielding gas Ar+18% CO_2.

The S/N ratio for hardness and mean value of Signal/Noise ratio for Hardness is tabulated in Table-10 and Table-11.

TABLE 10. S/N ratio for Hardness

S. No	S/N ratio	S.No	S/N ratio	S.No	S/N ratio
1	45.008	4	45.105	7	44.860
2	44.910	5	44.959	8	44.710
3	44.811	6	44.710	9	44.6090

TABLE 11. mean value of Signal/Noise ratio for Hardness

Weld Parameter	Level-1	Level-2	Level-3
Welding Current	44.99	44.86	44.71
Welding Voltage	44.81	44.87	44.88
Shielding gas	44.91	44.93	44.73

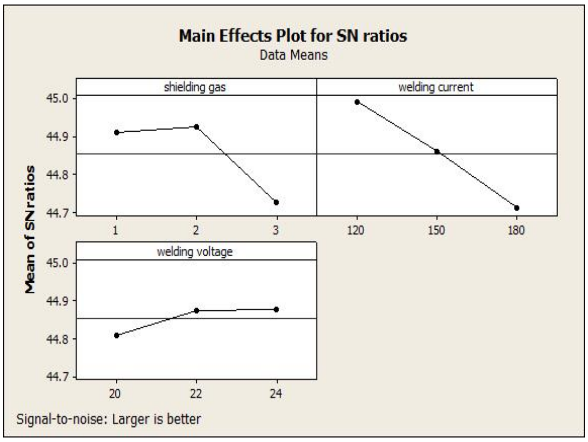

Fig. 2 influence of weld parameters on Signal/Noise ratio for Hardness

The Table-11 and Figure-2shows the results of the mean value of Signal/Noise ratio for hardness of welded specimen, and then the optimum value for hardness is found out.

The optimum process parameters are welding current 120 Amps, welding voltage 24 Volts and shielding gas is pure carbon dioxide.

The Signal/Noise ratio for toughness and the mean value of the Signal/Noise ratio for toughness of specimen is tabulated in the Table-12 and Table-13.

TABLE 12. S/N ratio for toughness

S.No	S/N ratio	S.No	S/N ratio	S.No	S/N ratio
1	37.841	4	37.616	7	37.266
2	38.061	5	37.952	8	37.025
3	38.485	6	37.729	9	37.616

TABLE 13. mean value of Signal/Noise ratio for toughness

Weld Parameter	Level-1	Level-2	Level-3
Welding Current	37.57	37.68	37.94
Welding Voltage	37.53	37.76	37.90
Shielding gas	38.13	37.77	37.39

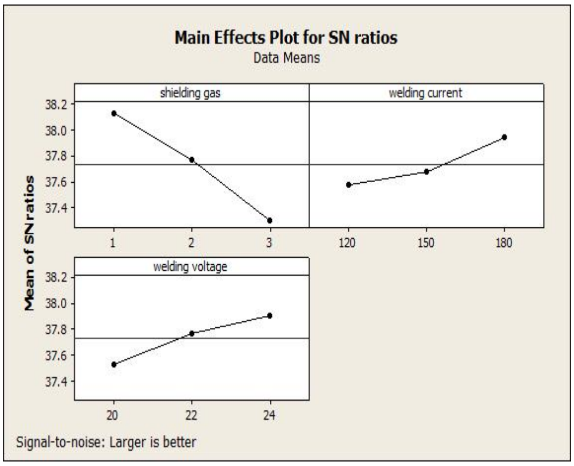

Fig. 3 influence of weld parameters on Signal/Noise ratio for Toughness

The Table 13 and Figure 3shows the results of the average value of Signal/Noise ratio for toughness of welded specimen, and then the optimum value for toughness is found it. The optimum point is at a process parameter of welding current 180 Amps, welding voltage 24 Volts, shielding gas Ar+18% CO_2.

Regression analysis

A regression analysis is established for predict the values of Y dependent variable, with the given a set of explanatory variables p (x_1,x_2…..x_p). The mathematical model provided can be used to determine a set a process parameters for a desired output characteristics. The input process parameter for equations are welding voltage, welding current, shielding gas and output characteristics are tensile strength, toughness and hardness of the welded specimen. Regression equation for the mechanical properties of the weldment is shown in below.

Tensile strength = 402 - 5.33 shielding gas - 0.100 welding current + 0.333 welding voltage

Weld metal hardness = 185 - 1.83 shielding gas - 0.0944 welding current + 0.333 welding voltage

Impact energy = Impact energy = 57.8 - 3.67 shielding gas + 0.0556 welding current + 0.833 welding voltage

Confirmation test

Optimum levels of design parameters is evaluated, then verify and predict the development of quality parameters using the optimum level of design parameters. Validation of optimum result as shown in the Table-14.

TABLE 14. Validation of optimum result

Mechanical properties	**Optimum point**	**Experimental value**	**Predicted value**
Tensile strength (N/mm^2)	A1 B1 C3	392	392.67
Hardness (BHN)	A2 B1 C3	178	178.4
Toughness (Joules)	A1 B3 C3	84	84.1

TABLE 15. Comparison between experimental values to the predicted values

	Ultimate tensile strength			**weld metal hardness**			**Impact energy**		
S.No	**E.V**	**E.V**	**E.V**	**E.V**	**E.V**	**Error%**	**E.V**	**P.V**	**Error%**
1	392	178	78	78	78	0.6	178	178.5	0.6
2	386	176	80	80	80	0.2	176	176.3	0.2
3	388	174	84	84	84	0.0	174	174.2	0.1
4	387	180	76	76	76	0.6	180	177.3	1.5
5	384	177	79	79	79	0.3	177	175.2	1.0
6	379	172	77	77	77	0.0	172	171.0	0.6
7	381	175	73	73	73	0.6	175	176.2	0.7
8	378	172	71	71	71	0.2	172	172.0	0.0
9	375	170	76	76	76	1.1	170	169.8	0.1

From the above table 15 show that the % of error between the experimental values to the predicted value is in the acceptable limit.

Identify the significant factor

The quality parameter characterises are significantly affected by design parameter, which is evaluated by ANOVA.Analysis of variance is done by using MINITAB software.

TABLE 16. The ANOVA table

	Source	**DF**	**Seq SS**	**Adi SS**	**Adj MS**	**F**	**P**
ultimate tensile strength	Shielding gas	2	170.67	170.67	85.33	19.69	0.048
	Welding current	2	56.00	56.00	28.00	6.46	0.134
	Welding voltage	2	4.67	4.67	2.33	0.54	0.650
	error	2	8.67	8.67	4.33		
	total	8	240				
		S = 2.08167		**R-Sq = 96.39%**		**R-Sq(adj) = 85.56%**	
weld metal hardness	Shielding gas	2	29.56	29.56	14.78	19	0.050
	Welding	2	48.22	48.22	24.11	31.00	0.031

	current						
	Welding voltage	2	3.56	3.56	1.78	2.29	0.304
	error	2	1.56	1.56	0.778		
	total	8	82.89				
		S = 0.881917		**R-Sq = 98.12%**		**R-Sq(adj) = 92.49%**	
toughness	Shielding gas	2	80.889	80.889	40.444	52.00	0.019
	Welding current	2	17.556	17.556	8.778	11.29	0.081
	Welding voltage	2	16.889	16.889	8.444	10.86	0.084
	error	2	1.556	1.556	0.778		
	total	8	116.88				
		S = 0.881917		**R-Sq = 98.67%**		**R-Sq(adj) = 94.68%**	

Analysis of tensile strength through ANOVA shows that, the shielding gas andwelding current are the most significant process parameters on the tensile strength of the MIG weldment. The welding voltage has the minor effect on the tensile strength for MIG weldment when compared to other process parameters. Similarly the ANOVA is carried out to the other response which shows, shielding gas and welding current is highly significant process parameter that affects the hardness of the weldment.The toughness value of the MIG weldmentis highly influenced by Welding current. Shielding gas has equal influence on the toughness of weldment. Conformation of experiment showed that the experimental observations are within 95% confidence level.

IV. CONCLUSION

In this research, the Taguchi method and the multiple linear regression analysis are determined the optimum weld parameters in gas metal arc welding. The signal/noise ratio and ANOVA technique used to study the influence of each parameter on the mechanical properties. The prediction of mechanical properties using numerical method is done by building a mathematical model.

The following conclusions are made based on the experimental results obtained.

- Using Taguchi method, the optimum process parameters for tensile strength are welding current - 120 Amps, welding voltage - 24 V, shielding gas - Ar+18% CO_2, gas flow rate - 10 LPM and corresponding tensile strength is 392 N/mm^2.
- For hardness, the optimum process parameters are welding current -120 Amps, welding voltage - 24 V, shielding gas - pure CO_2, gas flow rate - 10 LPM and the corresponding hardness value is 178 BHN.
- For toughness, the optimum process parameters are welding current - 180 Amps, welding voltage - 24 V, shielding gas - Ar+18% CO_2, gas flow rate - 10 LPM and the corresponding toughness value is 84 Joules.
- The maximum welding current and voltage increases the weldment impact strength and also reduces the weldments tensile strengthand weldment hardness.
- Finally using the regression analysis, predicted values and the experimental values are compared and the error percentage is within the acceptable limit.

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