RESEARCH ARTICLE

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Enhancing the Notch Tensile Strength of GMAW welded AISI 1013 Low Carbon Steel with Taguchi Optimization

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Abstract

There is currently no exact dynamic model which predicts hysteresis and creeps in a piezoelectric actuator under varying operating conditions (increasing frequency and amplitude of input, time of operation, temperature effects), and is stable against uncertainties. Thus, research needs to be carried out to predict the hysteresis and creep on the modeling and identification of the non-linear dynamics of a piezoelectric actuator. It would aid the implementation of a model-based control algorithm such as the precise positioning of a nano-positioning.

Keywords: GMAW Welding, MIG, Notch Tensile Strength, Taguchi method

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Introduction

In many fabrication industries, the employability of Gas Metal Arc Welding (GMAW) is increasing rapidly. The process is versatile because it can be applied for all position welding which is easily automated and can easily be integrated into the robotized production centers. These advantageous features of this process have motivated many researchers to study the GMAW process in detail. GMAW process has widely used in a range of plate thicknesses even though it has been most dominant in thin welding sheets. It is due to its easiness in starting and stopping, and thereby its relatively high productivity. However, to achieve optimum welding performance, the welding parameters must be set correctly.[1] In general, the nature of a weld joint is straightforwardly affected by the welding input parameters during the welding process. Lamentably, a typical issue that has confronted the producer is the control of the process input parameters to acquire a better-welded joint with the necessary bead geometry and weld quality with insignificant negative remaining anxieties and contortion.

Generally, it has been essential to decide the weld input parameters for each new welded item to acquire a welded joint with the necessary specification details. To do as such requires a tedious experimentation improvement exertion, with weld input parameters picked by the expertise of the machine operator or the engineer. At that point, welds are inspected to decide if they meet the particular or not. The weld parameters can be chosen to create a welded joint that intently meets the joint requirements at long last. Likewise, what isn't accomplished or frequently considered is a streamlined welding parameters combination since welds can regularly be produced with different parameters. There is regularly a more ideal to decide the welding parameters combination,[2] and the electrode wire can likely be used as a welding variable.[3] Industries are fabricating compressor tanks using low carbon steel (AISI 1013). GMAW welding parameters are set to the rough qualities dependent on laborer experience (not definite estimations of voltage, current, and welding velocity). It was likewise discovered that appropriate joint spacing isn't kept up during the welding process.

Weld quality improved with the impact of parameters on weldments like welding current, type, flow, and pressure of inert gas, electrode feeding speed, arc voltage, travel speed, electrode orientation, electrode extension, and electrode diameter.[4,5] The strength of the welded steel is upgraded with sufficient edge arrangement of the weldment, and strength and hardness of the joint increment with a decline in heat input.[6,7] Many investigators have designed

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the experimental procedure for parametric optimization with different optimization tools, and the most commonly used is Taguchi approach[8,9] to obtain the best result by minimization or maximization. This methodology has wider application discussed with various materials in other process manufacturing and other than welding process with mechanical properties.[10-12] The erosion obstruction was discovered less in the weldment than in correlation with the base metal on the use of support plates.[13] The different aspects of the pulsed parameters and their selection to obtain good quality welds and concluded that only a few had used the (DOE) design of experiments to complete their experiments to select the process parameters and study their influence on the properties of weld metal.[15] Tensile strength of ferritic/austenitic laser-welded segments was improved by a factual design of experiment (DOE) was utilized to optimize selected LBW parameters. Taguchi approach was utilized, and joint strength was resolved utilizing the notched-tensile strength (NTS) technique. The trial results demonstrate that the F/A laser-welded joints are improved viably by upgrading the Taguchi approach's input parameters. Laser butt-welding of a thin plate of magnesium composite utilizing the Taguchi technique has been optimized.[16] A dark-based Taguchi technique was received to improve the beat metal idle gas welding process parameters. It is discovered that pulse voltage and pulse frequency recurrence is the most persuasive elements influencing the weld quality.[17] Correlation on welding process parameters to weld bead geometry is developed with mathematical models for experimental investigation with Taguchi methods applied to plan the experiments. Five process parameters, viz., wire feed rate, plate thickness, pulse frequency, pulse current magnitude, and travel speed, are selected to develop the multiple regression analysis models.[18] The effectiveness of optimizing multiple quality characteristics of Nd: YAG laser welded titanium alloy plates via Taguchi method-based Grey analysis improved the weld quality.[19] Ganjigatti et al.[20] have explored to build up connections between process parameters and responses for 'bead-on-plate'- type GMAW welding measure utilizing the statistical regression investigation completed on the information gathered according to the full-factorial design of experiments (DOE). The selected input parameters in this examination are as per the following: welding speed, welding voltage, wire feed rate, gas flow rate, nozzle-to-plate distance, torch angle, and the responses considered are bead height, bead width, and penetration. The optimized machine parameter process settings improved the quality attributes of welded plates contrasted with quality levels accomplished for traditional machine parameter settings.

Therefore, this exploration aims to research the GMAW process parameters impacts of voltage, curent and welding speed with Taguchi Optimization to deal with acquire the improved values of notch tensile strength when welding low carbon steel (AISI 1013) sheet.

Experimental Procedure

The details of the welding materials, properties of base material, and the specification of the Gas Metal Arc Welding (GMAW) used for the study are listed below

Base material Low carbon steel (AISI 1013)
Electrode material : Copper coated mild steel
Diameter of electrode material : 0.8 mm
Electrode grade : ER70S6
E - Welding electrode
R - Can be used as filler rod
70 - Tensile strength in thousands of pounds per square inch.
S - Solid core wire
6 - Chemical composition of wire
Electrode make : ZOGO
Size of base material : 250 mm X 150 mm X 3.15 mm

Specification of GMAWwelding equipment
Model : ZUPERARC 300
Make : Larsen and Toubro
Supply voltage : 415 Volts
Phase : 3
Frequency : 50 Hz
Rating : 40% Duty Cycle
Cooling : Forced air
Number of Voltage settings : 30
Current range : 0 -300 Amps.
Open circuit Voltage : 14 – 37 Volts
Transformer Type : DC
Tack Weld time range : 1-5 Seconds
Phase time range : 1-5 Seconds
Suitable wire size : 0.8 – 1.2 mm

Mechanical properties of base material

Hardness : 73 HRB
Yield Strength : 363 MPa
Ultimate tensile strength : 445 MPa
Elongation : 37%

The proportionate chemical composition of the filler material and base material are shown in Table 1. A ZUPERARC 300 transformer type DC welding machine (Make: Larsen

Table 1: Base material and filler material chemical composition

Grade	*Chemical composition (%)*						
	C	*Mn*	*Si*	*P*	*S*	*Al*	*N*
AISI 1013 (Base material)	0.111	0.750	0.153	0.021	0.017	0.038	0.005
ER70S6 (Filler Material)	0.10	1.5	0.9	0.025	0.035	-	-

Table 2: Levels of process parameters

Factors	*Unit*	*Level 1*	*Level 2*	*Level 3*
Voltage (A)	Volt	18	22	26
Current (B)	Amps	75	105	135
Welding speed (C)	mm/min.	250	330	410

Table 3: Constant process parameters

S.No	*Process parameters*
1	Electrode used: ER70S6
2	Filler rod diameter: 0.8 mm
3	Position: Horizontal
4	Stick out: 14 mm
5	Gas flow rate: 8 lpm
6	Joint spacing: 1.58 mm

and Toubro) was utilized to weld a single butt joint on AISI 1013 Low carbon steel. The primary interaction of process parameters in GMAW welding is voltage, current, and welding speed, which are, for the most part, considered for controlling the quality of the weld. In the current investigation, the impact of voltage, current, and welding speed on mechanical properties has been examined, and the other process parameters, for example, shielding gas flow rate, stick out, and joint separating, were kept consistent throughout the process. Preliminary attempts were directed by varying one of the interactions in process parameters and keeping other process parameters constant. In addition, the operating range of voltage, current, and welding speed was investigated by examining bead appearance and the total penetration of the weldment. The range of the process parameters chosen under the current examination and the steady process parameters appear in Tables 2 and 3 separately. In the current examination, the Taguchi strategic method was utilized to optimize the interaction in process parameters to maximize the weldment's mechanical properties. The quantity of process parameters considered under this examination is three, and the level of every parameter is also three. The degrees of freedom of all the three parameters are seven, and interactions were not considered; hence, the L9 orthogonal array is selected in the design of the experiment (DOE). Each state of the experiment was repeated twice to decrease the noise/error effects, and the details of the selected orthogonal array are presented in Table 4.

The base metal sheets of dimension measures 250 × 150 ×3.15 mm have been prepared, and butt joints were made utilizing the exploratory design layout in Table 4. The weld joint is finished in a single pass with GMAW. Specimens for tensile testing (both plain and notched examples) were taken at the center of the multitude of joints and machined to ASTM E8 standard guidelines.[21] The specimens utilized for the plain tensile test and notch tensile test appear in Figure 1 and Figure 2 separately. Tensile test was conducted utilizing a universal testing machine (make: KRYSTAL ELMEC, model: UTK-20). All the welded specimens failed in the base metal region, and the properties identified with the base metal are acquired; however, not the weld metal, and henceforth, a notch tensile test is conducted to uncover the weld metal properties. The quality attributes for the notch tensile strength of the base metal were assessed, and afterward, statistical analysis of variance (ANOVA) was completed. In light of the ANOVA, the contribution of each process parameter influencing the quality characteristic is assessed and additionally gives a sign of which process parameters are statistically significant. The welding process parameter combination on GMAW is predicted and verified for the optimum values.

Table 4: Experimental layout L9 orthogonal array

Experiment Number	*A*	*B*	*C*
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

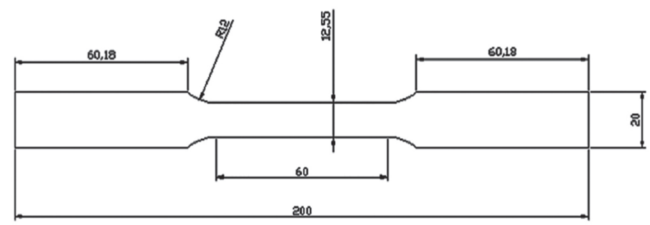

Figure 1: Plain tensile test specimen specimen

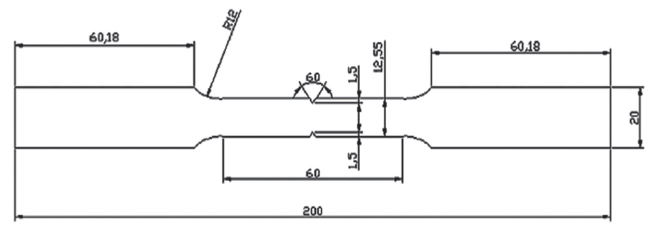

Figure 2: Notch tensile test specimen specimen

Result And Discussions

Mechanical Properties

In some small-scale industries, GMAW welding parameters are set to the approximate values concerned on the worker's experience, and it was identified that proper joint spacing is not maintained during the welding process. This does not ensure that selected welding parameters can produce the optimal or near-optimal quality attributes. On conducting the experiments for the existing welding parameters (Table 5)

Table 5: Existing welding parameters

S.No.	*Parameter*	*Parameter condition*
1	Electrode used	ER70S6
2	Filler rod diameter	0.8 mm
3	Position	Horizontal
4	Voltage	26 V
5	Current	118 Amps
6	Stick out	14 mm
7	Gas used	Carbon di-oxide
8	Gas flow rate	8 lpm
9	welding speed	320 mm/min

Table 6: Mechanical properties of AISI 1103 low carbon steel welds as per existing welding parameter

Specimen ID	*Notch tensile strength (MPa)*		
	Trial 1	*Trial 2*	*Average*
S	365	368	366.5

Table 7: Mechanical properties of AISI 1103 low carbon steel welds

Specimen ID	*Notch tensile strength (MPa)*		
	Trial 1	*Trial 2*	*Average*
S1	209	217	213
S2	260	256	258
S3	308	296	302
S4	266	268	267
S5	320	318	319
S6	369	373	371
S7	309	327	318
S8	379	375	377
S9	408	416	412

with 0.5 mm joint spacing, results are shown in Table 6 was obtained. Further experiments as per designed L9 orthogonalarray by keeping the joint spacing as 1.58 mm was conducted.[15] Notch tensile strength, impact toughness, and hardness of GMAW welds are presented in Table 7.

Optimization of Process Parameters

The evaluation of impacts of individual parameters autonomous of other parameters on the identified quality attributes, i.e., notch tensile strength (NTS), permits process parameters optimization using the Taguchi method. The analysis of variances (ANOVA) results shows what parameters are critical for the quality attributes. Table 8.shows the percentage contribution for the process parameters on the quality attributes. Regression equations were developed using MINITAB software. The regression equation (Table 9) is used to predicting the notch tensile strength within the factorial space exploited.

The main effect plot for means on optimum conditions was found and shown in fig. 3. This plot for means was verified by manual means calculation.[16] For optimum conditions, the optimal results were predicted by simple calculations and MINITAB software. The validated optimum results are evaluated, and the average results are presented in Table 10 by conducting experiments as per the mechanical properties and optimum conditions. Optimum values were observed close to that experimental values, and also figure 3 shows the graphical representation of the S/N ratio. In this study, the S/N ratio was chosen according to the criterion the-bigger-the-better to maximize the responses. The S/N ratio for the "bigger is better" target for all the responses were evaluated as follows:

$$S/N = -10\ \log 1/n\,[\sum 1/y^2]$$

Where y is the average measured response and n is the number of experiment runs. Table 11 provides the S/N ratio of measured responses. The scope of this work is to maximize the notch tensile strength, hardness of the weldment, and impact toughness, so it is recommended to use a means plot. The plot for the S/N ratio was not used for finding optimum

Table 8: ANOVA Table for Notch tensile strength

Factor	*Degree of freedom*	*Sum of squares*	*Mean squares*	*F cal*	*Ft.*	*Inference*	*Percent contribution*
Voltage	2	18656.89	9328.45	11959.55	9	Significant	57.32%
Current	2	13762.89	6881.45	8822.37	9	Significant	42.28%
Welding speed	2	118.23	59.12	151	9	Significant	0.35%
Error	2	1.55	0.78	-	-	-	-
Total	8	29606.22	-	-	-	-	-

Table 9: Regression equations for NTS

S. No.	*Response*	*Regression equation*
1	Notch tensile strength (MPa)	X = –143 + 13.9 A + 1.59 B –0.0458 C

where, A = Voltage, B = Current, C = Welding speed, and X = Response

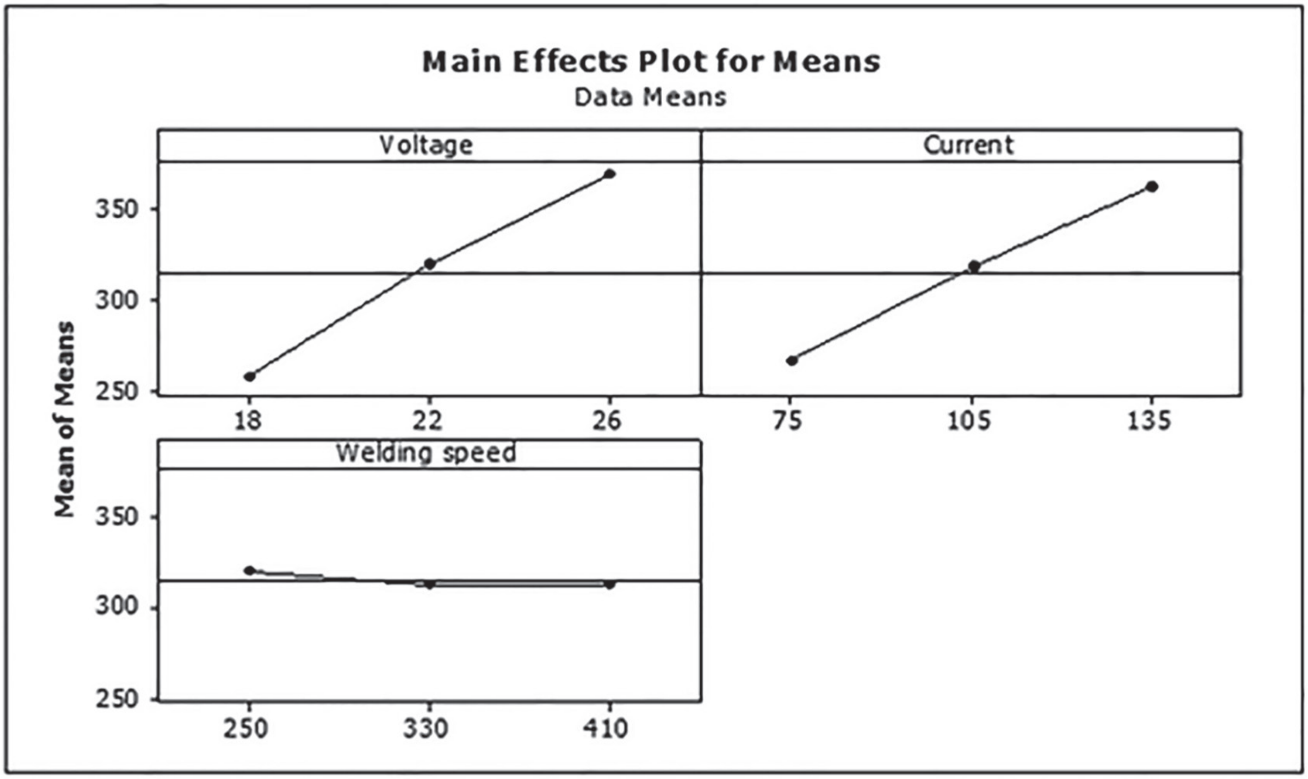

Figure 3: Graphical representation of Means -Notch tensile strength

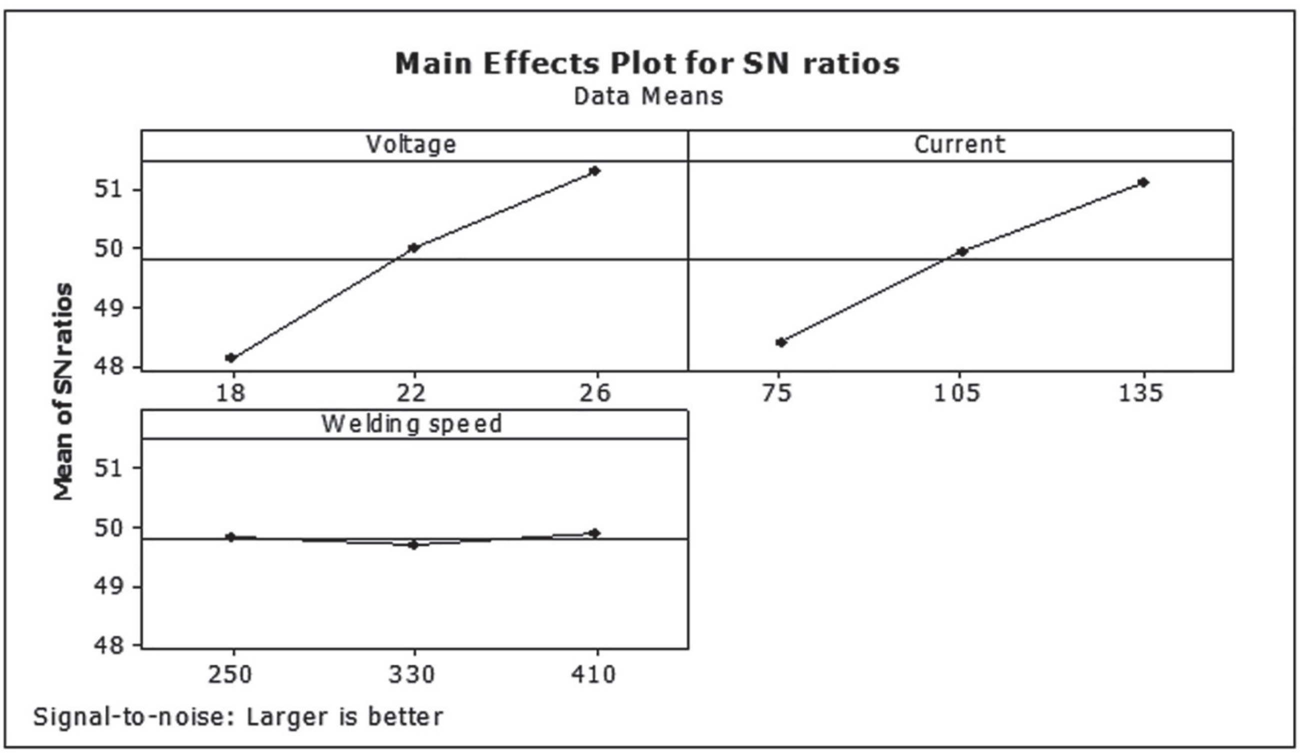

Figure 4: Graphical representation of S/N ratios - Notch tensile strength

Table 10: Validation of the optimum results

S.No	Response	Optimum condition	Predicted value	Experimental value
1	Notch tensile strength (MPa)	A3B3C1	420.58	418

Table 11: S/N ratio

S.No	Voltage (Volts)	Current (Amps)	Welding speed (mm/min)	Notch tensile strength (MPa)
S1	18	75	250	– 46.56
S2	18	105	330	– 48.23
S3	18	135	410	– 49.59
S4	22	75	330	– 48.53
S5	22	105	410	– 50.08
S6	22	135	250	– 48.38
S7	26	75	410	– 50.04
S8	26	105	250	– 51.52
S9	26	135	330	– 52.30

conditions because the plot for the S/N ratio gives optimum conditions for minimizing the changeability of the process, not for maximizing the attributes of weld quality.

Conclusion

The evidence of improved notch tensile strength on the optimal choice of welding process parameters for Gas Metal Arc Welding (GMAW) was done using the Taguchi method. An L9 orthogonal array was adopted to select welding parameter combinations with analysis of variance (ANOVA) performed to find the impact of process parameters on the quality welding process parameter. For the considered optimization problem, maximum notch tensile strength was observed when the voltage and current are on the higher side and welding speed is lower. Welding joints produced by optimized welding parameters improved the mechanical properties of the weldment compared to existing welding parameter settings. Notch tensile strength of AISI 1103 low carbon steel welds increased to 14.05% with Gas Metal Arc Welding (GMAW) process.

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