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Optimization of GMAW Protocols and Parameters for Improving Weld Strength Quality Applying the Taguchi Method

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Abstract—**The strength value most desired in any welding process is an excellent Ultimate Tensile Strength (UTS) of the weld, compared with the parent metal. Process parameters applied during the welding process ought to be subjected to continuous scrutiny and assessment because of the ever increasing demand for structural and industrial materials with weld joints possessing higher strength values. This study is intended to investigate the inadequacies of existing GMAW welding process parameters utilized by the investigated industrial firm in its signature welding protocol, by suggesting alternative, uniquely crafted, and improved process parameters to replace its existing signature welding protocol, thereby improving the weld results by attaining higher UTS. These suggested process parameters were thereafter subjected to reported literature, following which optimization was achieved by employing the Taguchi Method. From the analysis conducted by applying the Taguchi Method, an optimum process parameter of A_3 B_3 C_1 D_1, which consists of welding current of 240A, welding time of 2.0 mins, welding speed of 0.0062 m/s, and welding voltage of 33V, was suggested. These optimum parameters were found to have an improvement of 2.32dB of the S/N ratio, and 1.11 times over the UTS of the existing process parameters. This study elucidates a step by step approach for applying the Taguchi Method. The study also shows that the use of the Taguchi Method has successfully improved on the existing process parameters, giving the industrial firm a more efficient signature welding protocol.**

Index Terms— **ANOVA, GMAW, Process parameters, Taguchi method, UTS.**

1. INTRODUCTION

The focus of this research is to address the challenges of a multinational industrial firm, specializing in pipeline installation and maintenance in the upstream and downstream sectors of the Nigerian oil industry. The weldability of steel and its alloys is of great importance to manufacturing and construction, and many modern everyday products and structures are made from steel. The success or failure of such industrial products depends a great deal on the welding process parameters chosen by industrial firms incorporated as part of their signature protocols. There is an ever increasing demand for better and more reliable welds, with greater quality control. However, most industrial firms have stuck to the same welding protocols and parameters for an inordinate number of years without much thought or investment in reassessment and improvement. Their managers seem to be content with the level of weld quality they have always produced, and even though they do have an earnest quest to improve overall weld quality, they are for the most part not as susceptible to change because they erroneously believe that they have limited options, and continue to count their losses.

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Steel alloys are susceptible to distortion due to their high coefficient of thermal expansion. In some cases, certain steel alloys are quite prone to cracking and reduced corrosion resistance [1]. These limitations are even more glaring when these steel alloys are subjected to the welding process. Considering these limitations and the stark relevance of the application of steel products to our everyday lives, it becomes imperative to optimize the welding process protocols and parameters. Optimization is defined by Dieter [2] as the process of maximizing a desired quantity or minimizing an undesired one. Thus, the welding process parameters should be controlled in order to obtain the optimum parameters that would reduce the limitations associated with steel alloys and further improve their weldability and performance.

In this study, the Taguchi method is employed to achieve this aim. The Taguchi method has been found to be a powerful tool used to improve overall process quality by optimizing the welding process parameters, in such a way that variation is reduced to the barest minimum, and is cost effective as well. Chang et al [3] described the Taguchi method as a powerful optimization tool for designing high quality systems that is based on orthogonal array experiments with an optimum setting of process control parameters. Amongst other investigators who have also worked on the optimization of welding variables using the Taguchi method are Kim and Lee [4]. They used the Taguchi experimental design to suggest optimal combinations for process factors of hybrid welding methods to optimize the welding parameters of the resistance spot welding process. Yoon et al [5] optimized the welding conditions in resistance spot welding of the 7075-T6 aluminum alloy using the Taguchi method.

This study assesses the quality of the welds produced and designed to meet the increasing strength demands in steel products, by first appreciating the inadequacy of the existing signature welding protocols and parameters, on one hand, and thereafter using optimum parameters available and discoverable having applied the Taguchi method, on the other hand.

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II. MATERIALS AND METHODS

In this study, the Gas Metal Arc Welding (GMAW) process was used to make weld deposits. This welding process has been widely used for joining both ferrous and non ferrous metals. Mild steel electrodes, 350 mm long and 3.2mm in diameter were used to make weld deposits using the GMAW machine which can be adjusted to various welding parameters as the need arises. Based on the Orthogonal array presented in Table II, 18 experiments were conducted, each consisting of 5 different weld deposits. These weld deposits were machined with the Lathe machine to produce tensile specimens used to conduct the required Tensile Tests. The results were thereafter computed and plotted from the resulting iteration. From the stress-strain curve obtained, the UTS of each weld specimen was itemized. The average value of these 5 specimens was recorded, as culled from the 18 experimental designs as shown in Table III.

A. Tensile Test

The stress-strain curve for steel is generally obtained from Tensile Tests on standard specimens as shown in Fig.1. The under listed steps were taken in performing the tensile tests.

1. Tensile test specimens of dimensions shown in Fig. 1 were machined from the all-weld metal deposits.

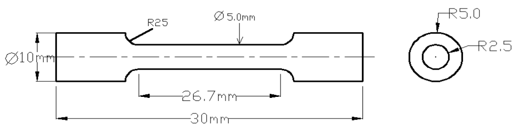

Fig. 1 Tensile Strength Test specimen

2. Tensile tests were performed on the specimens using the Monsato Extensometer;
3. The UTS was determined for each experiment using the stress - strain curve [6].

III. PRESENTATION OF RESULTS

Table 1 is a presentation of the process parameters and the different levels used for making the various weld deposits. Tensile tests were thereafter conducted on the weld deposits and the UTS, thereafter determined.

Table 1: Process parameters and their levels

Plate thickness mm	Electorde Diameter mm	Symbol	Process parameter	unit	Level 1	Level 2	Level 3
3	3.2	A	Welding current	A	170	196	240
		B	Welding Time	min	1.0	1.7	2.0
		C	Welding Speed	m/s	0.0062	0.092	0.0120
		D	Welding Voltage	V	23	25	28

In this study, an $L_{18}(3^4)$ orthogonal array which has 17 degrees of freedom was used. Eighteen experiments are expected to be carried out using the proposed L_{18} orthogonal array. The experimental layout for the L_{18} orthogonal array is expressed in Table II.

Table II: Experimental layout using an $L_{18}(3^4)$ orthogonal Array

	Process Parameter level			
Experiment Number	A Welding Current	B Welding Time	C Welding Speed	D Welding Voltage
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	3
5	2	2	2	1
6	2	3	3	2
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2
10	1	1	3	1
11	1	2	1	2
12	1	3	2	3
13	2	1	2	2
14	2	2	3	3
15	2	3	1	1
16	3	1	3	2
17	3	2	1	3
18	3	3	2	1

Each level in Table 1 was inserted in the appropriate level in Table II, and each row of the eighteen rows was used to make five weld deposits which were machined into five standard specimens for conducting Tensile Tests. The average UTS values obtained from the tensile tests conducted are presented in Table III.

Table III: The Ultimate Tensile Strength (UTS) Results

Experiment Number	UTS(MPa)
1	420
2	448
3	415
4	500
5	414
6	386
7	482
8	405
9	520
10	492
11	378
12	462
13	315
14	338
15	530
16	442
17	382
18	436

A. Overall Loss Function and its S/N Ratio

The UTS of the welded structure is in the category of the larger – the – better quality features. The loss function of the larger – the – better quality feature is therefore expressed as presented in (1)

$$L_f = \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right) \quad (1)$$

$$\eta_j = -10 \log L_f \quad (2)$$

Where n is the number of tests conducted and y_i is the experimental value of the ith quality feature; L_f is the overall loss function, and η_j is the S/N ratio. Applying (1) and (2), η_j which is the S/N ratio for each experiment of L_{18} is obtained and summarized as presented in Table IV.

Table IV: S/N Ratios for the UTS measurements

Experiment Number	S/N ratio dB
1	52.47
2	53.03
3	52.36
4	53.98
5	52.34
6	51.73
7	53.66
8	52.15
9	54.32
10	53.84
11	51.55
12	53.29
13	49.97
14	50.58
15	54.49
16	52.91
17	51.64
18	52.79

From the L_{18} layout in Table II and the corresponding values of S/N ratios in Table IV. The welding process parameters were summarily arranged in their various levels as shown in Table V.

Table V: Summary of the welding process parameters and their levels

Symbol	Process parameter	S/N Level 1	Ratio Level 2	dB Level 3	Total Mean	Max -Min
A	Welding current	52.76	52.18	52.91*		0.73
B	Welding time	52.81	51.88	53.16*		1.28
C	Welding speed	53.08*	52.51	52.26	52.62	0.82
D	Welding voltage	53.01*	52.25	52.59		0.76

Note: * signifies the optimum level based on the larger - the - better criterion

From Table V, the optimum levels or composition is A_3 B_3 C_1 D_1.

Fig. 2 shows the S/N ratio graph where the dashed line is the value of the total mean of the S/N ratios. Fig. 2 clearly shows the interactions between the levels of each process parameter.

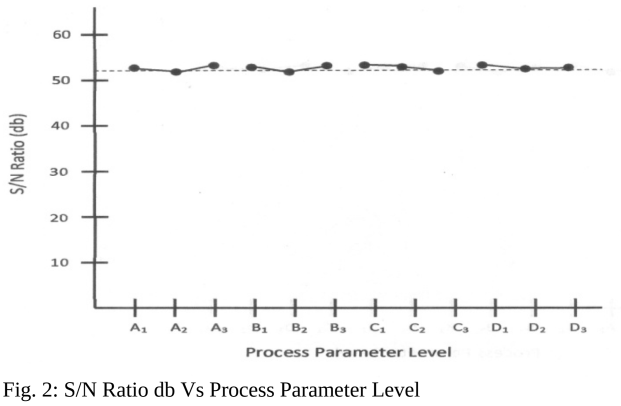

Fig. 2: S/N Ratio db Vs Process Parameter Level

A. *Analysis of Variance (ANOVA)*

The ANOVA is a statistical tool used to determine the level of contribution of each process parameter to the overall improvement of the strength and quality of the weld.

Table VI: A NOVA table

Parameter	Process parameter	Degree of freedom	Sum of square	Variance	F-ratio	Contribution
A	Welding current	2	0.30	0.150	0.06	1.15
B	welding time	2	0.88	0.440	0.16	3.39
C	Welding speed	2	0.36	0.180	0.07	1.38
D	Welding voltage	2	0.29	0.145	0.05	1.12
Error		9	24.17	2.685	-	92.96
Total		17	26.00	-	-	100

The values in Table VI were obtained by determining the sum of squares, S_i^2 using (3) [7],[8].

$$S_i^2 = \sum (y_i)^2 - \frac{\left(\sum y_i\right)^2}{n} \quad (3)$$

Where y_i represents the result of each variable of the experiment, and n is the number of tests conducted.

B. *Confirmation Tests*

The confirmation experiment validates the initial experimental results obtained and the conclusion thereof. In this case, the improvement of the performance characteristics of the welding process are predicted and verified. The predicted S/N ratio η using the optimal levels of the welding parameters can be calculated by using (4)

$$\eta = \eta_m + \sum_{i=1}^{n} \left(\bar{\eta} - \eta_m\right) \quad (4)$$

Where η_m is the total mean of S/N ratio, $\bar{\eta}_i$ 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.

Equation (4) was used to obtain the results of experimental confirmation using optimal welding parameters and comparing it with existing/initial processes as shown in Table VII.

Table VII: confirmation Experimental Test Results

	Initial process parameter	optimal process parameters prediction	improvement in S/N ratio
Flux composition	$A_2B_1C_3D_3$	$A_2B_3C_1D_1$	
Ultimate Tensile strength, MPa	485	538	2.32
S/N dB	51.98	54.30	

The improvement in S/N ratio is 2.32 dB from the initial welding parameters to the optimal welding parameter and the UTS increased by 1.11 times. Therefore the UTS is significantly improved by using the Taguchi Method.

III. DISCUSSION OF RESULTS

In this study the GMAW process was used to conduct welding operations by joining steel pipes in a Multinational industrial firm operating in the upstream and downstream of the Nigerian oil industry. The company had always utilized its signature protocol applying the same process parameters for their pipeline welding processes for over twelve years, but had continually endured the limitation that the welded structures did not attain their design life span because of unwarranted structural failures. These failures were found to be as a result of low weld strength when compared with the parent metal. After a thorough brainstorming session with experts, management had resolved that the status quo was

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unsatisfactory, and the need for welds with higher strength and reliability, was emphasized. They concluded that the demand for higher weld strength can be achieved by controlling the welding process parameters at source, and changing their signature protocols, hence this research study.

Kim and Lee [4] observed that in order to determine the weldability of an experimental procedure, the UTS should be ascertained. In this study, the UTS was therefore adopted as the determinant strength property for controlling the overall weld quality. It was found from using the Taguchi Method, that the optimum process parameters to actually attain the desired weld quality that would optimize the process parameters, with minimum cost implications is as follows: $A_3B_3C_1D_1$, being a welding current of 240A, a welding time of 2 mins, a welding speed of 0.0062 m/s and a welding voltage of 23V, here suggested.

From Tables V and VI, and considering the contributions made by kim and Lee [4] and Esme [9], the welding time had the largest difference of 1.28. This has been found to have the most influence on weldability. Thus, a little variation in the welding time is expected to greatly affect the quality of the weld. Hence, the longer the welding time, the more annealed is the weldment, and the higher the strength.

From the confirmation tests done thereafter, it was discovered that there was an increase in the overall UTS of 1.11and 2.32 dB of the S/N Ratio when using the new optimum process parameters obtained after applying the Taguchi method, as opposed to the now outdated signature protocol and process parameters the industrial firm depended on. This finding shows that there is a significant improvement using the new optimal process parameters obtained from applying the Taguchi method.

IV. CONCLUSION

In this research study, the structural steel failure problems encountered by a multi-industrial firm operating in the upstream and downstream sector of the Nigerian oil industry was successfully addressed by applying the Taguchi Method. Following the confirmation tests conducted to validate the experimental results obtained, it was observed that there is a significant improvement in the quality of weld produced by using the new optimum process parameters obtained from adopting the Taguchi Method.

REFRENCES

[1]. K. Kishore, P.V. Gopal Krishna, K. Veladri and Ali Syed Qasim "Analysis of Defects in Gas Shielded Arc Welding of AISI 1040 Steel Using Taguchi Method". ARPN Journal of Engineering and Applied Sciences, vol. 5, no. 1, 2010, pp. 37 - 41.

[2]. G.E. Dieter *Engineering Design: A Materials and Processing Approach*. United States: McGraw Hill, Inc., 1991, Ch 5.

[3]. C. Chang, J. Yang, C. Ling and C. Chou "Optimization of Heat Treatment Parameters with the Taguchi Method for the A 7050 Aluminim Alloy". IACSIT International Journal of Engineering and Technology, vol.2, no. 3, 2010, pp. 269-272.

[4]. H. R. Kim, and K. Y. Lee "Application of Taguchi Method to determine Hybrid Welding Conditions of Aluminum Alloy" Journal of Scientific and Industrial Research, vol. 68, 2009, pp. 296 - 300.

[5]. H. Yoon, M. Byeong Hyeon, L. Chil Soon, K.D. Hyoung, K.Y. Kyoun and P.W. Jo. "Strength Characteristics on Resistance Spot Welding of Al Alloy Sheets by Taguchi Method". International journal of Modern physics B, 20, 2006, pp. 4297 - 4302

[6]. J. I. Achebo, "Development of Aluminium Welding Flux from Local Raw Materials". PhD dissertation, Dept. Prod. Eng., Univ. of Benin, Nigeria, 2008.

[7] B. Berginc, Z. Kampus and B. Sustarsic "The Use of the Taguchi Approach to determine the Influence of Injection-Moulding Parameters on the Properties of Green Parts". Journal of Achievements in Materials and Manufacturing Engineering, Vol. 15, Issue 1 - 2, 2006, pp. 63 - 70.

[8]. R. K. Roy, *Design of Experiments Using the Taguchi Approach*. New York, NY: John Willey & Sons, Inc. 2001

[9]. U. Esme. "Application of Taguchi Method for the Optimization of Resistance Spot Welding Process". The Arabian Journal for Science and Engineering, vol. 34, no. 2B, 2009, pp. 519 - 528.