

PARAMETRIC OPTIMIZATION OF METAL INERT GAS WELDING BY USING TAGUCHI APPROACH

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Abstract

The present work deals with optimization of welding process variables by using Metal inert gas welding. In this process input variables are voltage (V), current (A) and welding speed(S) with tensile properties, hardness, and penetration as responses of low carbon steel (ASTM A29). The design of experiments based on Taguchi orthogonal array [L9], acquires Analysis of variance (ANOVA) to determine the influence of parameters with the optimal condition.

Keywords: MIG Welding, Mild Steel, Taguchi Approach, Hardness, Tensile Strength.

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1. INTRODUCTION

Welding is a process of joining metal parts or we can say it is fabrication process, in which by heating the surfaces of the workpiece with the help of arc (may be mechanical or electrical) or by other means and uniting them by hammering or pressing, etc. We know that MIG welding is one of most versatile technique till now in modern production technology and most importantly, it is suitable for both either for thin sheet or thick section components. Basically, in this process, an electric arc is produced between the consumable wire electrode and the workpiece, due to this heat workpiece metal melts and join. Now in order to protect weld pool from contamination from the atmosphere, i.e. Moisture or oxygen, we are using inert gasses like argon, helium or a mixture of argon-helium or by a mixture of argon-carbon dioxide. While compared to other welding process in this method we are not providing any external filler metal because the wire electrode provides the arc as well act as a filler metal [1]. Now in this experiment we are using mild steel, so basically mild steel means which contain only a small percentage of carbon and also it is strongest and most important it is not easily tempered or hardened. As we know that using high carbon steel it is very difficult to weld, as mild steel is easy to weld and most important fact that most of the people are not aware of this fact that certain types of high carbon steel, for example, stainless steel and special technique are used for welding due to that reason that, it is less brittle than high carbon steels. The mild steel is more flexible than other steel [6]. We all know about that MIG welding, widely used in most of the industry sectors due to its flexibility, deposition rates, and suitability. So, in this era, determination of optimum values of process parameters in the manufacturing industry are the area of greatest interest for either for manufacturing engineers or researchers. Most importantly, this process parameter plays a vital role in determining the quality of a welded joint. There are various parameters will affect the

welding because this parameter varied over a large extend. Since they are considered as the primary adjustments i.e. tool in any welding process. We all knew that the depth of penetration is the most dominant magnitude related to the weldability of the processes material, the welding conditions, and the strength requirements. Therefore, we have to attempt in such a way that the depth of penetration should be maximized. The most important thing that penetration is indirectly proportional to welding speed and electrode diameter and penetration decreases with the increase in the welding speed because the time during which the arc force is allowed to penetrate into the material's, thus surface decreases [20]. So, the demand for producing joints of dissimilar materials is continuously increasing due to cost reduction and also good mechanical properties. As we discuss earlier that it is extensively used in manufacturing industries due to its simple technique and very easy to learn and use, so welding defects can be minimized easily, as this process, there is no slag and machine can run by automatic or semi-automatic, so less skilled worker can easily complete his task easily, metal deposition rates are high and a lot more advantage than other forms of welding. Their application such as aluminum, copper, stainless steel and carbon steel can be joined with the help of MIG welding via suitable electrode, shielding gas and different welding conditions [3-5].

The present work mainly focuses on the weldability of ASTM A29 with the process of MIG welding. The work details of process parameters (welding voltage, welding current and wire speed) influence on the response (Tensile strength and Hardness) by using analysis of variance (ANOVA) with the help of Taguchi array [L9].

2. LITERATURE REVIEW

Ajit Hooda et al., 2012 [3] conducted an experiment, in this experiment they are going to develop a response surface

model to the measured tensile strength of AISI 1040 carbon steel joints of MIG welding. They have chosen process parameters such as voltage, wire speed, current, and gas flow rate. In this experiment, they found that longitudinal strength is more effect than the transverse yield strength. Now for future references they state the relationship between the transverse and longitudinal yield strength by comparing their value and give detail for studying their microstructure.

B. Mishra et al., 2014 [1] conducted an experiment on MIG welding parameter optimization. In this experiment, they present the effect of welding parameters like voltage, speed, current on the depth of penetration on AISI 1020 steel during welding. They made their experiment based on Taguchi technique from where they optimize the welding parameters as well as the process. Finally, they get conduct tests, from where they carried out the difference between the predicted values with the experimental values to find the effective result of analysis of the penetration and finally they got experimental value are for penetration is 5.82mm and for S/N ratio is 15.01.

H. J. Park et al., 2008 [4] conducted an experiment. In this experiment, they conducted various wire feed speeds range from 0.5m/min to 1.5m/min and also the bead characteristics were evaluated and shape factors of the bead width, back bead width, weld bead and bead cross section area are measured. According to their weld quality, the wire speed is optimized by varying welding speed. After the experiments, they found that wire feed speed is optimized at welding speeds of 0.50m/min, a. 0m/min, and 1.5m/min.

Satyaduttsinh P. Chavda et al., 2014 [5] conducted an experiment. They have taken medium carbon steel and optimize the welding parameters. Finally, conduct the test to compare with the predicted number with the experimental number to confirm its results in the analysis of weld strength and depth of penetration.

Vikas Chauhan and Dr. R.S Jadoun in 2014 [6] conducted an experiment. In this method, the analysis for signal-to-noise ratio was done by using the MINITAB-15 software. Finally, they conduct the test to compare the predicted values and experimental values, to confirm its results in the analysis of the tensile strength of the joint. In these experiments, they get an average value of UTS is 549.85 N/mm², which is within the confidence interval for the predicted UTS at an optimum level. The percentage error between the predicted value and the experimental value is found in 1.97%.

Diganta and Parimal Bakul Barua in 2015 [7] conducted experiments on Taguchi optimization of MIG welding parameter those are affecting tensile strength of C20 welds. In this experiment, they are going to find out three process parameters of the MIG welding i.e. current, voltage and gas flow rate on the tensile strength of welded joints which is having Grade C20 Carbon Steel as the parent metal and ER70S-4 electrode. This experiment was designed by using

Taguchi's Orthogonal Array L9. Finally, conduct the test to predict the mean tensile strength is 475.87 N/mm².

Vineeta Kanwal *et al.*, 2015 [2] conducted experiments on optimization of MIG welding parameters for the hardness of aluminum alloys using Taguchi method. The materials used are aluminum alloys of grade 6061 and 5083 having a dimension of (75x60x6) mm. In this experiment Argon gas used as shielding gas. Finally, they found that both aluminum alloys 5083 and 6061 having great hardness, and most important that welding current has more effects on the hardness of welded sample.

S. V Sapakal *et al.*, 2012 [8] conducted an experiment. In this experiment shows the effect of welding parameters like welding voltage, current speed on the depth of penetration of MS C20 metal. Finally, conduct the test to compare the predicted numbers with the experimental numbers to confirm its results in the analysis of penetration. Finally, they got the penetration is 5.25mm and S/N ratio is 14.40.

Milind M. Ghogale *et al.*, 2013 [9] conducted an experiment. This paper represents an experimental study to investigate the effects of welding parameters, i.e. welding current, voltage, and gas flow rate on cold rolled steel of 3mm thick steel strip. From this experiment, they get a conclusion that most influence the parameters on penetration are current and voltage while the gas flow rate is less significant as compared to current and voltage.

Vikas Mukhraiya *et al.*, 2014 [10] conducted an experiment on parametric optimization of MIG welding with the help of Taguchi method. In this paper represent the investigation at the optimization of welding parameters and effect on the torsional rigidity of MIG welded steel of ST-37 rod.

Praful Kumar in 2015 [11] conducted an experiment on parametric optimization of angular distortion on mild steel by using MIG welding. Since it is very difficult to obtain a complete analytical solution to predict the angular distortion in welding. In this experiment, they are using Mild Steel AH36 grade 20 mm plates. Finally, after the experiment, they conclude that the optimal value of angular distortion is 6.64° and also that the angular distortion increases with the increase in the number of passes within the design range of the parameters.

Er. Rahul Malik *et al.*, 2015 [12] conducted an experiment on parameter optimization for tensile strength & hardness of MIG welding joint of HSS & mild steel by using Taguchi technique. In this experiment, they are using high-speed steel of grade M2 and low carbon steel under varying parameters. They finally conclude that Taguchi parametric design process is best suitable for the cost of operation.

Faseeulla *et al.* (2012) [13] conducted an experiment. Finally, after experiments they get the maximum tensile shear strength of the welded sample.

G. Haragopal *et al.* (2011) [14] presented an experiment. This experiment was conducted using the L9 orthogonal array. Finally, a confirmation test was conducted at the optimum condition to predict correctness of the analysis.

Omar Bataineh *et al.* (2012) [15] conducted an experiment. After the experiment they set, a conclusion that at voltage 24 V and filler rate is 7 in/s, at the same time mean weld strength is maximized.

Pawan Kumar *et al.* (2013) [16] conducted an experiment. They conducted a total nine number of experimental runs using orthogonal array (L9) and finally they get the tensile strength and hardness i.e. WZ and HAZ.

Sudesh Verma *et al.* (2014) [17] conducted an experiment. In this experiment, they obtain better bead height and bead width separately.



Fig-1: MIG welding setup

3. METHODOLOGY

In this experimental work, as shown in Fig-1, setup of MIG welding, we are going to weld the specimen, the sample is welded at four different levels of welding parameter, i.e. welding current, welding voltage, wire speed as shown in Table 1. Taguchi is a most widely used in manufacturing industry, which is use to predict optimal performance level based on optimal control factor level combination and conduct a confirmation experiment to verify the results product designed. Most important Taguchi Experiments verification is done on the basis of the orthogonal array (L9) technique using MINITAB-16 [18].

Table-1: Welding parameter and their levels

Parameters	Welding Voltage(V)	Welding current(A)	Wire speed
Units	Volt	Amp	RPM
Symbol	V	A	S
Level 1	20	200	2.2
Level 2	22	215	2.65
Level 3	24	230	3.1

Table-2: Chemical Composition of Low Carbon Steel ASTM A29

Element	%
Carbon	0.70-0.80
Iron, Fe	98
Manganese, Mn	0.40-0.70
Sulphur, S	0.05
Phosphorous, P	0.04

In this process, authors are utilized the sample with dimension of 200x100x90mm along with groove of 60° on each face of with help of Hacksaw driven by motor [19]. The chemical composition of Low Carbon steel ASTM A29 is shown in Table-2.

Table-3 L9 Orthogonal Array Design matrix

Run	V	A	S
1	20	200	2.2
2	20	215	2.65
3	20	230	3.1
4	22	200	2.2
5	22	215	2.65
6	22	230	3.1
7	24	200	2.2
8	24	215	2.65
9	24	230	3.1

Total nine experiments were done based on orthogonal array (L9) shown in Table 3. The main effect of different parameters such as welding voltage, current and wire speed of low carbon steel ASTM A29 was analyzed and observed the hardness and tensile strength of all nine weld metal and observed the value of hardness and tensile strength with its S/N ratios are predicted in Table 4. Fig. 2 shows the figure of welded sample.

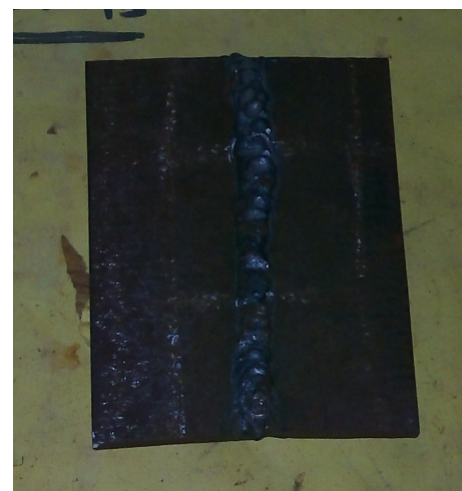


Fig-2: Welded Sample of Low Carbon Steel ASTM A29

For measuring micro-hardness they are first rubbed with emery paper size no. 1/0, 2/0 & 4/0 and then clean with the help of acetone solution.

Table- 4: Response of Tensile and Hardness with S/N ratio.

Run	Tensile Strength (Mpa)	S/N Ratio	Hardness HAZ	S/N Ratio
1	351.2	50.91109	168.5	44.532
2	325.2	50.243011	147.5	43.376
3	315.1	49.968968	156.5	43.89
4	481.2	53.646512	247	47.854
5	382.5	51.652629	189	45.529
6	325.6	50.253688	166.5	44.428
7	425.1	52.569822	219	46.809
8	352.2	50.935787	153.5	43.722
9	342.1	50.683061	179.5	45.081

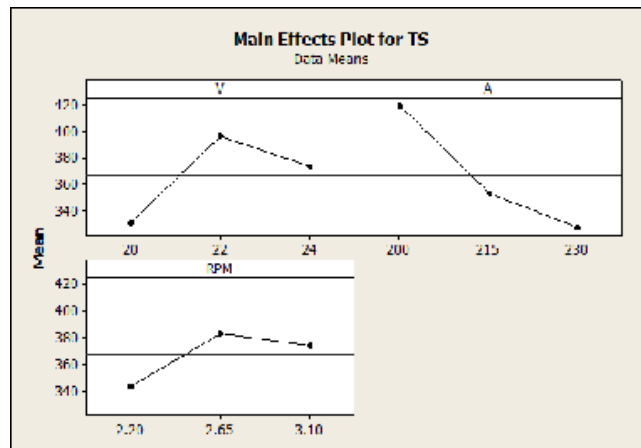


Fig-4: Main Effects plot of process parameters on tensile strength for S/N ratio

4. RESULTS AND DISCUSSION

Fig. 3 predict the various steps in the Taguchi analysis [19]. Analysis of variance (ANOVA) is a statistical tool used to analyze the S/N ratios. We also know that the term “signal” represents the desirable mean value, and the “noise”-undesirable value. Hence, we can say that S/N ratio show the amount of variation, which is presented in the performance characteristics.

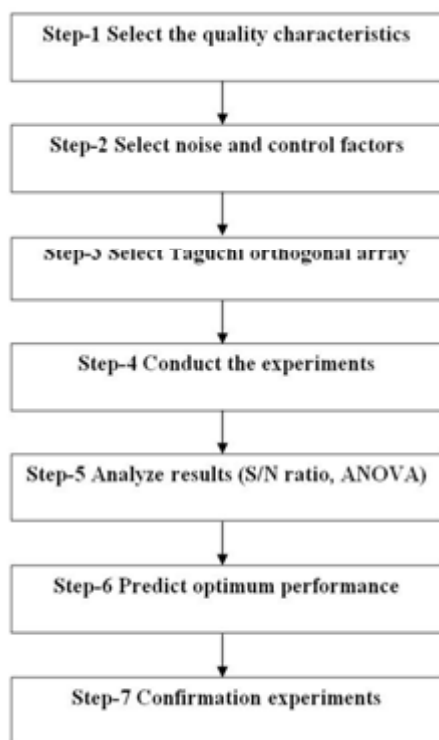


Fig-3: Steps of Taguchi’s Analysis

4.1 ANOVA of Tensile Strength

In this experiment, Tensile strength is calculated experimentally and Taguchi method is used for the analysis with the help of ANOVA (L9). According to data are found, we get a graph of the signal-to-noise (S/N) ratio is shown in Fig-4. The calculated S/N ratio is shown in Table 4.

The ANOVA is one of the most widely used methods for portioning variability into an identifiable source of variation and the associated DOF in an experiment. F-test for analyze the significant effects of the process parameters, which form quality characteristics. In Table-5 show, the result of ANOVA analysis of S/N ratio of low carbon steel ASTM A29.the ANOVA obtained R² and R_{adj}² as 96.3 and 85.2%. The ANOVA revealed the influence of process parameters with a response. Welding current (A) is the most influencing parameter (57.25%) and followed by the welding voltage (V) as (29.05%) and wire speed as 10%. The influence of parameters such as voltage, current, and wire speed was analyzed on table-6. It is observed that the process parameters with the greater S/N ratio will have optimum quality with less variance.

Table-5: Analysis of Variance for Signal to Noise Ratio of tensile strength

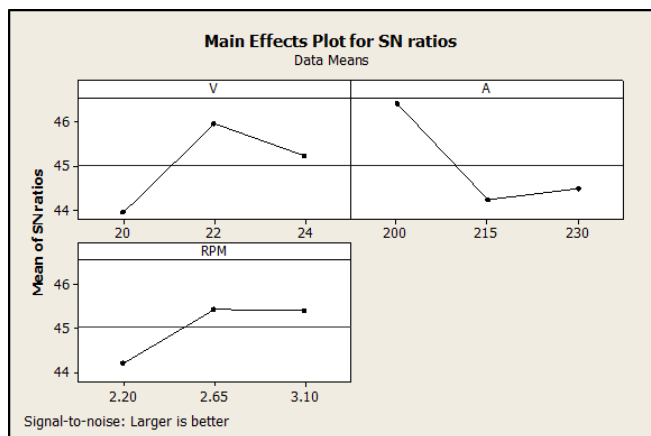
Source	DF	Seq Ss	Adj SS	Adj MS	F	P
V	2	3.4313	3.4313	1.7156	7.84	0.113
A	2	6.7637	6.7637	3.3819	15.46	0.061
S	2	1.1809	1.1809	0.5904	2.70	0.270
Error	2	0.4376	0.4376	0.2188		
Total	8	11.8135				

The response value for S/N ratio is shown in Table-6 which shows their ranking and factors level values of each factor. From the response tables, the optimal condition for Tensile strength as the welding current (A 3) is a dominant parameter on the tested specimens, followed by welding voltage (V1) and wire speed (S1). The ranking of the parameters is shown in Table 6. This refers the optimal condition of Tensile strength as V1A3S1.

Table-6: Response Table for S/N Ratio for Tensile Strength

LEVEL	V	A	S
1	50.37	52.38	50.70
2	51.85	50.94	51.52
3	51.40	50.30	51.40
DELTA	1.48	2.07	0.82
RANK	2	1	3

4.2 ANOVA of Hardness

**Fig-5:** Effects of process parameter on hardness S/N ratio

From Fig. 5 it was observed that the welding voltage (20 volts), welding current (215 amp), and wire speed (2.2) gives an optimal Hardness. We know that the S/N ratio for each parameter was determined by averaging the S/N ratios at the corresponding level. The effect of parameters such as welding voltage, welding current, and wire speed was analyzed on Table-4. It is observed that the process parameters with the greatest S/N ratio have optimum quality with less variance.

The ANOVA obtained R^2 and R_{adj}^2 as 99.3 and 97.2%. The ANOVA revealed the influence of process parameters with a response. Welding current (A) is the most influencing parameter (48.14%) and followed by the welding voltage (V) as (34.78%) and wire speed as 16.12%.

Table-7: Analysis of Variance for Signal to Noise Ratio of Hardness

Source	DF	Seq Ss	Adj SS	Adj MS	F	P
V	2	6.1716	6.1716	3.08581	49.88	0.020
A	2	8.5902	8.5902	4.29509	69.43	0.014
S	2	2.8608	2.8608	1.43042	23.12	0.041
Residual	2	0.1237	0.1237	0.06186		
Total	8	17.7463				

From response table, we can predict that the wire speed is a dominant parameter on the tested specimens, followed by welding voltage and welding current. The ranking of the parameters is shown in Table 8. From the response tables, the optimal condition for Tensile strength as the welding current (A2) is a dominant parameter on the tested specimens, followed by welding voltage (V1) and wire speed (S1). This refers the optimal condition of the Hardness as V1A2S1.

Table-8: Response Table for S/N Ratio for Hardness

Level	V	A	S
1	43.93	46.4	44.23
2	45.94	44.21	45.44
3	45.2	44.47	45.41
Delta	2	2.19	1.21
Rank	2	1	3

4.3 Multiple Linear Regression Models:

Multiple linear regression equations were developing a relation between the process variables and response. The value of regression coefficient R^2 (0.963) is in good agreement with the adjusted R^2 (0.852) for the Tensile strength of the ASTM A29. R^2 (0.993) is in good agreement with the adjusted R^2 (0.972) for the Hardness of the ASTM A29. Considering that both values are close to unity, this model gives a good result between the independent parameters and responses.

The regression equation developed for the surface roughness of the Tensile strength is as follows:

$$TS = 696 + 10.7 v - 3.05 A + 34.7 S \quad \text{---- (1)}$$

The regression equation developed for the Hardness of ASTM A29 is as follows:

$$HS = 276 + 6.62 v - 1.47 A + 28.1 S \quad \text{---- (2)}$$

We can predict from Equations. (1) & (2) that the Welding Current (A) plays a greater role on Tensile and Hardness, followed by welding voltage (V) and wire speed (S). The coefficient associated with welding current (A) is negative, thus indicating that the Tensile and hardness as decreases with increasing welding current. Conversely, the Tensile and hardness increase with increasing welding voltage and wire speed because the coefficients of these factors are positive. Wire speed has a greater effect on Tensile and hardness as compared with other parameters according to its coefficient value in the welding of MIG.

4.4 Confirmation Test

The confirmation test is the last step in the experiment. The confirmation test is shown in Table 9.

Table-9: Conformation Test

Exp Run	T S			HS		
	Cal.	Exp.	Error	Cal.	Exp.	Error
1	376.3	351.2	-7.16	176.2	168.5	4.38
3	316.1	315.1	-0.31	157.4	156.5	0.58
5	367.6	382.5	3.89	180.1	189.0	-4.97
6	337.5	325.6	-3.65	170.7	166.5	2.43
9	358.9	342.1	-4.90	183.9	179.5	2.39

The % of error determined with ratio of the difference of actual and predicted to actual once. As shown in Table 9, the % of error less than ($\pm 5\%$) which is significant.

5. CONCLUSIONS

The investigation results show that

1. The Welding Current has the greatest influence on Tensile and Hardness in the Weldability of ASTM A29 followed by welding voltage and wire speed.
2. The optimal conditional for Tensile strength as the welding current (250) is a dominant parameter on the tested specimens, followed by welding voltage (20) and wire speed (2.2).
3. The optimal condition of Hardness, such as the welding voltage (20 volts), welding current (215 amp), and wire speed (2.2) can be used to achieve better hardness in ASTM A29.

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