Optimization of Quality of Energy Consumption and Weld Quality Response Parameters in Gas Metal Arc Welding

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Abstract - This research examines the optimization of two weld quality response parameters (tensile strength and hardness) used in gas metal arc welding (GMAW) on SAE1020 mild steel, as well as the quality of the energy consumption parameter power factor (PF). Welding voltage, travel speed, and gas flow rate are the three input welding parameters that have been chosen. The Taguchi technique was used to choose the L9 orthogonal array for the design of the trials, and an ANOVA with a 95% confidence level was used to identify the variables that had the greatest impact. The welding input parameters of 30 volts welding voltage, 15 lpm gas flow rate, and 19.05 cm/min travel speed produced an optimal PF (0.73). The welding input parameters have been determined to include a welding voltage of 35 volts, a gas flow rate of 12 lpm, and a travel speed of 16.03 cm/min for the optimum tensile strength (672 MPa). The optimal combination of welding input parameters for optimum hardness (247.05 Hv) is a welding voltage of 30 volts, a gas flow rate of 10 lpm, and a travel speed of 25.39 cm/min. The welding input parameter that contributes the most to all response parameters is welding voltage. The percentage of error between the PF and hardness values that were experimentally validated and those that were predicted is between -2.66 and 0.43%.

Keywords: Welding, GMAW, Weld Quality, Power Factor, Optimization, Taguchi, ANOVA.

I. INTRODUCTION

The two surfaces are joined together permanently through the process of welding. In the manufacturing industry, it is frequently utilised. In the manufacturing sector, welding uses a lot of energy. The manufacturing sector contribute 37% of the world's total energy usage. [Franco et al., (2016)].

The majority of academics' work has focused on comparing various welding techniques and optimising welding input parameters for weld attributes including weld strength, microstructure, and hardness, among others. They discovered that the most significant factor influencing weld quality was welding voltage.[Saha et al., (2012)].

Industries endeavor to reduce energy consumption during manufacturing processes to make them sustainable. Energy consumption parameters have been explored by few researchers, although these parameters are very important for sustainability of these processes. GMAW and friction stir welding (FSW) for aluminium 6061 were compared by Shrivastava et al. in their study. These two welding techniques were investigated for their energy usage and environmental effects. FSW used 40% less energy than GMAW, according to their research. Compared to GMAW, FSW produces 31% lower greenhouse gases. Research on the quality of power and energy consumption for various manufacturing processes like turning, milling, etc. has only been conducted by a small number of researchers. For turning operation, Bilga et al. [Bilga et al., (2016)] optimised the response parameters of power consumption, energy efficiency, and PF. 27 experiments had been run as part of this study's taguchi technique experiment design. When compared to typically used settings, the energy efficiency and PF were improved by 61.776% and 7.49%, respectively. Thein et al.'s [Thien et al., (2009)] investigation looked into the issues with industrial facilities' power quality. In this study, the capacitor bank boosted the plant's voltage level, improving PF and resulting in reduced electric consumption.

The quality of electrical power and energy consumption used during welding is reflected by PF. Generally, the importance of PF did not focused by researchers in case of welding operation. Electricity board can put penalties to the industrialists or manufacturer, if the PF of equipment is not nearest to the unity.

The power factor (PF) is defined as the ratio of real or active power that flows to load to apparent power of the circuit.

PF = Real power/Apparent power

Real power is also called active power. It is the power which actually consumed by the machine for useful work and the power which doesn't consumed for productive work is called reactive power.
The main focus of the present study is on the optimization of quality of energy consumption and weld quality response parameters of GMAW. PF is needed near to unity with best weld bead quality. Welding voltage, gas flow rate and travel speed are the welding input parameters selected for experimentation. In weld quality parameters tensile strength and hardness are selected for the study.

II. METHODS AND MATERIALS

Selection of Material

For the study, mild steel SAE1020 is selected. It is used in making the motor shafts, hydraulic shafts and pump shafts as well as machinery parts. Table I shows the composition of material according to report of spectroscopy test from authorized agency.

Table I Chemical Composition of SAE 1020 Mild Steel

Element (%)	C	Fe	Mn	P	S
Composition (as per test report)	0.181	98.93	0.563	0.004	0.001

Selection of Input and Output Parameters

The welding input parameters selected for experimentation are shown in Table II. Trial runs have been performed to select the range of welding input parameters.
The output parameters selected for the study are quality of energy consumption i.e. PF and weld quality parameters viz. tensile strength and hardness.

Table II Welding Input Parameters for Experimentation

Parameters (Factors)	Units	Level 1	Level 2	Level 3
Welding Voltage	Volts	30	32	35
Gas Flow Rate	Lpm	10	12	15
Travel Speed	cm/min	16.03	19.05	25.39

Design of Experiments

Taguchi method has been used for design of experiments. L9 orthogonal array has been selected for the study. Taguchi method is most convenient technique of design and analysis of the experiments. Table III shows the orthogonal array of design of experiments for the study along with values of welding input parameters.

Table III Design of Experiments Orthogonal Array by Taguchi Method

Experiment No.	Welding Voltage (V)	Gas Flow Rate (lpm)	Travel Speed (cm/min)
1	30	10	16.03
2	30	12	19.05
3	30	15	25.39
4	32	10	19.05

5	32	12	25.39
6	32	15	16.03
7	35	10	25.39
8	35	12	16.03
9	35	15	19.05

Instruments and Equipment

The gas metal arc welding equipment (Fig. 1) has been used for experimentation, whose specifications are shown in Table IV:

Table IV Specifications of Welding Equipment

Open Circuit Voltage Range	16-36 V
Maximum Semi Automatic current	250 A
Input supply	415 V, 3 ϕ, 50Hz

Fig. 1 GMAW Equipment

HIOKI made energy logger (PW3360) of compact 3-Phase 4-Wire has been used which monitors power demand and other power parameters to aid in energy audits and validate energy saving measures. Power logger is used to observe the readings of PF. Specifications of power logger are shown in Table V.

Table V Technical Specification of Power Logger

Voltage range	90 V- 780V
Current range	500 mA to 5 kA AC
Power range	300W – 9000 MW

Tensile testing has been done on ultimate tensile testing machine and hardness testing has been done on Micro Vickers Hardness Tester.

Experimental Procedure

Work pieces of mild steel are cut from sheet into the dimensions of 300mm x 150mm x 5mm. V-grooves of 60^o are machined on each work piece before welding. Two work pieces are held on the trolley which is moved by a motor. Then, power logger is installed as per manual [Hioki et al., (2014)] at the main power supply box of gas metal arc welding equipment. Then, welding is done and observations of PF have been directly recorded from the power logger. This procedure is repeated for nine set of experiments and three runs have been made for each set of experiments. After that, testing has been done on welded specimens for tensile strength and hardness. Preparation of test specimens and their testing for tensile strength is done according to IS 1608-2005 standard and for hardness as per ASTM E384 . The results have been analyzed using Minitab software and optimization has been done for all the response parameters.

III. OBSERVATIONS AND CALCULATIONS

Table VI shows observations of PF,tensile strength (TS) and Vickers hardness. Observations of PF have been directly recorded from power logger and they are named as PF 1, PF 2 and PF 3 as per three runs of same experimental conditions. For same experimental conditions, two specimens have been tested for tensile test. They are termed as TS1 and TS2. One specimen has been made for one experimental condition for micro Vickers hardness(MVH), so, total nine specimens are made for the hardness testing.

Table VI Observations of Response Parameters

Expt. No.	PF1	PF2	PF3	TS 1* (MPa)	TS 2* (MPa)	TS avg. (MPa)	MVH (Hv)		
							HvWB	HvHAZ	HvBM
1	0.74	0.72	0.73	256	240	248	246.2	202.6	164.3
2	0.72	0.74	0.77	240	216	228	230.7	196.3	155.9
3	0.75	0.73	0.75	192	184	188	207.1	181.8	151.9
4	0.71	0.71	0.70	464	472	468	202.7	165.5	150.3
5	0.73	0.73	0.73	448	440	444	217.3	196.4	178.5
6	0.76	0.73	0.72	480	504	492	188.6	166.8	149.3
7	0.67	0.68	0.65	544	528	536	207.1	181.7	140.4
8	0.67	0.72	0.67	664	680	672	189.7	165.9	135.1
9	0.69	0.72	0.72	608	584	596	160.9	151.2	146.8

*Specimen cross section area 12.5mm x 5 mm so it is 62.5mm2. Tensile load (tonnes) has been converted into tensile strength (MPa).
HvWB–Hardness at weld bead
HvHAZ-Hardness at heat affected zone
HvBM –Hardness at base metal

IV. RESULTS AND DISCUSSION

The values of means and S/N ratios are reported in Table VII and VIII for all the response parameters respectively. There are three types of S/N ratio quality characteristics which are larger the better, smaller the better and nominal the better. In the present research, all response parameters should be maximum, so, larger the better equation is considered for all response parameters according to equation (1).

$$S/N = -10\times\log[\Sigma(1/Y2)/n] \text{--------}(1)$$

Where, Y = responses for the given factor level combination and n is the number of responses in the factor level combination.
Further ANOVA has been conducted for means and S/N ratios of all response parameters at 95% confidence level. Ranks and percentage contributions are calculated by ANOVA.

Table VII Means of Response Parameters

Expt. No.	PF	TS (MPa)	HvWB (Hv)
1	0.728	248	246.2
2	0.743	228	230.7
3	0.744	188	207.1
4	0.708	468	202.7
5	0.733	444	217.3

6	0.736	492	188.6
7	0.668	536	207.1
8	0.687	672	189.7
9	0.710	596	160.9

Table VIII S/N Ratios of Response Parameters

Expt. No.	PF	TS (MPa)	HvWB (Hv)
1	-2.749	47.875	47.825
2	-2.585	47.122	47.261
3	-2.570	45.477	46.319
4	-2.993	53.404	46.137
5	-2.697	52.946	46.741
6	-2.668	53.831	45.510
7	-3.503	54.580	44.131
8	-3.274	56.545	45.537
9	-2.977	55.499	46.323

Analysis for PF

Table IX(a) represents ANOVA for means of PF which reveals that welding voltage is a significant factor (P=0.045). Most influencing parameter is welding voltage with the percentage contribution of 73.2%. Percentage contributions of gas flow rate and travel speed are 22.4 % and 0.8% respectively. Figure 2(a) shows main effects plot for mean of PF. It is shown that PF decreases with the increase in the welding voltage. So, welding voltage of 30 volts is responsible for maximum PF. By increasing the gas flow rate, PF also increases. PF is maximum at gas flow rate 15 lpm. PF first increases by increasing the travel speed and after increasing the speed up to third level from second level, the PF started decreases. At travel speed of 19.05 cm/min PF is found to be maximum.

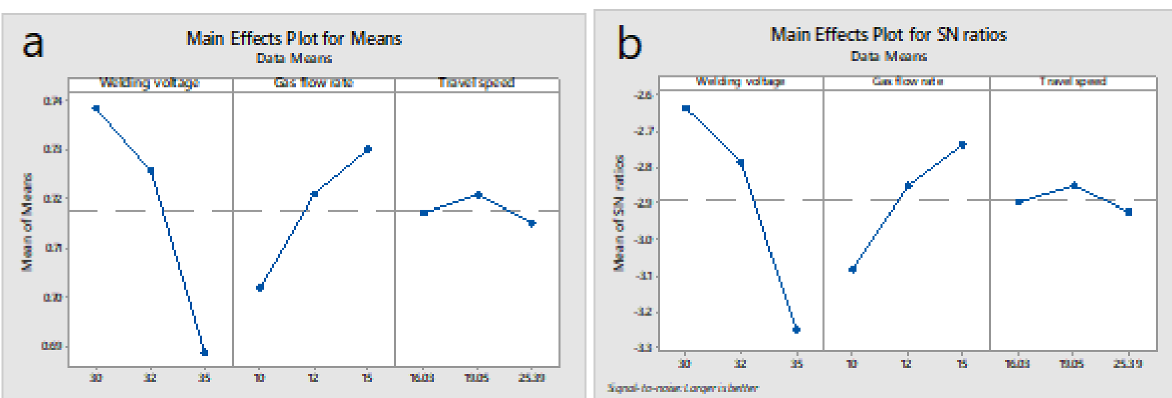

Fig. 2 (a) Main Effects Plot for Means of Power Factor (b) Main Effects Plot for S/N Ratios of Power Factor

Table IX(b) represents the ANOVA results for S/N ratios for PF which reveals that welding voltage is a significant factor (P=0.049). Most affecting and contributing parameter for PF is welding voltage with 73.4% contribution. Percentage contributions of gas flow rate and travel speed are 21.7 % and 0.9% respectively. Figure 2(b) illustrate main effects plot for S/N ratios of PF which shows that welding voltage, gas flow rate and travel speed of 30 volts, 15 lpm and 19.05 cm/min respectively are conditions found for optimum PF.

Table IX(a) ANOVA for Means of Power Factor

Source	Seq SS	F	P	PC	Rank
Welding Voltage (V)	0.004068	21.46	0.045	73.2	1

Gas Flow Rate (lpm)	0.001249	6.59	0.132	22.4	2
Travel Speed (cm/min)	0.000048	0.25	0.798	0.8	3
Residual Error	0.000190				
Total	0.005554				

PC- Percentage contribution

Table IX(b)ANOVA for S/N Ratios of Power Factor

Source	Seq SS	F	P	PC	Rank
Welding Voltage (V)	0.619822	19.33	0.049	73.4	1
Gas Flow Rate (lpm)	0.183844	5.73	0.149	21.7	2
Travel Speed (cm/min)	0.007923	0.25	0.802	0.9	3
Residual Error	0.032069				
Total	0.843658				

PC- Percentage contribution

From table IX(c), welding voltage, gas flow rate and travel speed of 30 volts, 15 lpm and 19.05 cm/min respectively did not lie together in design of experiments for optimum PF. Therefore, predicted values are calculated using Taguchi analysis. The predicted value for optimum PF is 0.75. After the validation of experiment, the optimum PF value is found to be 0.73 with percentage error of -2.66%.

Table IX(c) Validation Table for Power Factor

Welding Input Parameters			Predicted Value of Power Factor	Experimental Value of Power Factor	Percentage Error (%)
Welding Voltage (V)	Gas Flow Rate (lpm)	Travel Speed (cm/min)			
30	15	19.05	0.75	0.73	-2.66

Analysis of Tensile Strength

Table X(a) represents ANOVA for means of tensile strength which reveals that welding voltage is a significant factor (P=0.004). Most affecting and contributing parameter for tensile strength is welding voltage of 94.7%. Contributions of travel speed and gas flow rate are 4.2 % and 0.6% respectively. Figure 3(a) shows main effects plot for mean of tensile strength. It is shown that tensile strength increases with the increase in the welding voltage. So, welding voltage of 35 volts is responsible for maximum tensile strength. Tensile strength first increases by increasing the gas flow rate and after increasing the gas flow rate up to third level from second level, the tensile strength decreases. Tensile strength is maximum at gas flow rate of 12 lpm. Tensile strength decreases by increasing the travel speed. At travel speed of 16.03 cm/min tensile strength is found to be maximum. Tensile strength is maximum at welding voltage of 35 volts which is maximum value of welding voltage and travel speed is minimum (16.03 cm/min), so, during welding, the material melts properly resulting from production of high amount of heat which softens the material but increases the tensile strength.

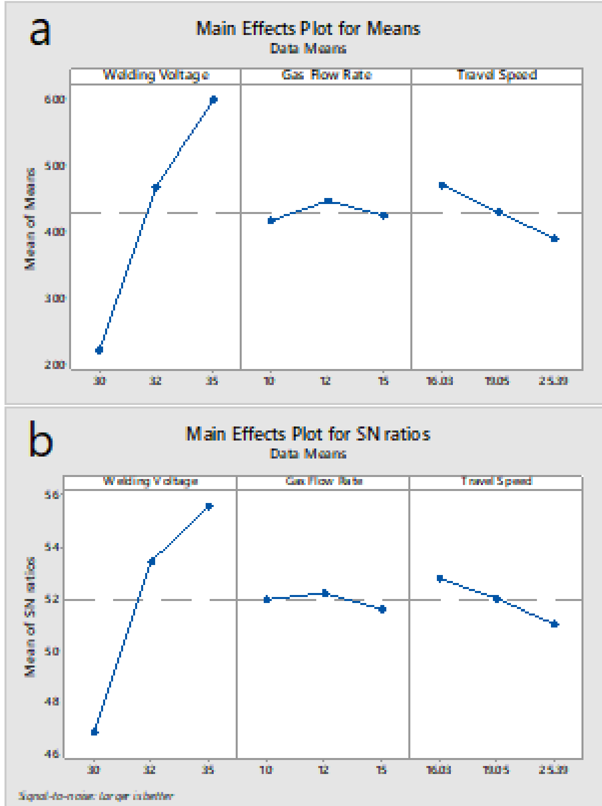

Fig. 3(a) Main Effects Plot for Means of Tensile Strength (b) Main Effects Plot for S/N Ratios of Tensile Strength

ANOVA results for S/N ratios for tensile strength are reported in Table X (b) that shows welding voltage and travel speed are significant factors. Most influencing and contributing parameter is welding voltage which is contributing up to 95.8 %. Contributions of travel speed and gas flow are 3.5% and 0.4% respectively. Figure 3(b) shows main effects plot for S/N ratios of tensile strength. It is shown that the optimum tensile strength (672MPa) is found to be at welding voltage of 35 volts, gas flow rate of 12 lpm and travel speed of 16.03 cm/min. Trend of results for tensile strength is same as achieved by Kumar et al. [Mishra et al., (2014)].

Table X(a) ANOVA for Means of Tensile Strength

Source	Seq SS	F	P	PC	Rank
Welding Voltage (V)	223022	257.07	0.004	94.7	1
Gas Flow Rate (lpm)	1518	1.75	0.364	0.6	3
Travel Speed(cm/min)	9924	11.44	0.080	4.2	2
Residual Error	868				
Total	235332				

PC- Percentage contribution

Table X(b) ANOVA for S/N Ratios of Tensile Strength

Source	Seq SS	F	P	PC	Rank
Welding Voltage (V)	123.746	777.61	0.001	95.8	1
Gas Flow Rate (lpm)	0.549	3.45	0.225	0.4	3
Travel Speed (cm/min)	4.626	29.07	0.033	3.5	2
Residual Error	0.159				
Total	129.079				

PC- Percentage contribution

Analysis of Hardness

Table XI(a) shows ANOVA for means of hardness. Most affecting and contributing parameter is welding voltage contributing up to 54.1%. Percentage contributions of, gas flow rate and travel speed are up to 37.5 % and 5.2% respectively. Figure 4(a) shows main effects plot for mean of hardness. It is shown that hardness decreases with the increase in the welding voltage. So, welding voltage of 30 volts is responsible for maximum hardness. By increasing the gas flow rate, hardness decreases. Hardness is maximum at gas flow rate of 10 lpm. It is found that hardness first decreases by increasing the travel speed and after increasing the speed up to third level from second level, the hardness increases. At travel speed of 25.39 cm/min, hardness is found to be maximum.

Table XI (a) ANOVA for Means of Hardness

Source	Seq SS	F	P	PC	Rank
Welding Voltage (V)	2692.0	17.98	0.053	54.1	1
Gas Flow Rate (lpm)	1865.8	12.46	0.074	37.5	2
Travel Speed(cm/min)	260.5	1.74	0.365	5.2	3
Residual Error	149.7				
Total	4968.1				

PC- Percentage contribution

Table XI (b) ANOVA for S/N Ratios of Hardness

Source	Seq SS	F	P	PC	Rank
Welding Voltage(v)	4.8730	24.82	0.039	52.6	1
Gas Flow Rate (lpm)	3.5709	18.19	0.052	38.5	2
Travel Speed(cm/min)	0.6190	3.15	0.241	6.6	3
Residual Error	0.1963				
Total	9.2592				

PC- Percentage contribution

Table XI(b) shows the ANOVA results for S/N ratios for hardness which reveals that welding voltage is a significant factor (P=0.039). Most affecting parameter is welding voltage followed by gas flow rate and travel speed. Welding voltage is contributing up to 52.6 %, gas flow rate and travel speed contributing up to 38.5 % and 6.6% respectively. Figure 4(b) shows main effects plot for S/N ratios of hardness which shows the conditions for optimum hardness i.e. welding voltage, gas flow rate and travel speed of 30 volts, 10 lpm and 25.39 cm/min respectively. The trend of results is similar as reported by Saha et al. [Kumar et al., 2014]. For optimum hardness, conditions for welding input parameters did not lie together in design of experiments. Therefore, predicted values of hardness are calculated using taguchi method. From Table XI(c), the predicted value for optimum hardness is 245.98Hv. After the validation of experiment, the averagehardness value is found to be 247.05Hv with percentage error of 0.43%.

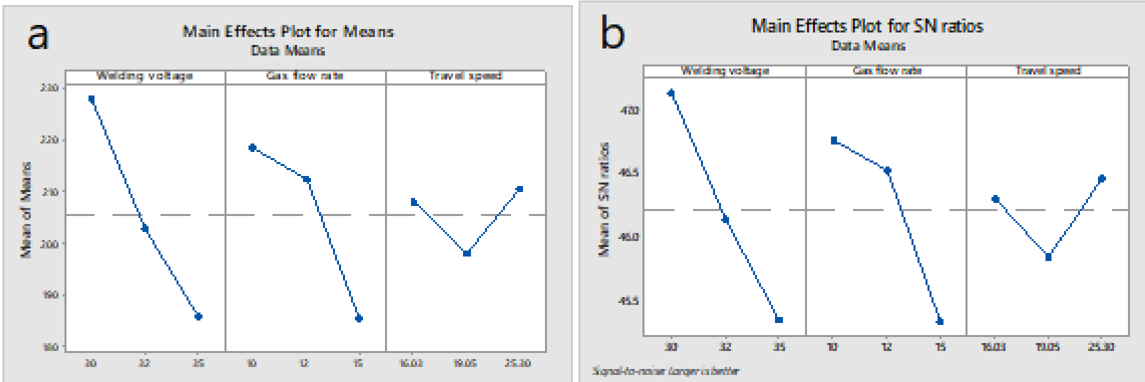

Fig. 4(a) Main Effects Plot for Means of Hardness (b) Main Effects Plot for S/N Ratios of Hardness

Table XI(c) Validation Table for Hardness

Welding Input Parameters			Predicted Value	Experimental Value			Percentage Error (%)
Welding Voltage (V)	Gas Flow Rate (lpm)	Travel Speed (cm/min)		Hv1*	Hv2*	Average Hardness (Hv)	
30	10	25.39	245.98	246	248.1	247.05	0.43

*Two specimens have been tested for same experimental condition.

V. CONCLUSIONS

Welding voltage is found to be most contributing welding input parameter for almost all response parameters.It has been observed from ANOVA for means table that welding voltage is significant for all the parameters except hardness. It has been observed from ANOVA for S/N ratios table that welding voltage is significant for all the parameters. Although, this study has been done as single objective optimization, therefore, multi objective optimization can be done with various welding input parameter and output parameters.

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