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Optimization of Process Parameters of Gas Metal Arc Welding using Taguchi Method

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Abstract

Achieving good welding quality is one of the major challenges in gas metal arc welding. Welding processes parameters significantly affects the quality of welding and needs to be optimized to ensure quality weld. The principal processes parameters affecting the weld quality are welding current, welding voltage, welding speed, and gas flow rate. Taguchi technique and ANOVA is an efficient method for optimizing the quality and performance output of manufacturing processes. Accordingly, Taguchi and ANOVA has been employed to optimize the process parameters. In addition, a comparison of the strengths of the various welded joints obtained by the gas metal arc welding Process has been presented. Welding voltage turns out to be the most important parameter of tensile strength and hardness.

Keywords: *GMAW, Hardness, Metal, MS2062, S/N Ratio, Taguchi, Tensile Test*

1.0 Introduction

Welding is the technique of permanent joining of similar materials by applying heat with or without pressure and with or without adding filler material[1]. This preserves the same materials, structures, and properties as the two joined parts. Welding is widely used in manufacturing as a separate casting or forging process and as an alternative to riveted and bolted joints. It's also used as a method of fixing that is, assembling a metallic piece at a time or producing small parts[2].

This paper predicts and fully manipulates gas metal arc welding for some of the same economically significant or similar items in the industry by using mathematical methods. This was attained by monitoring the selected weld parameters to match the rigid retention power to the selected welding input parameters. This result demonstrates better tensile storage capacity for predictable power and MIG use in the welding industry, leading to efficient selection of machine parameters to obtain better tensile final strength. Gas Metal Arc Welding (GMAW) welding is an arc welding process. In this process, consumable electrodes are used. A roll of wire is used to supply the electrode. In this process, heat is generated because they are in between the electrode and workpiece. Here, solid wire type electrodes are continuously supplied to the weld zone. When consumed, it becomes a filler metal. The burning of gas or an electric arc is the main reason behind the heat that fuses the material. This method is most broadly used because of its greater welding speed.

Pujari *et al.*, conclude that the experimental results were correlated using Taguchi techniques and utility concepts to determine the effect of GMAW process parameters on the welding of AA7075-T6 aluminum alloy[3]. They chose process parameters like quality of penetration, face width, and back width. The results revealed that optimal process parameters for GTAW are

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critical for achieving maximum penetration while also maximizing face width and back width. An ANOVA was applied to create a predictive model, assess its adequacy, and identify significant factors. According to ASTM E155, radiological analysis was also performed and found to be free of cracks, low porosity, and acceptable. Amit *et al.,* look into welding 304 stainless steel and medium carbon steel 45C8 and reported yield strength, high storage capacity, welding hardness, dense bead thickening, and welded joint strength[4]. Manipulating different processes parameters, the experiment was designed using the Taguchi method. According to ANOVA and S/N ratio analyses, the process parameters that affect the most responses are current welding. The stiffness of the welded area decreases as the welding current increases. It has been observed that as increase in welding current results higher thicker weld bead with decrease in stiffness. Small metal structures, both in HAZ and welding areas, have been analyzed. Major process parameters along with contact tip-work distance, type of shielding gas, etc. were examined by Shekhar *et al.,* analyzed the response surface method on IS:2062 mild steel to optimize GMAW process parameters[5]. According to the results of the analysis, wire feed rate was found to be the most effective parameter, followed by voltage and travel speed, and gas flow rate was the least effective parameter. Erdal *et al.,* carried out research on penetration in robotic gas metal arc welding processes in order to observe the impact of process parameters such as welding current, arc voltage, and welding speed[6]. They discovered that increasing the welding current deepened the penetration. The results also revealed that arc voltage is an important parameter in the detection of penetration. Haragobal *et al.,* have developed process parameters for optimizing the mechanical characteristics of weld samples for aluminum alloy used in the fabrication of aerospace wings[7].

In this MIG welding setup, process parameters such as current, groove angle, gas pressure and pre-heat were taken into account. It was reported that the most influential parameter for proof stress was current. In the work of Praveen *et al.,* the weld microstructure, hardness, and rigidity were investigated[8]. They chose three information variables and moved them up three levels. Similarly, nine tests were conducted using the Taguchi method's L9 orthogonal array and three knowledge variables. The Analysis of Variance (ANOVA) was used to establish the degrees of noteworthiness of information variables. The root hole has the greatest influence on elastic behaviour, followed by the welding current and voltage. The voltage of the circular section, followed by the root hole and welding current, has a significant effect on its hardness. Fine grains of ferrite and pearlite make up the microstructure of weld metal. Ghosh *et al.,* analyses the implications of welding parameters such as current welding, gas flow rate, and nozzle distance from the plate on tensile (UTS) storage capacity and percentage (PE) in MIG welding processes of AISI409 ferritic stainless-steel materials[9]. The Taguchi method's L9 orthogonal sequence was used for the test. Observation and X-ray radiographic inspection were also carried out to detect more and lesser failures in welded specimens. The Taguchi technique and signal-to-signal noise ratio analysis were used to interpret, discuss, and analyses data from UTS and PE. Mohanavel *et al.,* performed experimental and numerical analysis of the AA6061 TIG welding process[10]. The parameter combination was carefully chosen in order to produce a weld with higher impact strength. Shanmugasundar *et al.,* examine the butt weld joints made with three different levels of current, gas flow rate, and nozzle to work piece distance[11]. The weld quality has been calculated using the ultimate tensile strength of the welded specimens. The welding process parameters were optimized in this paper using Taguchi's and analysis of variance methods. Chellappan *et al.,* performed tungsten inert gas welding on super martensitic stainless steel using the technique for order preference by similarity to ideal solution method (TOPSIS)[12]. Stainless steel martensitic is far superior to low-alloy steel, which is commonly used in the gasoline industry. TIG welding was carried out using the Taguchi orthogonal array approach. The input process parameters considered for this function were welding voltage, operating current, flow speed, and shielding gas flow rate. Weld quality was determined by measuring bead width, depth penetration, and weld hardness. TOPSIS was used to create multi-purpose performance features. Metallographic analysis of the best and worst welds in terms of bead geometry and hardness was also carried out. The final results of the experimental investigation demonstrated that the method can successfully improve welding quality.

2.0 Methodology

2.1 Selection of Material

Mild steel is one of the most common materials in several industries and hence selected in the present work. As a base material, IS 2062 mild steel has been taken. It has exceptional weldability and machinability, which has caused an increase in its usage. Mild steel is one type of steel with low carbon. Essentially, carbon steel is a material that includes a small percentage of carbon, usually 2.1%, that increases the characteristics of pure iron. Mild steel chemical composition is presented in the Table 1. There are absolutely exceptional grades of steel. However, all of them have carbon content within the previous limits. Elements are also value-added to enhance beneficial properties like corrosion resistance, wear resistance, and tensile strength.

2.2 Welding Variables

The experimental process parameters and their operating range data were selected. Table 2 lists the chosen process parameters and their values.

2.3 Experimental Details

The machine used in the experiment is a welding/cutting transformer. Maximum power supply 400 volts. This GMAW machine is equipped with an automatic metal inert gas torch and an automatic supply unit.

2.4 Experimental Input Parameters

Experimental input parameters are welding voltage, welding current, gas flow rate and welding speed. Tensile strength and hardness have been measured as output results.

2.5 Taguchi Methodology

In Taguchi methodology, the undesired value or standard deviation of output characteristic depicted by the noise whereas the mean value by term signals. Therefore, the signal-to-noise ratio is used to measure off-target quality attributes. The signal-to-noise ratio η is defined as follows:

η = 10log (MSD), MSD refers root-mean squared deviation of the output characteristics. Higher selection of penetration quality features is required for optimum welding performance. MSD can be expressed as:

$$M.S.D = \frac{1}{m}\sum \frac{1}{P_1^2}$$

Where, P_1 is the value of penetration.

Table 1. Mild steel 2062 composition

Element	C	Mn	S	P	Si
w%	0.2	1.55	0.045	0.045	0.45

Table 2. Welding variables with their levels

Variable	Notation	Level			
		1	2	3	4
Welding current (Amp)	A	120	130	140	150
Arc voltage (Volts)	V	26	27	28	29
Welding speed (mm/sec)	S	6.42	7	8	9.5
Gas flow rate (Lit/min)	G	10	11	12	13

Table 3. Result of tensile strength and hardness

Para-meters	Symbol	Level 1		Level 2		Level 3		Level 4		Delta		Rank	
		Tensile strength	**Hard-ness**	**Tensile strength**	**Hard-ness**	**Tensile strength**	**Hard-ness**	**Tensile strength**	**Hard-ness**	**Tensile strength**	**Hard-ness**	**Tensile strength**	Hard-ness
Current	A	52.75	36.76	52.77	37.2	53.12	37.83	52.54	36.4	0.58	1.42	2	2
Voltage	B	53.21	38.07	52.72	37.02	52.61	36.47	52.64	36.63	0.6	1.61	1	1
Gas flow rate	C	52.91	37.02	52.6	36.7	52.61	36.67	53.06	37.8	0.46	1.14	3	3
Welding speed	D	52.8	37.2	52.84	37	52.61	36.74	52.94	37.24	0.32	0.51	4	4

2.6 Experimental Results

Larger signal-to-noise ratio values improve the performance of these parameters, regardless of the performance characteristics of the category.

In this investigational analysis, optimum tensile strength was estimated using main effect plot. This graph is plotted between the mean signal-to-noise ratio and the input parameters for current, voltage, gas flow, and weld rate. Maximum tensile strength requires a current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 liters/minute, and a welding speed of 9.5 mm/sec. Result of tensile strength and hardness is tabulated in Table 3. Further, results of tensile strength with S/N ratio have been listed in Table 4 and corresponding response is tabulated. Furthermore, the variation of strength and S/N ratio has been shown in Figure 1.

2.7 ANOVA for Tensile Strength

Table 3 details the study of tensile strength vs. parameters applied in this experiment using Minitab 16. This shows that the response parameter factor is important, if the values of probability (P) are less than 0.05.

From the results of ANOVA, the processes parameters affect the tensile strength, and the P of the voltage against input parameter is 0.003, which is the lowest, so it has a great influence on tensile strength. The voltage (0.006), is lower than the P-value of the current, the P-value of the gas flow rate is less affected than the voltage (0.007), The P-value for welding speed is the maximum among three parameters, 0.029, so it has less effect on tensile strength. The effect of individual processes parameters has also been investigated. The voltage contribution rate is 39.06%, the current is 27.30%, the gas flow rate is 24.61%, the welding speed is 9.01%, and the error is 0.02%. Machining vibration is the reason of error.

2.8 Measurement of Hardness

Brinell hardness number has been measured for each specimen. The results for hardness response are tabulated in Table 4 and corresponding S/N ratio has been presented in the Table 4 and corresponding. Furthermore, the variation of hardness and S/N ratio has been shown in Figure 2. The higher hardness value has a great effect on the welded joints, that's why the higher is better signal-to-noise (S/N) ratio is selected for calculation. S/N ratio is assessed using Minitab software.

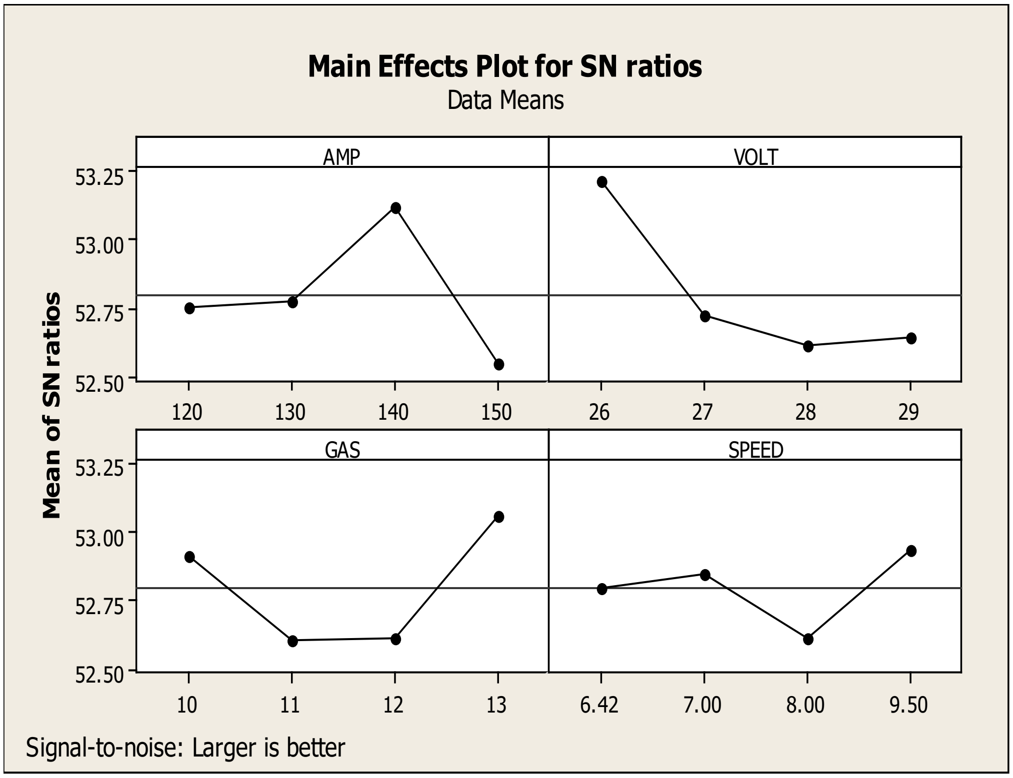

Figure 1. Plot of mean signal-to-noise ratio and level of tensile strength parameter.

Table 4. Result of tensile strength and hardness with S/N ratio

Weld run	Current (amp)	Voltage (volt)	Gas flow rate (lit/min)	Welding speed(mm/sec)	Tensile strength (Mpa)	S/N Ratio	Hardness (HRB)	S/N Ratio
1	120	26	10	6.42	460.667	53.26774	79	37.95254
2	120	27	11	7	421.333	52.49251	65	36.25827
3	120	28	12	8	406.667	52.18478	60	35.56303
4	120	29	13	9.5	449.405	53.05276	73	37.26646
5	130	26	11	8	440	52.86905	75.33	37.53936
6	130	27	10	9.5	444	52.94766	74.23	37.41159
7	130	28	13	6.42	437.33	52.81619	74.6	37.45478
8	130	29	12	7	420	52.46499	66	36.39088

9	140	26	12	9.5	470.667	53.45427	85	38.58838
10	140	27	13	8	452.333	53.10917	82	38.27628
11	140	28	10	7	454.667	53.15387	72	37.14665
12	140	29	11	6.42	434.667	52.76313	73.19	37.28904
13	150	26	13	7	460.6	53.26648	81.45	38.21782
14	150	27	12	6.42	413.667	52.33302	64	36.1236
15	150	28	11	9.5	411.667	52.29092	61	35.7066
16	150	29	10	8	411.333	52.28387	60	35.56303

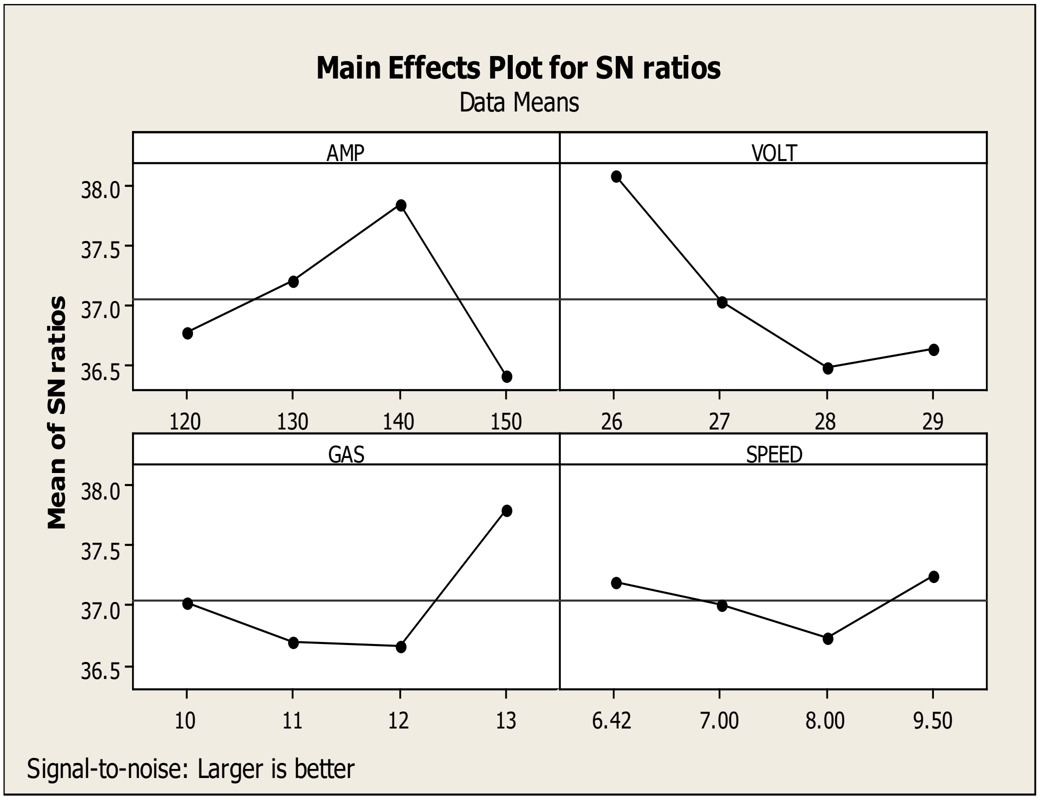

Figure 2. Mean S/N ratio and levels of parameters for hardness.

The main effect plot was utilized to evaluate the hardness under ideal conditions in this experimental investigation. The mean S/N is represented against the input process parameters in this graph. A current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 litres per minute, and a welding speed of 9.5 mm per second are required for maximum hardness.

Table 5. Analysis of variance of ultimate tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
AMP	3	1713.38	1713.38	571.13	42.35	0.006	27.30
VOLT	3	2450.46	2450.46	816.82	60.58	0.003	39.06
GAS	3	1544.20	1544.20	514.73	38.17	0.007	24.61
SPEED	3	565.69	565.69	188.56	13.98	0.029	9.01
ERROR	3	40.45	40.45	13.48	--	--	0.02
TOTAL	15	6314.18	--	--	--	--	100

2.9 ANOVA for Hardness

Table 6 details an ANOVA investigation of hardness vs. current, voltage, gas flow rate, and welding speed employing Minitab 16 software. This demonstrates the significance of the response parameter factor, if the probability (P) values are less than 0.05.

The current, voltage, gas flow rate, and welding speed are all influencing parameters for hardness, with the p value of voltage being the lowest at 0.001, indicating that this parameter is highly influencing on hardness. The p value of current is higher than voltage at 0.003, indicating that this parameter is less influencing on hardness than voltage. Because the p value of gas flow rate is 0.004, it is a very low influential parameter when it comes to hardness. The welding speed has the highest p-value of all values, 0.049. As a result, these parameters have less of an impact on hardness. The above results also revealed how individual process parameters affect the hardness of the GMAW process. The welding voltage contributes 44.16 percent, the welding current contributes 29.61 percent, the gas flow rate contributes 22.35 percent, the welding speed contributes 3.86 percent, and the error contributes 0.02 percent. The cause of this error is machining vibration.

2.10 Confirmation Test

A conformational experiment performed to verify the initial experimental results obtained and conclude the experiment. The signal-to-noise ratio predicted using the

Table 6. ANOVA of hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
Amp	3	291.404	291.404	97.135	72.06	0.003	29.61
Volt	3	434.677	434.677	144.892	107.49	0.001	44.16
Gas	3	220.019	220.019	73.340	54.41	0.004	22.35
Speed	3	37.995	37.995	12.665	9.40	0.049	3.86
Error	3	4.004	4.004	1.348	--	--	0.02
Total	15	988.138	--	--	--	--	100

optimum values of welding parameters can be calculated as follows:

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

where, n_m signifies total mean of S/N ratio, n_i signifies mean of S/N ratio at optimized level, and n denotes the number of significant welding parameters.

2.10.1. Confirmation test for tensile strength

$\eta_{opt} = n_m + (nA_3 - n_m) + (nB_1 - n_m) + (nC_4 - n_m) + (nD_4 - n_m)$

$\eta_{opt} = 52.796 + (53.12 - 52.796) + (53.21 - 52.796) + (53.06 - 52.796) + (52.94 - 52.796) = 53.942$

$Y^2_{opt} = 10^{\eta/10}$ = for properties higher is better.

$Y^2_{opt} = 10^{53.942/10} = 247856.321$

Y = 497.85

So, Optimum value of tensile strength =497.85

2.10.2. Confirmation test for Hardness

$\eta_{opt} = n_m + (nA_3 - n_m) + (nB_1 - n_m) + (nC_4 - n_m) + (nD_4 - n_m)$

$\eta_{opt} = 37.04 + (37.83 - 37.04) + (38.07 - 37.04) + (37.80 - 37.04) + (37.24 - 37.04) = 39.82$

$Y^2_{opt} = 10^{\eta/10}$ for properties higher is better.

$Y^2_{opt} = 10^{39.82/10} = 9594.006$

Y = 97.94

So, Optimum value of hardness = 97.94

From the above calculations, it can be concluded that the optimum results should be parameters with a welding current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 lit/min and a welding speed of 9.5 mm/sec.

3.0 Conclusion

The present study is focused on effects of welding process parameters in order to make sure good weld quality. The principal processes parameters affecting the weld quality are welding current, welding voltage, welding speed, and gas flow rate were analyzed. Welding voltage has been identified as the most important parameter to select in order ensures tensile strength as well as hardness. Optimal welding conditions achieved by the Taguchi process for maximum tensile strength are A_3 B_1 C_4 D_4 (i.e., current 140 amps, voltage 26 volts, flow rate of gas 13 lit / min, welding speed 9.5 mm / sec) and for maximum hardness A_3 B_1 C_4 D_4 (that i, the welding current should be 140 amps, the voltage should be 26 volts, the gas flow rate should be 13 lit/ min, and the welding speed should be 9.50 mm/sec).

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