Optimization of the process parameters for MIG welding of dissimilar welding using Taguchi method

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Abstract- Joining of dissimilar metals is really a challenging task due to different in their thermal, mechanical and chemical properties welded under a common welding condition. A variety of problems involves in dissimilar welding cracking, migration of atom during welding causing stress concentration on one side, large weld residue stress, compressive and tensile stresses, stress corrosion etc. To overcome these challenges, it is required to study the effect of welding process parameters on mechanical properties. However, joining of dissimilar metals has found its use extensively in power generation, nuclear reactors, electronic, petrochemical and chemical industries due to environmental concerns, high performance, energy saving, cost saving and so on. The aim of this research is to predict and optimize MIG welding of some economically important dissimilar materials in industry through applying a full factorial design of experiments, develop mathematical models and optimize the welding operation. This was achieved by controlling selected welding parameters; welding current, welding voltage and gas flow rate to relate the ultimate tensile strength and hardness to the selected input welding parameters. In the present study, stainless steel plate of AISI-304 has been welded with mild steel plate of IS: 1015 by Metal Inert Gas (MIG) welding processes.

The experiment results which are obtain corresponding to effect of different welding current (130, 135 and 140 Amp), different welding voltage (22, 24 and 26 Volt) and various gas flow rate (3, 4 and 5 m/min) on ultimate tensile strength and hardness of dissimilar welding, are use to find the significant of input parameter on output by using Taguchi and ANOVA method. The results were compared for different joints made by MIG welding processes and finally optimize the best combination of input parameter.

Keywords— SS 304, MS 1015, MIG welding, Tensile Strength, Hardness, Taguchi, ANOVA

I. INTRODUCTION

Welding is a manufacturing process of creating a permanent joints obtained by the fusion of the surface of the parts to be joined together, with or without the application of pressure and a filler material. The joint materials may be similar or dissimilar to each other. The heat required for the fusion of the materials may be obtained by burning of gases or by an electric arc. The latter method is more extensively used because of the greater welding speed. Welding is commonly used in fabrication as an alternative method for casting or forging and as a replacement for bolted and riveted joints. It is also used as a repair medium. There are different kinds of metals feature different physical, chemical and metallurgical properties usually join through various metals joining process. Joining dissimilar metals are different properties of metals in order to minimize material costs and at the same time maximize the performance of equipment. In present the method of joining dissimilar metals include brazing, fusion welding, and soldering. In the present article, we discusses only fusion welding, because it is uses in wide range of industries. Dissimilar metal welding joint refers to the joining of two different alloy systems. There are all fusion welds have dissimilar metal welds because the metals are joined have a wrought structure and weld have a cast structure. Composition of filler wire used is deliberately altered from that of the base alloy [1]. The presence of chromium (16-26), along with nickel (6-21), enhances its strain resistance, corrosion and strain hardening properties.

MIG welding is an arc welding process in which heat is generated by arc between a consumable electrode and the work piece. The consumable electrode is in the form of wire reels which is fed at a constant rate, through the feed rollers. The welding torch is connected to the gas supply cylinders which provide necessary inert gas. Inert gas provide gaseous shield to protect the adjacent area of base metal from atmospheric contamination [2]. Shielding gas used in MIG welding is CO_2, argon etc.

II. LITERATURE REVIEW

L.Suresh Kumar et al. [**3**] have investigated for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding. The mechanical properties

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of austenitic stainless steel for the process of MIG and TIG welding have discussed here. The welding voltage has taken constant and various characteristics such as strength, hardness, grain structure, ductility, tensile strength breaking point, HAZ have observed in these two processes.

Vikas Chauhan et al. [**4**] have optimized process parameters of MIG welding for Stainless Steel (SS-304) and low carbon steel using Taguchi design method. Three parameters of MIG welding viz. welding current, voltage and travel speed were taken for the analysis. The analysis for signal-to-noise (S/N) ratio was use for higher-the-better quality characteristics. The significance of each process parameter was studied by using the ANOVA (Analysis Of Variance). Finally the confirmation tests were performed to compare the predicted value with the experimental values which confirm its effectiveness.

Radha Raman Mishra et al. [**5**] have studied on dissimilar metals joint as a structural material for various industrial applications which provided good combination of mechanical properties like toughness, strength, corrosion resistance with lower cost. In the present study, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joint were calculated and tensile strength of dissimilar metals joints was investigated. The results were compared for different joints made by TIG welding and MIG welding processes and it was observed that the TIG welded of dissimilar metal joints have better physical properties than MIG welded joints.

Dinesh Mohan Arya et al. [**6**] have performed the optimization process parameters for Metal Inert Gas (MIG) Welding. This paper presented the influence of welding parameters like welding current, wire diameter, arc voltage, welding speed and gas flow rate optimization based on bead geometry of welding joints. The objective function have been chosen in relation to parameters of Metal inert gas welding bead geometry, Tensile strength, Bead width, Bead height, Penetration and Heat Affected Zone (HAZ) for quality target. Analysis Of Variance (ANOVA) has also applied to identify the welding current is the most significant factor. Experiment with optimized parameter setting, which have been obtained from the analysis.

Pawan Kumar et al. [**7**] have obtained the use of Taguchi's parameter design methodology for parametric study of Gas Metal Arc Welding of Stainless Steel & Low Carbon Steel. The input process variable considered here includes welding current, welding voltage and gas flow rate. A total no. of 9 experimental runs were conducted using an L9 orthogonal array, and calculate the signal-to-noise ratio. Subsequently, using the Analysis Of Variance (ANOVA) significant coefficients for each input parameter on tensile strength & Hardness (PM, WZ & HAZ) were determined.

III. EXPERIMENTAL SETUP

The machine used for performing the MIG welding is MAXIMIG 251 CD, having maximum voltage supply is 415 volts with Forced air type cooling and semi automated welding set up. In this MIG welding machine automated Metal Inert Gas torches and automated feeding units have provided.

Fig 1: MAXIMIG 251 CD MIG welding machine
(Courtesy: Production Workshop, B.I.T Mesra, Ranchi)

A. Material selection

The present study has been carried out with stainless steel plate of AISI 304 and mild steel plate of IS 1015 having thickness 4mm. This material is used for general industrial purpose.

Table 1: Chemical composition

Material composition	C	Mn	Si	Cr	Ni	P	S
Weight % AISI- 304	**0.06**	**1.24**	**0.23**	**19.44**	**9.12**	**0.035**	**0.025**
Weight % IS: 1079	**0.11**	**0.41**	**-**	**-**	**-**	**0.03**	**0.023**

B. Proposed Design of Experiment

For this present investigation, three number of process parameters each having three levels is taken into consideration. The L_9 orthogonal array [8] was used.

Table 2 Orthogonal Array (L_9) and control parameters

Exp. no	Current (A)	Voltage(B)	Wire feed rate (C)
1	130	22	3
2	130	24	4
3	130	26	5
4	135	22	4
5	135	24	5
6	135	26	3
7	140	22	5
8	140	24	3
9	140	26	4

C. Experimental parameter

Input parameters: Welding current, welding voltage and gas flow rate.
Output parameters: Tensile strength and hardness

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Table 2: control Factor and their level

SI. NO	Factors	Symbol	Unit	Level 1	Level 2	Level 3
1	Welding current	A	Ampere	130	135	140
2	Welding voltage	B	Volt	22	24	26
3	Gas flow rate	C	m/min	3	4	5

D. Taguchi Methodology

The standard S/N ratio use is generally as follows:

- Smaller is better
- Larger is better
- Nominal is best

The S/N ratio (η) is mathematically represented as

η = -10log10 (MSD) [**9**]

Larger is better type

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}$$

Where yi = Observed data (quality characteristics) at the ith trial

n = Number of trials

MSD= Mean Square Deviation from the desired value and commonly known as quality loss function.

E. Experimental work

Welding specimen has been prepared for MIG welding joints. The specimen in the form of block with dimension 130mm x 70mm x 4mm was considered for welding with butt joints. Welding process is carry by MIG welding machine. Experimental was conducted based on full factorial design.

IV. MEASUREMENT OF TENSILE STRENGTH

Tensile strength is measure by the use of Universal testing machine with maximum capacity 1000 N.

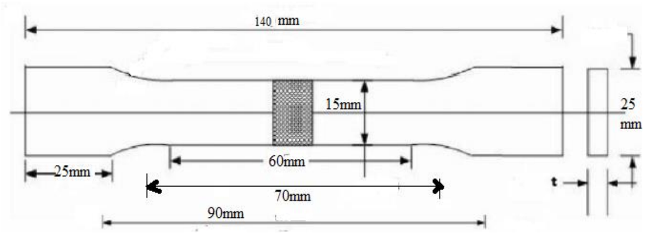

Fig 2: Standard size of specimen for tensile test

The observed values of tensile test responses are shown in table 3. Higher Tensile strength is better hence higher is better S/N ratio is selected.

Table 3: Result of tensile strength with S/N ratio

Exp. No.	Current (Amp.) A	Voltage (Volt) B	Wire feed Rate (m/min) C	Tensile Strength (MPa)	S/N Ratio
1	130	22	3	460	53.2552
2	130	24	4	453	53.1220
3	130	26	5	456	53.1779
4	135	22	4	468	53.4049
5	135	24	5	446	52.9867
6	135	26	3	453	53.1220
7	140	22	5	435	52.7698
8	140	24	3	422	52.5062
9	140	26	4	442	52.9084

Table 4: S/N ratio response table for Tensile strength

Symbol	Parameters	Level1	Level 2	Level 3	Delta	Rank
A	Current	53.19	53.17	52.73	.46	1
B	Voltage	53.14	52.87	53.07	.27	2
C	Wire feed rate	52.96	53.15	52.96	.18	3

Regardless of category performance characteristics, a greater S/N ratio value is corresponding to a better performance on these parameters.

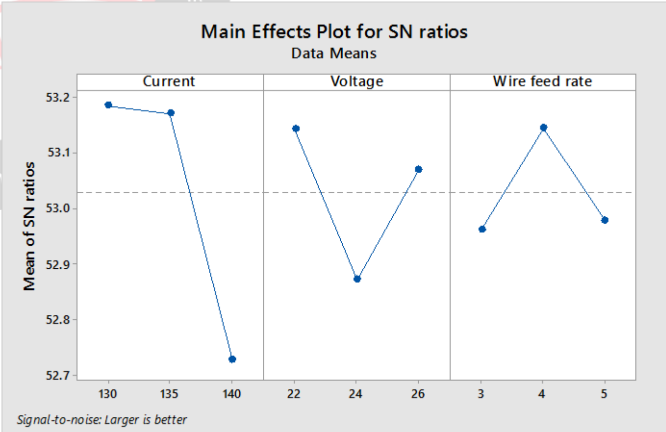

Fig 3: Graph between mean S/N ratio and levels of parameters for tensile strength

In this experiment analysis, the main effect plot in fig 3 has been used to estimate the tensile strength in optimal condition. Graph is plotted between means of S/N ratio and input parameters current, voltage and wire feed rate. In order to obtain maximum tensile strength, the current should be 130 Ampere; voltage should be 22 Volt and wire feed rate should be 4 m/min has been chosen.

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A. ANOVA for Tensile strength

The ANOVA analysis for ultimate tensile strength verses current, voltage and gas flow rate by using Minitab 18 software are shown in Table 5. This analysis done by the Minitab software, if the values of probability are less than 0.05, it indicated that the factors are significant to the response parameters.

Table 5: ANOVA of Ultimate tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F Value	P Value	Percentage contribution
Current	2	0.005376	0.005376	0.002688	129.79	0.008	68.85
Voltage	2	0.001571	0.001571	0.000785	37.91	0.026	20.11
Wire feed rate	2	0.000820	0.000820	0.000410	19.80	0.048	10.50
Error	2	0.000041	0.000041	0.000021			0.53
Total	8	0.007809					100

From ANOVA result for Tensile Test it is observed that the voltage, current and feed rate all three are influencing parameter for tensile strength and P Value for input parameters "current" are lowest which is 0.008 these parameter current are highly influencing parameter. P Value for voltage are higher than current which is 0.026, voltage are less influence than current. P Value for wire feed rate are highest of all three parameters but less than 0.005 hence it is less influence on tensile strength. Above results also describe the percentage contribution of individual process parameters on tensile strength of MIG Welding. The percentage contribution of current is 68.85%, voltage is 20.11%, wire feed rate is 10.50% and error is 0.53%. This error is due to machining vibration.

V. MEASUREMENT OF HARDNESS

One measurement for each run was made for hardness using Brinell Hardness Machine. The observed values of hardness response are given in Table 6. Higher the hardness value is good hence higher is better S/N ratio is selected. S/N ratio is evaluated by the use of software Mini Tab 18.

Table 6: Results of Hardness and S/N ratio

Exp. No.	Current (Amp.) A	Voltage (Volt) B	Wire feed Rate (m/min) C	Hardness (HRB)	S/N Ratio
1	130	22	3	98	39.8245
2	130	24	4	96	39.6454
3	130	26	5	102	40.1720
4	135	22	4	112	40.9844
5	135	24	5	109	40.7485
6	135	26	3	104	40.3407
7	140	22	5	116	41.2892
8	140	24	3	100	40.0000
9	140	26	4	104	40.3407

Table 7: S/N ratio response table for Hardness

Symbol	Parameters	Level 1	Level 2	Level 3	Delta	Rank
A	Current	39.88	40.69	40.54	.81	1
B	Voltage	40.70	40.13	40.28	.57	3
C	Wire Feed Rate	40.06	40.32	40.74	.68	2

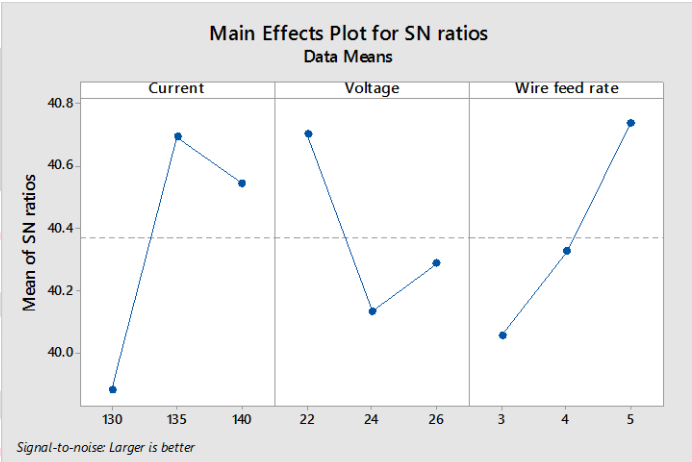

Fig 4: Graph between mean S/N ratio and levels of parameters for Hardness

In this experiment analysis, the main effect plot in figure 4 has been used to estimate the hardness in optimal conditions. Graph is plotted between means of S/N ratio and input parameters current, voltage and wire feed rate. In order to obtain maximum hardness, the current should be 135 Ampere; voltage should be 22 Volt and wire feed rate should be 5 m/min has been chosen.

A. ANOVA for hardness

The ANOVA analysis for ultimate hardness verses current, voltage and gas flow rate by using Minitab 18 software are shown in Table 8.

Table 8: ANOVA of Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F Value	P Value	Percentage contribution
Current	2	168.979	168.979	84.4897	108.97	0.009	51.41
Voltage	2	63.309	63.309	31.6547	40.76	0.024	19.26

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Wire feed rate	2	94.835	94.835	47.4177	61.06	0.016	28.85
Error	2	1.553	1.553	0.7766			0.47
Total	8	328.677					100

From ANOVA result for Hardness test it is observed that the voltage, current and feed rate all three are influencing parameter for hardness because P Value of all three parameters is less than 0.05. P Value for input parameters "current" are lowest which is 0.009 these parameter current are highly influencing parameter on hardness. P Value for wire feed rate are higher than current which is 0.016, wire feed rate are less influence than current on hardness. P Value for "voltage" is highest of all three parameters but less than 0.005 hence it is less influence on hardness. Above results also describe the percentage contribution of individual process parameters on hardness of MIG Welding. The percentage contribution of current is 51.41%, wire feed rate is 28.85%, voltage is 19.26% and error is 0.47%. This error is due to machining vibration.

VI. CONFORMATION TEST

The conformation experiment done to validates the initial experiment results obtained and the conclusion of experiment. 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 n_m is total mean of S/N ratio, n_i 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.

A. Conformation test for tensile strength

$$\eta_{opt} = n_m + (n_{A1}-n_m) + (n_{B1}-n_m) + (n_{C2}-n_m)$$

n_m = mean of S/N ration = 53.0281

n_{A1} is the mean of mean of S/N ratio data for welding current at level 1, n_{B1} is the mean of S/N data for welding voltage at level 1 and n_{C2} is the mean of S/N data for wire feed rate at level 2.

η_{opt} = 53.0281+ (53.19-53.0281) + (53.14-53.0281) + (53.15-53.0281) = 53.444

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

$Y^2_{opt} = (10)^{53.444/10}$ =221003.94

Y_{opt} = 470.22

So, Optimum value of tensile strength =470.22

From this we conclude that optimum value of tensile strength at the parameters of welding current 130 ampere, welding voltage 22volts and wire feed rate 4 m/min.

Table 9: Conformation test for tensile strength

	Initial Parameter setting	Optimal MIG welding parameters	
		Predict value	Experiment value
Level	$A_1B_1C_1$	$A_1B_1C_2$	$A_1B_1C_2$
Tensile strength (MPa)	460	470.22	**468.12**
S/N ratio	53.2552	53.444	**53.362**

B. Conformation test for Hardness

$$\eta_{opt} = n_m + (n_{A2}-n_m) + (n_{B1}-n_m) + (n_{C3}-n_m)$$

n_m = mean of S/N ration = 40.3717

n_{A2} is the mean of mean of S/N ratio data for welding current at level 2, n_{B1} is the mean of S/N data for welding voltage at level 1 and n_{C3} is the mean of S/N data for wire feed rate at level 3.

η_{opt} = 40.3717+ (40.69-40.3717) + (40.70-40.3717) + (40.74-40.3717) = 41.397

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

$Y^2_{opt} = (10)^{41.397/10}$ =13794.32

Y_{opt} = 117.5

So, Optimum value of hardness =117.5

From this we conclude that optimum value of hardness at the parameters of welding current 135 ampere, welding voltage 22volts and wire feed rate 5 m/min.

Table 10: Conformation test for Hardness

	Initial Parameter setting	Optimal MIG welding parameters	
		Predict value	Experiment value
Level	$A_1B_1C_1$	$A_2B_1C_3$	$A_2B_1C_3$
Hardness (MPa)	98	117.5	**115.2**
S/N ratio	39.8245	41.397	**40.743**

VII. CONCLUSION

In this project a Taguchi orthogonal (L_9) array, the signal to noise (S/N) ratio and analysis of variance (ANOVA) were used to optimize the MIG Welding process parameters of dissimilar material joints of stainless steel and mild steel. The following conclusion can be drawn based on the experimental results of this project work.

- The experiment design by Taguchi method full fills the desire objective. ANOVA has been used to find contribution of process parameters on welded joint.
- From the ANOVA results, it is found that welding current are most significant parameters for tensile strength and its contribution is 68.85%, welding voltage contribution is 20.11% and wire feed rate contribution is 10.50%.
- ANOVA result for hardness, it is found that welding current most significant and its contribution is 51.41%, wire feed rate contribution is 28.85% and voltage contribution is 19.26%.
- The optimum welding condition obtained by Taguchi method for maximum tensile strength is $A_1B_1C_2$ (i.e. welding current=130 ampere, voltage =22volts, wire feed rate=4m/min) and for maximum hardness is

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$A_2B_1C_3$ (i.e. welding current =135ampere, voltage =22volts, wire feed rate =5m/min).

- Conformation test confirms the improvement of tensile strength and hardness which is also indicates the validity of the present optimization procedure by Taguchi method.

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