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Retraction

Retracted: Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] K. B. Behredin, P. Janaki Ramulu, B. Habtamu, N. Besufekad, and N. Tesfaye, "Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 8276496, 16 pages, 2022.

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Research Article

Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding

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Advanced high strength steels (AHSS) are multiphase steels that contain various concentrations of ferrite, bainite, martensite, and retained austenite phases. The unique physical characteristics of AHSS present some challenges to welding and bonding processes. AHSS have tendency to change microstructure and mechanical properties by any welding process like other steels. Based on the significant applications in various industries, the experimental works are carried out on one of AHSS materials, EN-10149-2 S700MC, with thickness of 2 mm steel sheet metal by MIG welding process parameters such as current, voltage, and welding speed. For all combinations of process parameters, the butt joints are fabricated. The butt joints are inspected through different nondestructive testing for defects detection. All the defect-free joints are characterized through microstructure (at different zones of joint), hardness, and tensile tests. From the obtained mechanical test results, the process parameters are optimized through design of experiment techniques (DoE). The analysis from DoE method is used to identify which parameter is the most significant among all parameters. Confirmatory test is also done by taking the optimal parameters and the result shows that the improvement of the response variables is acceptable and also shows that the method that is used for optimization was valid.

1. Introduction

Metal Inert Gas (MIG) welding is one of the extensively used joining processes in manufacturing industries. The input parameters of MIG welding play a significant role in determining the quality of welded joints. Weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices get affected. The weld quality is depending on the process parameters, hence the selection of the best parameters to be known for optimum results. Earlier, in most of the research, the considered MIG parameters were welding current, arc voltage, and welding speed. These parameters affect the weld characteristics remarkably. Because they can be varied over a large range, they are considered the primary adjustments in any welding operation. During the MIG welding process, the electrode melts within the arc and becomes deposited as filler material. The shielding gas that is used prevents atmospheric contamination from atmospheric contamination and protects the weld during solidification. The shielding gas also assists with stabilizing the arc which provides a smooth transfer of metal from the weld wire to the molten weld pool. Based on the literature on MIG welding process, parameters effect on weld quality and optimization impact on various materials are described as Sathiya et al. [1] optimized the gas metal arc welding (GMAW) process input parameters considering the multiple output variables (bead width (BW), bead height

(BH), and depth of penetration (DP)) for 904L SASS sheet. For optimization, grey-based Taguchi approach was used and the experiment designed, L27 orthogonal array. The predicted bead profiles had better DP and lower BH and BW. It was found that the optimized setting values are improving the response values by 10 percent. Katherasan et al. [2] optimized the process parameters (wire feed rate (F), voltage (V), welding speed (S), and torch angle (A)) in order to obtain the optimum bead geometry (bead width (W), reinforcement (R), and depth of penetration (P)), considering the ranges of the process parameters using evolutionary algorithms, namely, genetic algorithm (GA) and simulated annealing (SA) algorithm. Pipavat et al. [3] presented the influence of MIG welding parameters like welding current, welding voltage, and welding speed on mechanical properties like tensile strength and hardness on austenitic stainless steel AISI 316. Experiments based on Taguchi technique were carried out to obtain the data. An orthogonal array and analysis of variance (ANOVA) employed and investigated the welding characteristics of AISI 316 material and optimized the welding parameters. Kumar et al. [4] investigated the influence of shielding gas composition of gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) on the mechanical properties of austenitic stainless steel 316L with 3 and 6 mm thick plates. Optimization of shielding gas mixtures, current intensities, flow rates, and welding speed is required to automate the process and to improve the overall efficiency of the weld process. The obtained results proved that the tensile strength, hardness, and impact strength were higher for GTAW weld specimens compared to GMAW weld specimens. Kalita and Barua [5] investigated the effect of MIG welding process parameters on C20 carbon steel as parent metal and ER70S-4 electrode such as welding current, voltage, and shielding gas flow rate on tensile strength. An experiment was designed using Taguchi's orthogonal array L9, three levels each. The selected levels for welding current were 170 A, 200 A, and 230 A, for voltage they were 20 V, 25 V, and 30 V, and for shielding gas flow rate (CO_2) they were 8 lit/min, 12 lit/min, and 16 lit/min. The experiments were conducted using TORNADO MIG 400 welding machine with three repetitions. The optimal set of process parameters for optimal tensile strength (475.87 N/mm^2) was found to be as follows: 200 A welding current, 30 V welding voltage, and 8 lit/min gas flow rate. The effect of shielding gas flow rate was found to be insignificant and was kept at the most economic level (8 lit/min).

Narwadkar and Bhosle [6] optimized controllable MIG input parameters such as current, voltage, and gas flow rate by using the Taguchi method for butt welded Fe410WA. Angular distortion was minimized by optimizing the input parameters. An orthogonal array of nine trials was considered for the design of the experiment. After measuring the distortion angle, observed readings were verified by using ANOVA and it was found that the "p" values were less than 0.05. Theoretical calculations were done to optimize the process parameters to achieve the minimum distortion angle. A confirmation test was taken for validation purposes and to confirm the result. Ghosh et al. [7] identified an optimal parametric combination of MIG welding for quality of weld of austenitic stainless steel AISI 316L by adopting Taguchi technique. An orthogonal array, S/N ratio, and ANOVA were employed, the welding characteristics of material were studied, and the welding parameters were optimized. The parameters like effect of current, gas flow rate, and nozzle to plate distance on quality of weld were studied through experiment and analyses. The result computed the contribution from each parameter, and optimized parameters were identified for maximum tensile strength and percentage elongation. Mvola and Kah [8] examined the effects of shielding gas mixtures and their components, presented a cross-comparison of shielding effects in fusion welding, and suggested guidelines for adaptive controllability of shielding gas in advanced adaptive fusion welding of both ferrous metals (i.e., carbon steels, stainless steels, and high-strength steels) and nonferrous metals (i.e., aluminium and its alloys, nickel and its alloys, and copper and its alloys).

Kalacska et al. [9] investigated the weldability of different advanced high strength steels (AHSS). The welding parameters were successfully optimized for butt welded joints. The joints were investigated by visual examination, tensile testing, and quantitative metallography and hardness measurements. Govinda Rao et al. [10] proposed the vibratory weld treatment during welding to enhance the flexural and impact strength of weldments. It was found that the mechanical properties showed nonlinear behavior with the chosen input parameters. An efficient neural network based prediction tool was developed to approximate the mechanical properties of weldments without performing the experiments, outputting values predicted for the given input values. Rizvi [11] optimized different welding process parameters which affect the weldability of stainless steel (AISI) 304H through Taguchi techniques by L9 orthogonal array and also studied the fracture mode characterization. Analysis of variance (ANOVA) and signal-to-noise ratio (SNR) were applied to determine the effect of welding current, wire feed speed, and gas flow rate on mechanical, microstructure properties of SS304H. Ultimate tensile strength, toughness, microhardness, and mode of fracture were examined and it was observed from results that welding voltage has a major impact, whereas gas flow rate has minor impact on ultimate tensile strength of the welded joints. Optimum process parameters were found to be 23 V, 350 IPM travel speed of wire, and 15 l/min gas flow rate for tensile strength and mode of fracture was ductile fracture for tensile test specimen. Odiaka et al. [12] reviewed on the improvement of weld integrity involved parametric optimization of MIG welding process. Some suggestions in terms of postweld heat treatment, pulsed current, hybrid welding, and vibratory welding were discovered to be alternative means of improving weld integrity. The use of reinforcing powders was also discovered, and it was suggested that the quality of MIG welded steel joints improved by using titanium alloy powder as weld joint reinforcement. Alagarsamy and Kumar [13] optimized the gas metal arc welding parameters on the impact strength, hardness, and flexural strength of dissimilar weld joints of SS316L and AISI D2 steels by using Taguchi based grey relational method. The experiments were planned as per Taguchi L8 orthogonal array by considering four input parameters: current, voltage, speed, and root gap. The experimental results showed that the maximum impact strength of 4.36 J/mm2, maximum hardness of 49.5 HRC, and maximum flexural strength of 583.3 MPa were obtained for the weld joints fabricated under the optimum welding conditions of current of 80 amps, voltage of 15 volt, speed of 45 cm/min, and root gap of 2.0 mm. The most significant parameter on multiple output response is the root gap. The contribution of root gap was 54.64% and followed by 20.26% and 11.94% of welding speed and voltage, respectively. Guizani et al. [14] optimized the mechanical brush finishing of MIG welded joints on AISI316L thin steel sheet. The experimental design methodology of the Taguchi design (L9) and the analysis of variance (ANOVA) with an objective function of microhardness in brushed layers was used. The effects showed the major influence of the depression and the number of passes on the magnitude of hardening of the brushed layers in the various zones of the weld. Gejendhiran et al. [15] focused on the effect of process welding parameters of GMAW and GTAW process for acquiring greater mechanical properties of weld plates of thin gauge mild steel and stainless. The shielding gas, weld voltage, and current were chosen as process parameters to acquire greater welding effectiveness and efficiency. The mechanical properties are ultimate tensile strength, toughness, and hardness of the weldment. After completion of the experimental work, the S/N ratio and mean S/N ratio were evaluated and optimum values of each parameters were evaluated through the Taguchi method. Subsequently, the significant coefficient for each input factor of the mechanical properties was evaluated by using ANOVA and prediction on the mechanical properties evaluated by using regression analysis. 15 mm IS2062 mild steel was welded by GMAW with the shielding gas mixtures of pure (100%) CO_2, Ar + 20% CO_2, and Ar + 10% O_2. The tensile strength optimum value was provided by the shielding gas mixture Ar + 20% CO_2 and also it gives the optimum value for toughness. The higher hardness value was obtained by pure (100%) CO_2 with respect to other shielding gas mixtures. Baskoro et al. [16] investigated the GMAW parameters for welding of A36 mild steel to get the minimum of distortion. The type of welded joint used was square groove T-joint fillet weld with filler wire ER70S-6. The welding current and the welding speed were selected as input parameters, while the response used was longitudinal bending distortion and angular distortion. L9 Taguchi's orthogonal array was applied. The minimum conditions were determined using S/N ratio with a quality character of the smaller the better. The results show that the welding current of 170A and the welding speed of 4.0 mm/s were obtained as the minimum of longitudinal bending distortion and angular distortion. Based on analysis of variance, the welding current was a parameter that greatly affects the longitudinal bending distortion with the percentage contribution of 64.36%, while angular distortion was strongly influenced by welding speed parameter with the percentage contribution of 53.38%.

Kumar and Gandhinathan [17] reviewed the effects of welding current, voltage, gas flow rate, welding speed, and gas pressure on mechanical properties like tensile strength and percentage of elongation of MIG welded joints of AISI 1018 mild/low carbon steel plates. Optimization was done and found optimum welding conditions to maximize tensile strength and percentage elongation of welded joints. From the study, it was found that when the welding current, voltage, and gas flow rate increase, the tensile strength decreases, but when welding speed increases, the tensile strength also increases for AISI 1018 steel weld joint. AISI 1018 is nonhardenable ductile steel belonging to low carbon steel categories. Rout et al. [18] proposed fuzzy-regression-particle swarm optimization (PSO) based hybrid optimization approach for getting maximum weld quality in terms of weld strength and bead depth of penetration. The predicted weld quality or the multiperformance characteristic index (MPCI) values in terms of combined weld strength and bead geometry found to be highly correlated with the weld process parameters. Radhakrishnan et al. [19] observed that the variation of mechanical properties depends on tensile strength in the MIG welding, for which parameters like arc voltage, welding speed, and current were considered and experimental analysis was carried out. The percentage influence of the welding characteristics on the tensile strength was also found using ANOVA method. The optimum welding framework combinations were obtained by using the analysis of S/N ratio.

In the literature survey of welding parameters on the conventional MIG welding machines like welding current, welding voltage, welding speed, arc length, angle of welding, air gap, and welding position, stick length, shielding gas, work piece material weldability, which affects the desired output like strength, hardness, and microstructure for different materials like mild steel, carbon steel, and aluminum alloys were studied. However, the optimization of welding parameters and characterization of AHSS steel sheets material welded by MIG welding process are not studied. Therefore, it is vital to study the optimization and characterization of welding parameters for AHSS of EN-10149-2 S700MC with thickness of 2 mm.

The difficulties in welding operation of AHSS of EN-10149-2 S700MC with thickness of 2 mm steel sheet metal on MIG welding process and how to overcome those challenges by selecting optimal welding parameters are discussed as follows:

(1) Identifying significant factors (welding current, welding voltage, and welding speed) that affect the surface quality of MIG welding process for AHSS of EN-10149-2 S700MC with thickness of 2 mm.

(2) Scientifically recommending the optimum welding process parameters for MIG welding process for AHSS of EN-10149-2 S700MC steel sheet metal material.

2. Experimental Methodology

2.1. Base Material. The experimental works were carried out on AHSS of EN-10149-2 S700MC with thickness of 2 mm steel sheet metal butt welded joints by different MIG welding process parameters. An advanced high strength AHSS of EN-10149-2 S700MC steel sheet metal chemical composition is shown in Table 1.

2.2. MIG Welding Machine. Metal Inert Gas (MIG) welding embraces a group of arc welding processes in which a continuous electrode (the wire) is fed by powered feed rolls (wire feeder) into the weld pool.

MIG welding is usually carried out with a handheld gun as a semiautomatic process. The MIG process was suited to a variety of job requirements by choosing the correct shielding gas, electrode (wire) size, and welding parameters. Telwin MIG-MAG made machine was used with the filler material of ER70S. The chemical composition of the ER70S filler material is indicated in Table 2. The fixed or preselected welding variables were electrode type (ER 70S-6), electrode size (0.8 mm diameter), type of current (DC), and so forth, which were set before the actual welding.

The primary welding variables that were considered in this research include welding current (I), arc voltage (V), and travel speed (S). Secondary adjustable variables considered were work angle and the travel angle of the electrode.

2.3. Metallurgical Microscope. The microstructure of the specimen was observed by using metallurgical microscope (model: Huvitz HRM-300 series; magnification: 50x, 100x, 200x, 500x, and 1000x; scanning area: 104×102 mm; illumination system: 12 V, 1000 W halogen lamp). All samples were seen at 100x magnification. The microstructures of welded samples were captured at different zones like base metal, weld zone, thermomechanical zone, and heat-affected zone.

2.4. Microhardness Testing. The Vickers hardness model HVS 50 testing machine with a square base diamond pyramid as the indenter was used. The included angle of the pyramid was l36° between opposite faces subjected to a test force between 1 gf and 100 kgf. The area of the sloping surfaces of the indentation was calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

2.5. Universal Tensile Testing Machine. Universal tensile testing machine was used to measure the tensile strength of the weld joint. Properties are usually determined by doing tensile test. For the test results, yield stress, tensile strength, percentage elongation on gauge length, and percentage reduction in area were extracted. The test was carried out using Bairoe computer controlled electrohydraulic universal testing machine (model HUT-600) with cross head speed of 1 mm/min. The tests were measured three times for each sample and the average was taken.

2.6. Specimen Preparation

2.6.1. Welding Specimen. The sample of advanced high strength steel EN-10149-2 as a base metal was taken and prepared to the required dimensions of 300 mm length, 90 mm width, and 2 mm thickness used as the workpiece. These specimens were prepared with a V-shaped groove with the root face, and the root gaps were 15°, 1 mm, and 0.9 mm, respectively. Thereafter, 27 pairs of specimens with constant groove angle and root face were prepared. To make a butt joint, two sheets were tacked at the two ends along the width, with a constant root gap of 0.9 mm. Copper coated mild steel wire with diameter of 0.8 mm was used in the experiment as the electrode. The wire was fed through the welding gun by a roller drive system. The shielding gas used was a mixture of 98% argon and 2% CO_2, supplied in a regulated manner at a constant flow rate and at a constant pressure.

In this work, horizontal (PA/1G) welding position was used to join the sample. The welding joint was done at root opening of 0.8 mm and at a bevel angle of 10° and groove angle of 15°.

2.6.2. Tensile Specimen. Tensile samples were prepared in standard form (dog bone) with the following dimensions: total length of 300 mm, gauge length of 100 mm, grip length of 90 mm, thickness of 2 mm, and width of 20 mm, as shown in Figure 1 schematically with dimensions; for every experiment three test samples were reputed.

2.7. Optimization of Process Parameters. MINITAB 18 tool was used to analyze data for optimization. Taguchi method was used as a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments to analyze the effect of welding parameters on mechanical property of EN-10149-2 AHSS.

Taguchi method was used to determine the minimum number of experiments to be conducted in the overall experiments based on the below equation.

$$N = L^P, \tag{1}$$

where is the number of experiments to be conducted, P is the number of parameters, and L is the number of levels.

Before selecting the particular orthogonal array (OA), it is necessary to set the number of controlled parameters and the number of levels for these parameters. The estimation of the selected parameters level was done by doing weld bead joint geometry. In the present work, there were three variables (welding current, welding voltage, and welding travel speed) and three levels for each parameter as described in Table 3.

According to full factorial design; a total of 27 experiments were required to optimize the parameters. Taguchi experimental design suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. This setup allows the testing of all three variables without having to run 27 (3^3) experiments as shown in Table 4.

Signal-to-noise (S/N) ratio technique was used for prediction of optimum results. The S/N ratio takes both the mean and the variability into account. Analysis of Variance (ANOVA) was also implemented to investigate which

Table 1: Chemical composition of base metal (S700MC).

C	Si	Mn	P	S	Al	Nb	V	Ti	Cu	Cr	Ni	Mo	B	Zr
0.056	0.18	1.78	0.01	0.003	0.038	0.06	0.01	0.116	0.011	0.04	0.03	0.005	0.0004	0.003

Table 2: Chemical composition of filler electrode ER70S.

Grade	C	Si	Mn	Cr	Ni	Mo	V	Ti	Al	Zr	P	S	Cu
ER70S	0.05	0.55	11.15	0.04	0.15	0.005	0.008	0.10	0.10	0.07	0.012	0.006	0.010

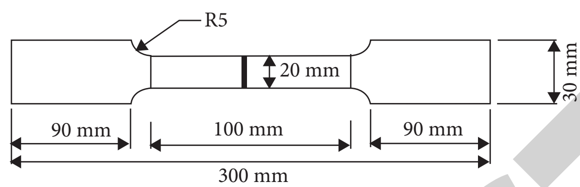

Figure 1: Sample for tensile test.

Table 3: Process parameters and their levels.

S. no	Process parameter	Unit	Levels		
			Level 1	Level 1	Level 1
1	Current (I)	A	60	65	70
2	Voltage (V)	V	16	17	18
3	Welding speed (S)	mm/s	2	4	6

Table 4: Orthogonal arrays for number of experiments.

Experimental runs	Experimental variables		
	Current (A)	Voltage (V)	Speed (mm/s)
1	60	16	2
2	60	17	4
3	60	18	6
4	65	16	4
5	65	17	6
6	65	18	2
7	70	16	6
8	70	17	2
9	70	18	4

welding process parameter significantly affects the quality characteristics. Taguchi recommended a logarithmic transformation of mean square deviation (S/N ratio) for the analysis of results. ANOVA separates the overall variation from the average S/N ratio into contribution by each of the parameters and the errors.

3. Results and Discussion

Experimental study was conducted to evaluate the effect of welding parameters, namely, welding current, welding voltage, and welding speed, on the welding material property of tensile strength, hardness, and microstructure of base material, fusion zone, and heat-affected zone. The results for each experiment are discussed in this section. Design of experiment techniques is used to identify the optimum welding parameters and to identify the most influential parameters.

3.1. Microstructural Analysis

3.1.1. Microstructure of Parent Material. Microstructural study of weld joint includes analysis of solidified molten zone, heat-affected zone (HAZ), and parent material region. Figure 2 shows the microstructure of EN-10149-2 S700MC steel; this sample contains 60% area fraction ferrite and 40% area fraction martensite. The structure of these steels is a soft ferrite phase in which the martensitic islands are scattered; by increasing the amount of martensite in the structure, the strength is raised. Ferrite is a soft phase with lower yield

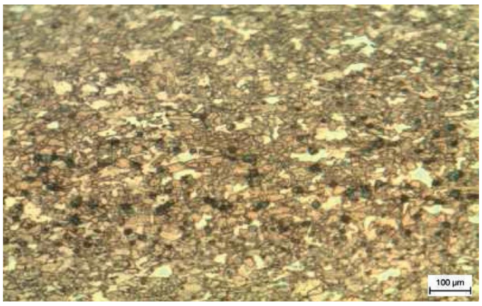

Figure 2: Microstructure of parent material (at 100x).

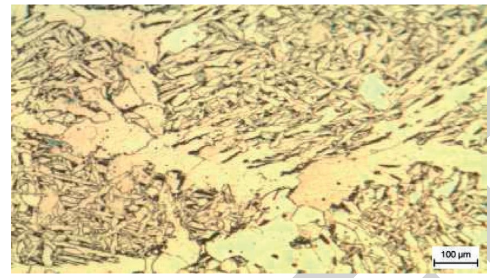

Figure 3: Microstructural analysis of WZ (100x).

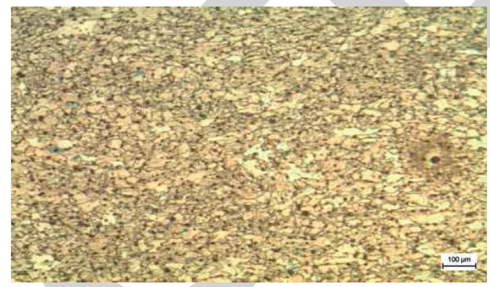

Figure 4: Microstructure analysis of HAZ (100x).

strength and more ductility. To have high strength and acceptable formability, the number of phases is essential. The behavior of these two-phase steels depends on the volume fraction of phases, morphology, grain size, and the carbon content.

3.1.2. Microstructure of Weld Zone. The weld metal microstructure of fusion welded joints is greatly influenced by the chemical composition of filler metal and the heat input ($V \times I \times t$) of the process. Since welding involves high temperature, the diffusion of atoms is better promoted. A transition zone gets formed along the fusion boundary which is chemically discrete compared to both base metals (mostly in concentration) shown in Figure 3. The intermetallic compounds that form also play a significant role in affecting the tensile strength of the material; that is why the tensile strength of the welded part is increased.

3.1.3. Microstructure of Heat-Affected Zone. The rate of solidification is different compared to the technique followed during the fabrication of the base metal. This results in a significant change in the size of the grains in the HAZ-fusion boundary (coarser grains are observed along the fusion boundary) indicated in Figure 4. However, lower heat input leads to fast cooling rate, which results in fine microstructure.

3.2. Hardness Analysis of Weld Zone. The hardness measurement values in the weld zone are tabulated in Table 5. The S/N ratio has been calculated using MINITAB 18 for each single number of experiments and is recorded in Table 5.

3.2.1. Response Table for Hardness of Welded Zone. As in Table 6, for S/N ratios, the larger the better.

Table 7 shows means for hardness of WZ.

In this experimental analysis, the voltage has the greatest influence on the signal-to-noise ratio, followed by current and speed. According to Taguchi‘s experimental principle, the S/N ratio must be larger. In this work, the level averages in the response table show that the greater S/N ratio and the mean are when the current, voltage, and speed were 70 A, 18 V, and 6 mm/s, respectively, as shown in Figures 5 and 6. Tables 6 and 7 show the average of each of the response characteristics (S/N ratio, mean) for each level of every variable. The tables contain the rank of each variable according to the delta statistics reading which compares the relative magnitude of each variables effect.

The S/N ratio allows us to quantify the size of the applied or controlled signal relative to fluctuations that are outside experimental control, or, in other words, it is a statistical method used to evaluate the ratio of mean of the required value to the standard deviation from the expected value. As shown in Table 6, the S/N of the optimum value of each parameter is almost similar, which means that each parameter in the welding process has equal chance to bring the performance change. The adequacy of the model has been investigated by the examination of residuals. From the normal probability plot, it is found that the residuals fall on a straight line; it implies that the errors are distributed normally. The plot of residual versus predicted/fitted surface roughness values reveals that there is no obvious pattern and unusual structure shown in Figures 7 and 8. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

3.2.2. Analysis of Variance (ANOVA) of Hardness for Weld Zone. In order to determine the significance of each variable, it is necessary to know the critical "*F*" value and compare this critical "*F*" value with the calculated "*F*" value. If the calculated "*F*" value is greater or equal to the critical "*F*" value which is obtained from 0.05 significance level, then the variable is significant. However, if it is less than critical value, the parameter is nonsignificant. The critical value can be obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significance

Table 5: Hardness of welded zone reading and S/N ratio.

S. no.	Welding current	Welding voltage	Welding speed	Hardness of weld zone	SNRA1	MEAN1
1	60	16	2	135	42.6067	135
2	60	17	4	152	43.6369	152
3	60	18	6	155	43.8066	155
4	65	16	4	140	42.9226	140
5	65	17	6	153	43.6938	153
6	65	18	2	150	43.5218	150
7	70	16	6	150	43.5218	150
8	70	17	2	158	43.9731	158
9	70	18	4	163	44.2438	163

Table 6: Response table for signal-to-noise ratio for hardness of WZ.

Level	Current	Voltage	Speed
1	43.35	43.02	43.37
2	43.38	43.77	43.60
3	**43.91**	**43.86**	**43.67**
Delta	0.56	0.84	0.31
Rank	2	1	3

Table 7: Response table for means for hardness of WZ.

Level	Current	Voltage	Speed
1	147.3	141.7	147.7
2	147.7	154.3	151.7
3	**157.0**	**156.0**	**152.7**
Delta	9.7	14.3	5.0
Rank	2	1	3

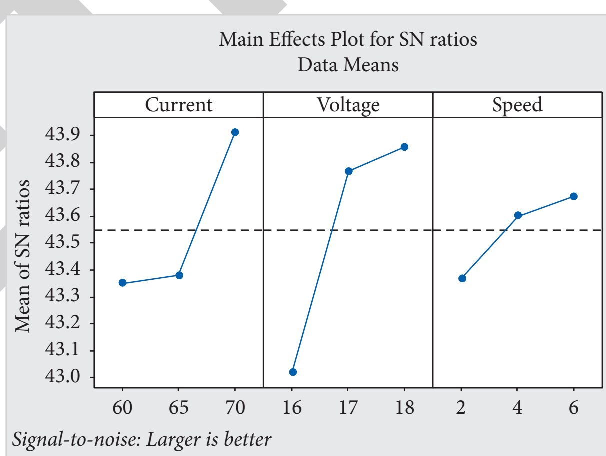

Figure 5: Main effect plot for S/N of hardness of welded zone.

level. Based on this, the critical value is "F_{cr}" (0.05, 2, 8) = 4.46 is noted which is lesser than "F" value shown in Table 8.

In statistical hypothesis testing, a result has statistical significance when it is very unlikely to have occurred given the null hypothesis. More precisely, a study's defined significance level, α, is the probability of the study rejecting the null hypothesis, given that it was true and the p value of a result, p, is the probability of obtaining a result at least as extreme, given that the null hypothesis was true. The result is statistically significant, by the standards of the study, when $p < \alpha$.

The effect of the significant feature can be determined according to "F" and "p" values, which is explained as follows.

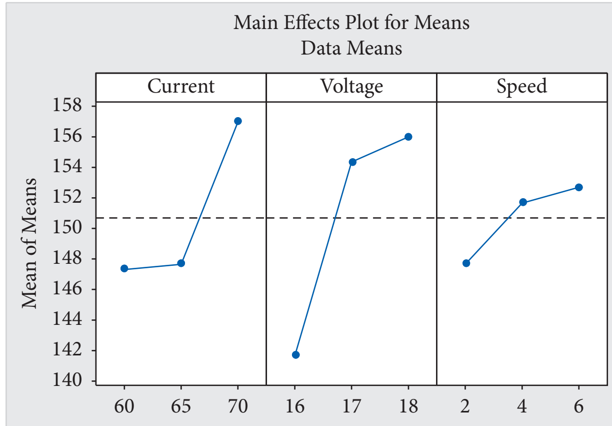

Figure 6: Main effects plot for means of welded zone.

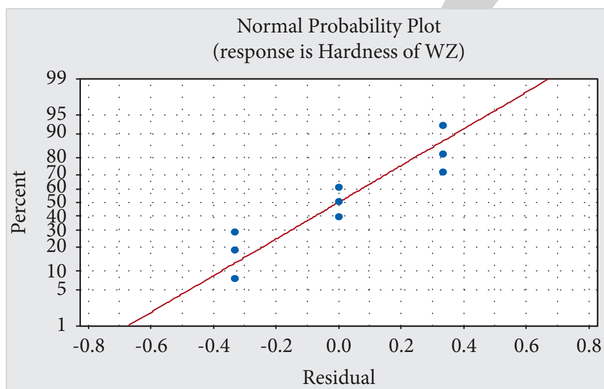

Figure 7: Normal probability plot of residual for hardness of weld zone.

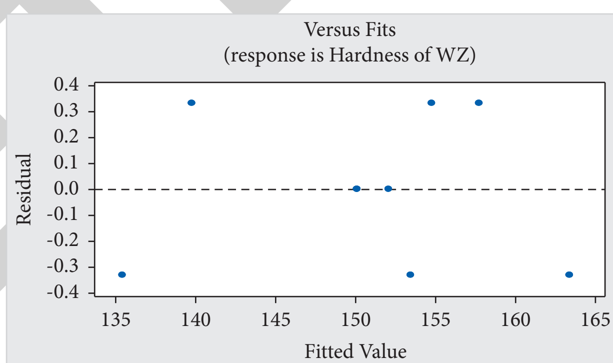

Figure 8: Plot of residual versus fitted hardness of weld zone values.

Table 8: General linear model of hardness of weld zone versus current, voltage, and speed for ANOVA.

Source	DF	Seq. SS	Percent of contribution (%)	Adj. SS	Adj. MS	*F*-value	*p* value	Significance
Current	2	180.667	30.52	180.667	90.333	271.00	0.004	
Voltage	2	368.667	62.27	368.667	184.333	553.00	0.002	
Speed	2	42.000	7.09	42.000	21.000	63.00	0.016	
Error	2	0.667	0.11	0.667	0.333			
Total	8	592.000	100.00					

Table 8 shows that the parameters current and voltage have "p" value less than 0.05% which means those variables have significant influence on the hardness of weld zone of the weld sample using GMAW process. When arranging their numerical value voltage has a greater influence with "p" and "f" values of 0.002 and 553, followed by current, 0.004 and 271, and speed, 0.016 and 63.

Also percentage contribution is one way to know the influence of each parameter on the hardness of weld zone. Parameter with high percentage of contribution has high power to change the performance of the system. In this case, voltage with 62.27%, current with 30.52%, and speed with 7.07% have a rank of 1 to 3, respectively, by their percentage of influence. Total allowable error = (0.667/592) × 100% = 0.11%

3.3. Hardness Analysis of Heat-Affected Zone. Hardness of heat-affected zone (HAZ) was recorded after the sample was measured using the hardness testing machine and the result of each experiment reading has been recorded and on the base of this reading of the signal-to-noise ratio for each sample was calculated as shown in Table 9.

As shown in Table 9, for the S/N ratio of each experiment, the larger the better. On the basis of these results, the S/N ratio has been calculated separately for every single number of experiments. The heat input at the weld zone is greater than that of HAZ during welding; the welding process and welding technique both influence the energy input, which is used to make a weld. The higher the energy input is, the slower the cooling rate is. Increasing heat input tends to soften the weld zone, and its hardness level is reduced.

3.3.1. Response Table for Heat-Affected Zone. Table 10 Shows that, for S/N ratios, the larger the better.

Table 11 shows the means.

Tables 10 and 11 show the average of each of the response characteristics (S/N ratio, means) for each level of every variable. The table contains the rank of each variable according to the delta statistics reading, which compares the relative magnitude of each variables effect. The S/N ratio allows us to quantify the size of the applied or controlled signal relative to fluctuations that are outside experimental control. As shown in Table 10, the S/N of the optimum value of each parameter is almost similar, which means that each parameter in the welding process has equal chance to bring the performance change, or they have similar significance for the change.

3.3.2. Analysis of Variance (ANOVA) for HAZ. The critical value is obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significance level, as shown in Table 12. Based on this principle "F_{cr}" (0.05, 2, 8) = 4.46 critical values, which is less than the "F" value in Table 12. The numerical value voltage has the greatest influence with "p" and "f" values of 1708 and 0.001, followed by current with "p" and "f" values of 703 and 0.001 and speed with "p" and "f" values of 199 and 0.005, respectively. In this case, voltage with 65.42%, current with 26.92%, and speed with 7.62% have a rank of 1 to 3, respectively, by their percentage of influence. Total allowable error = (0.222/580.22) ∗ 100 = 0.04%

3.4. Parent Metal Hardness. The average hardness number of the sample is 158.70. Table 13 shows the trials of test for samples. The data were taken on all the samples.

3.5. Tensile Test Analysis. After doing tensile testing operation on prepared samples as shown in Figure 9, the results of the tensile strength on different combination of parameters data are recorded and organized to calculate the S/N ratio of each sample. The input experimental values are measured using universal tensile testing machine.

The signal-to-noise ratio was measured using MINITAB 18 software as shown in Table 14.

From Table 14, for the S/N ratio of each experiment, the larger the better. By using this formula or the software, the results of tensile strength on different set of combination of parameters are shown in Table 14. On the basis of these results, the S/N ratio has been calculated separately for every single number of experiments.

3.5.1. Response Table for Tensile Strength. Table 15 shows the average of each of the response characteristics (S/N ratio, means) for each level of every variable. Table 15 contains the rank of each variable according to the delta statistics reading, which compares the relative magnitude of each variables effect.

In this experimental analysis, the voltage has the greatest influence on the signal-to-noise ratio and means analysis followed by current and speed. The level averages in Tables 15 and 16 show that the S/N ratio and mean are high when voltage, current, and speed, are at 18 volt, 65 A, and 4 mm/sec, respectively, as shown in Figures 10 and 11.

Therefore these values are the proper or optimum welding variables based on which maximum tensile strength was achieved.

3.5.2. Analysis of Variance (ANOVA) for Tensile Strength. The critical F_{cr} value can be obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significance level, as shown in Table 17. Based on this principle F_{cr} (0.05, 2, 8) = 4.46.

As shown in Table 17, all factors have p value less than 0.05% which means the variables have their own influence on the tensile strength of the weld sample using GMAW process. However, their numerical value is different. When we arrange their values, voltage, current, and speed have p and f values of 1843 and 0.001, 291 and 0.003, and 79 and 0.012, respectively. From this, it was obvious that voltage followed by current and speed have significant effect on tensile strength on welded sample of EN-10149-2 S700MC sheet metal with 2 mm thickness. Also percentage contribution is one way to know the influence of each parameter on the response. Parameter with

Table 9: Hardness of HAZ reading and S/N ratio.

S. no.	Current	Voltage	Speed	Hardness of HAZ	SNRA1	MEAN1
1	60	16	2	129	42.2118	129
2	60	17	4	146	43.2871	146
3	60	18	6	149	43.4637	149
4	65	16	4	134	42.5421	134
5	65	17	6	147	43.3463	147
6	65	18	2	144	43.1672	144
7	70	16	6	143	43.1067	143
8	70	17	2	151	43.5795	151
9	70	18	4	157	43.9180	157

Table 10: Response table for signal-to-noise ratio of the hardness of HAZ.

Level	Current	Voltage	Speed
1	42.99	42.62	42.99
2	43.02	43.40	43.25
3	**43.53**	**43.52**	**43.31**
Delta	0.55	0.90	0.32
Rank	2	1	3

Table 11: Response table for S/N ratio of the hardness of HAZ.

Level	Current	Voltage	Speed
1	141.3	135.3	141.3
2	141.7	148.0	145.7
3	**150.3**	**150.0**	**146.3**
Delta	9.0	14.7	5.0
Rank	2	1	3

Table 12: General linear model of hardness of HAZ ANOVA table.

Source	DF	Seq. SS	Percent of contribution (%)	Adj. SS	Adj. MS	*F*-value	*p* value	Significance
Current	2	156.222	26.92	156.222	78.111	703.00	0.001	Significant
Voltage	2	379.556	65.42	379.556	189.778	1708.00	0.001	Significant
Speed	2	44.222	7.62	44.222	22.111	199.00	0.005	Significant
Error	2	0.222	0.04	0.222	0.111			
Total	8	580.222	100.00					

Table 13: Vickers hardness test value.

Sample	Parent metal			
	Trial 1	Trial 2	Trial 3	Average value
Sample no. 1	166	153	159	159
Sample no. 2	168	160	170	166
Sample no. 3	165	150	156	157
Sample no. 4	140	155	158	151
Sample no. 5	150	154	162	155
Sample no. 6	155	168	170	164
Sample no. 7	171	166	154.3	164
Sample no. 8	158	157	146.3	154
Sample no. 9	166	158	149.1	158
Average value	160	158	158	158.70

FIGURE 9: Tensile tested samples.

TABLE 14: Tensile strength reading and signal-to-noise ratio.

S. no.	Current (A)	Voltage (V)	Speed (mm/s)	Tensile strength (MPa)	S/N ratio	MEAN1
1	60	16	2	745	57.4431	745
2	60	17	4	762	57.6391	762
3	60	18	6	775	57.7860	775
4	65	16	4	762	57.6391	762
5	65	17	6	768	57.7072	768
6	65	18	2	785	57.8974	785
7	70	16	6	750	57.5012	750
8	70	17	2	759	57.6048	759
9	70	18	4	782	57.8641	782

TABLE 15: Response table for S/N ratio of tensile strength (the larger the better).

Level	Current	Voltage	Speed
1	57.62	57.53	57.65
2	**57.75**	57.65	**57.71**
3	57.66	**57.85**	57.66
Delta	0.13	0.32	0.07
Rank	**2**	**1**	**3**

TABLE 16: Response table for means of tensile strength.

Level	Current	Voltage	Speed
1	760.7	752.3	763.0
2	**771.7**	763.0	**768.7**
3	763.7	**780.7**	764.3
Delta	11.0	28.3	5.7
Rank	**2**	**1**	**3**

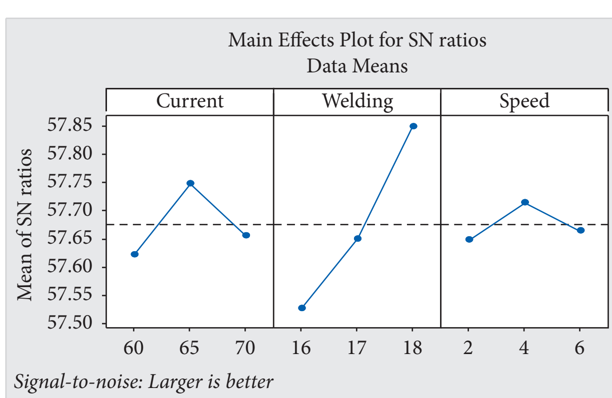

FIGURE 10: Main effects plot for S/N of tensile strength.

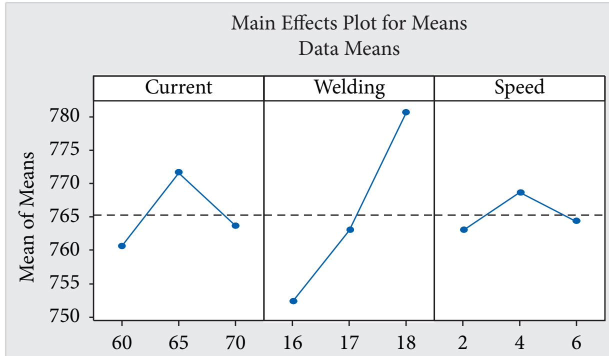

FIGURE 11: Main effects plot for means of tensile strength.

TABLE 17: General linear model of tensile strength versus current, voltage, and speed.

Source	DF	Seq. SS	Contribution (%)	Adj. SS	Adj. MS	F-value	p value	Significance
Current	2	194.00	13.14	194.00	97.000	291.00	0.003	Significant
Voltage	2	1228.67	83.24	1228.67	614.333	1843.00	0.001	Significant
Speed	2	52.67	3.57	52.67	26.333	79.00	0.012	Significant
Error	2	0.67	0.05	0.67	0.333			
Total	8	1476.00	100.00					

high percentage of contribution has high power to change the performance of the system. So voltage with 83.24% %, current with 13.14%, and speed with 3.57% have a rank of 1 to 3, respectively, by their percentage of influence. Total error = (0.67/1476) ∗ 100 = 0.05%

3.6. Taguchi Parameter Optimization Formula for Confirmatory Test

$$P_{opt} = X + (C - X) + (V - X) + (S - X), \quad (2)$$

where P_{opt} is optimal condition, X is the overall mean of S/N data, C is mean of S/N data for welding current at optimal level, V is mean of S/N data for welding voltage at optimal level, and S is mean of S/N data for welding travel speed at optimal level.

3.6.1. Parameter Optimization of Hardness of Weld Zone. The optimal condition for maximum hardness of weld zone was obtained using MINITAB 18 software.

From Table 3, the following data are taken:

The optimum working parameters are I3, V3, and S3 (i.e., current at I3 = 70A, voltage at V3 = 18 V, and speed at $S3$ = 6 mm/s).

X is the overall mean of S/N data = 43.54.

I1 is mean of S/N data for welding current at level 1 = 43.54.

V1 is mean of S/N data for welding voltage at level 1 = 43.55.

$S3$ is mean of S/N data for welding travel speed at level 3 = 43.54.

Then the optimal condition for hardness of WZ is as follows:

$$\begin{aligned} P_{opt} &= (X + (I3 - X) + (V3 - X) + (S3 - X), \\ P_{opt} &= (43.54 + (43.54 - 43.54) + (43.55 - 43.54) + (43.54 - 43.54), \\ P_{opt} &= 43.55. \end{aligned} \quad (3)$$

Predicted performance of WZ hardness is as follows:

$$y^2\text{opt cond} = 10^{(\text{Popt}/10)},$$
$$y^2\text{opt cond} = 10^{(43.55/10)},$$
$$y^2\text{opt cond} = 10^{(4.355)}, \quad (4)$$
$$y^2\text{opt cond} = 22646.44,$$
$$y = \sqrt{22646.44},$$
$$= 150.48\ \text{VHN}.$$

Therefore the optimal value for weld zone hardness is 150.48 VHN.

From this, the researchers conclude that the optimal value of weld zone hardness at parameters of current at 70 A, voltage at 18 V, and speed at 6 mm/s is **150 VHN**.

3.6.2. Parameter Optimization of Hardness of HAZ. The optimal condition for maximum hardness of HAZ was obtained as follows:

Current at I3 = 70 A, voltage at V3 = 18 V, and speed at $S3$ = 6 mm/s.

X is the overall mean of S/N data = 43.18.

I1 is mean of S/N data for welding current at level 1 = 43.18.

V1 is mean of S/N data for welding voltage at level 1 = 43.18.

$S3$ is mean of S/N data for welding travel speed at level 3 = 43.18.

Then the optimal condition for hardness of HAZ is as follows:

$$P_{\text{opt}} = (X + (I3 - X) + (V3 - X) + (S3 - X),$$
$$P_{\text{opt}} = (43.18 + (43.18 - 43.18) + (43.18 - 43.18) + (43.18 - 43.18), \quad (5)$$

$$P_{\text{opt}} = 43.18. \quad (6)$$

Predicted performance of hardness of HAZ is as follows:

$$y^2\text{opt cond} = 10^{(\text{Popt}/10)},$$
$$y^2\text{opt cond} = 10^{(43.18/10)},$$
$$y^2\text{opt cond} = 10^{(4.318)}, \quad (7)$$
$$y^2\text{opt cond} = 20796.96,$$
$$y = \sqrt{20796.96},$$
$$= 144.21\ \text{VHN}.$$

Therefore the optimal value for HAZ hardness is 144.21 VHN.

From this, the researchers conclude that the optimal value of HAZ hardness at parameters of current at 70 A, voltage at 18 V, and speed at 6 mm/s is **144 VHN**.

3.6.3. Taguchi Parameter Optimization Formula for Tensile Strength. The optimal condition for maximum tensile strength was obtained as follows:

Current at I2 = 65 A, voltage at V3 = 18 V, and speed at $S2$ = 4 mm/s.

X is the overall mean of S/N data = 57.6757.

I2 is mean of S/N data for welding current at level 2 = 57.6766.

V3 is mean of S/N data for welding voltage at level 3 = 57.6766.

$S2$ is mean of S/N data for welding travel speed at level 3 = 57.6633.

Then the optimal condition for tensile strength is as follows:

$$P_{\text{opt}} = (X + (I3 - X) + (V3 - X) + (S3 - X),$$
$$P_{\text{opt}} = \begin{pmatrix} 57.6757 + (57.6766 - 57.6757) \\ +(57.6766 - 57.6757) \\ +(57.6733 - 57.6757) \end{pmatrix}, \quad (8)$$
$$P_{\text{opt}} = 576751.$$

Predicted performance of tensile strength is as follows:

$$y^2\text{opt cond} = 10^{(\text{popt}/10)},$$
$$y^2\text{opt cond} = 10^{(57.6751/10)},$$
$$y^2\text{opt cond} = 10^{(57.6751/10)},$$
$$y^2\text{opt cond} = 10^{(5.76751)}, \quad (9)$$
$$y^2\text{opt cond} = 585477.21,$$
$$y = \sqrt{585477.21},$$
$$= 765.16\ \text{MPa}.$$

Therefore the optimal value for tensile strength is 765.16 MPa.

From this, the researchers conclude that the optimal value for tensile strength at parameters of current at 65 A, voltage at 18 V, and speed at 4 mm/s is **765 MPa**.

3.6.4. Confidence Interval versus Confidence Level. Confidence interval is a range of values that are expected to include an unknown population parameter based on the experiment sample, and confidence level is how likely the

Table 18: Compression between actual (experimental value) and theoretical (expected value) values of tensile strength, hardness of weld zone, and hardness of HAZ.

Optimum parametric condition obtained by Taguchi method	Maximum tensile strength obtained by confirmatory test	Prediction for parametric optimization by Taguchi method	% error
Current 65 A Voltage 18 V Speed 4 mm/s	765 MPa	780 MPa	0.5%
Optimum parametric condition obtained by Taguchi method	**Maximum hardness of weld zone obtained by confirmatory test**	**Prediction for parametric optimization by Taguchi method**	**% error**
Current 70 A Voltage 18 V Speed 6 mm/s	150 HVN	157.38 HVN	0.38%
Optimum parametric condition obtained by Taguchi method	**Maximum hardness of HAZ obtained by confirmatory test**	**Prediction for parametric optimization by Taguchi method**	**% error**
Current 70 A Voltage 18 V Speed 6 S	144 HVN	144.57 HVN	0.57%

value will fall within the experiment confidence interval. Interval is a range but confidence level is a percentage. In this work, 95% confidence level was used. Probability for 95% (0.95) confidence interval is calculated as

$$\text{Probability} = \frac{\text{Confidence interval} + \text{Alpha}}{2}, \tag{10}$$

where Alpha is just a shorter word for level of significance. Alpha is the complement of confidence level.

$$\text{Alpha} = 1 - \text{confidence level}. \tag{11}$$

For 95% confidence level, Alpha = 1–0.95 = 0.05.

$$\text{Probability} = \text{Confidence interval} + \frac{\text{Alpha}}{2}, \tag{12}$$

Probability is (0.95 + 0.05/2) = 0.9750. z value = 1.96, for the probability 0.9750. with 95% confidence interval.

Margin of Error (E) is calculated as follows:

$$\text{Margin of Error } (E) = \text{Standard error} \times Z, \tag{13}$$

$$\text{But Standard error} = \frac{\text{Standard deviation}}{\text{Square root sample size}}. \tag{14}$$

Standard deviation can be calculated using the following formula:

$$SD = \sum_{i=1}^{n} \frac{(\text{Reading } i - \text{Average})2}{n - 1}, \tag{15}$$

where n is the number of experiments.

Average of the sample can be calculated as

$$\sum_{i=1}^{n} \frac{(x1 + x2 \ldots . + xn)}{n}. \tag{16}$$

Using equation (13), averages for hardness of weld zone, hardness of heat-affected zone, and tensile strength were, 150 VHN, 144 VHN, and 765 MPa, respectively.

By using equation (15), standard deviations for tensile strength, hardness of weld zone, and hardness of heat-affected zone were 23.12, 37.89, and 41.92, respectively.

Standard error was calculated using

$$Serror = \frac{S\,D}{\sqrt{n}}, \tag{17}$$

where $Serror$ is standard error; SD is standard deviation; n is the number of experiments.

Using equation (6), standard errors for tensile strength, hardness of weld zone, and hardness of heat-affected zone were obtained as 7.70, 12.33, and 13.97, respectively.

$$\text{Margin of error} = \text{standard error} * Z. \tag{18}$$

Margins of Error (E) for tensile strength, hardness of weld zone, and hardness of heat-affected zone are 15.08, 7.16, and 8.37, respectively.

Then confidence interval can be calculated as

$$\text{Predicted value} \pm E. \tag{19}$$

For hardness of welded zone, we have the following:

Upper interval = predicted value + E = 150 + 7.16 = 157.16 VHN.

Lower interval = predicted value − E = 150–7.16 = 142.84 VHN.

For hardness of HAZ zone, we have the following:

Upper interval = predicted value E = 144 + 8.37 = 152.37 VHN.

Lower interval = predicted value − E = 144 − 8.37 = 135.63 VHN.

For tensile strength, we have the following:

Upper interval = predicted value + E = 765 MPa + 15.08 = 780.08 MPa.

Lower interval = = predicted value − E = 765 MPa − 15.08 = 744.02 MPa.

3.7. Confirmatory Test. After the experiment has been done and the optimal level of welding process parameters has been selected, the final step is to predict and verify the improvement of the performance characteristics using the optimum level of the welding process parameters. The purpose of confirmation of experiment is to verify the optimum conditions so as to reduce the variation. Therefore confirmation experiment is conducted by using the levels of optimal setting parameters. This experimental combination of parameters resulted in substantial reduction in variation of performance characteristics and shows the factors or parameters and levels chosen from the experiment do provide the desired results. This is done by welding the same base metal by using the same material and selected optimal welding parameters. In this study, the experiment has been done three times and the final result was recorded from the average of them. If the predicted and the observed values are close to each other, then the used model is adequate for describing the effect of parameters on quality characteristics, and if there is a large difference in observed values and predicted values, then the used model is not adequate. Table 18 shows the compression between actual (experimental value) and theoretical (expected value) values of tensile strength, hardness of weld zone, and hardness of HAZ, in which the % error is indicated.

4. Conclusions

This research has described the use of Taguchi method statistical techniques ANOVA and S/N ratio for analyzing and optimizing the effect of welding parameters on the mechanical properties of AHSS of EN-10149-2 S700MC with thickness of 2 mm structural steel with MIG process. The process was performed using a specific set of controllable variables, voltage, current, and welding speed, for the response variables of tensile strength and hardness microstructure of weld joint.

The study found that the controlled factors had significant influence on the response variables. The orders of the significant effect on the response variable were determined according to their percentage contribution. The result shows the comparison between the experimental and the theoretical values of the tensile strength and the hardness of weld zone.

Optimization is done for increasing the tensile strength, hardness of weld zone, and hardness of HAZ. The tensile strength was increased from 765 MPa to 780 MPa with a minimum error of 0.5%. The hardness of weld zone has been increased from 150 VHN to 157 VHN and the hardness of HAZ increased from 145.1 VHN to 166.47 VHN. Increasing the hardness of weld zone and HAZ means increasing the resistivity of plastic deformation of welded joint and the opposite is true.

The confirmatory test was done by taking the optimal parameters and the result shows that the improvement of the response variables is acceptable and also shows that the method that was used for optimization is valid. The contribution of the parameters on the change of tensile strength, hardness of weld zone, and hardness of heat-affected zone has been explained in terms of percentage. The parameter with higher percentage has a great contribution to the change and the parameter with low percentage has low contribution to the performance change. Based on this principle, for tensile strength, voltage, current, and speed have 83.24%, 13.14%, and 3.57% percentage contributions, respectively.

For hardness of weld zone, voltage, current, and speed have 62.27%, 30.52%, and 7.07% percentage contributions, respectively. For hardness of heat-affected zone, current, voltage, and speed have 51.69%, 16.16%, and 16.10% percentage contributions for the change. The main scientific finding of this work is as follows: using optimum MIG welding process parameters, it is possible to weld AHSS of EN-10149-2 S700MC with thickness of 2 mm and to get defect-free high-quality weld joint with maximum required mechanical and microstructural property.

Data Availability

The data were extracted from the MIG welding process on advanced steel material and made for M.S. thesis. The entire thesis is available in the university database.

Disclosure

This work was submitted as M.S. thesis on "Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding."

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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