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Process Parameter Optimization of TIG Welding by Taguchi Method and Its Effect on Performance Parameter of Stainless Steel Grade 302HQ

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Abstract

Joining of various materials TIG welding process is widely used. The process parameters of TIG welding are most important as they affect the quality of the weld, productivity of the process and cost required for the welding process. This research will give the relationship of process parameters like the direct current of welding, supplied voltage, Speed of Welding, gas flow rate, etc. To study performance parameters like weld strength (UTS) in the case of Stainless Steel- Grade 302HQ for which Taguchi's method of Optimization can be used. Taguchi's Technique can be applied for various TIG welding parameters and can be optimized for desired weld quality. The suitable array is used to determine the optimum number of experiments based on Taguchi's technique. For collecting required data to analyze the welding characteristics of Stainless Steel Grade 302HQ and to go for optimization of welding parameters this method of optimization will be very useful. The results obtained by the experimental values and the theoretical values should be compared to confirm the best weld strength for Stainless Steel Grade 302HQ.

Disciplinary: Welding Engineering & Technology.

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1 Introduction

In day-to-day life erect the steel structure required for the various industrial applications such as oil refineries, sugar factories, construction of storage tanks, civil infrastructure, major repair work, etc. for which TIG welding is used.

In manual welding operation welder must adjust various welding parameters which directly affect the penetration of weld, weld geometry and quality of the weld. Proper values of weld parameters considering the optimized set point of welding current (A), welding voltage (V), travel speed of welding torch, and type of shielding gas used in the welding process, weld joint position and electrode angle will affect weld quality.

TIG welding process finds wide application for metals such as alloy and carbon steels, various types of cast Iron, wide grades of stainless steel, copper and aluminum alloys, nickel alloys, etc. all those metals can be welded in all standard welding positions. Also for the thin metallic plates.

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In manual welding operation, the welder must adjust the number of welding variables that affect the weld penetration, weld geometry and overall weld quality. Optimized and controlled values of weld parameters such as welding current (A), welding voltage (V), travel speed, and type of shielding gas used, weld joint position and electrode angle will affect weld quality.

TIG welding process finds wide application for metals such as alloy and carbon steels, various grades of cast iron and stainless steel, copper alloys, aluminum alloys, nickel alloys, etc. they can be welded in all standard welding positions. Also for the thin metallic plates.

1.1 TIG welding Process For Welding Similar Metals

In the TIG Welding process, as shown in Figure 1, the power source will generate an arc between the non-consumable electrode made up of Tungsten material and the work pieces. The high heat flux generated between the electrode and the workpieces melts down the two base metal pieces by fusion process and will give a strong weld with or without filler material. (Pal Amit et.al., 2015)To avoid the weld from oxidation a shielding gas is used. In the TIG welding process, the connection is made with a welding torch to a DC Direct current Electrode Negative power supply with a shielding gas connection. For joining two base metal plates sometimes the TIG welding process is carried out with or without the filler material of the same base metal. In the TIG welding process, the power source will develop a continuous spark and filler metal is supplied in the space provided between two base materials. Due to continuous sparking high heat is produced and the filler metal melts and fills the space provided between the two metal pieces and forms a strong weld. During the welding process, it is also observed that due to the atmospheric contamination the oxidization phenomenon will take place which affects the overall performance of the welded joint. To minimize it shielding gas process is used. Shielding process in which Argon (Ar) is used as a shielding gas which is allowed to spread near the weld area and develops a protective atmosphere around the weld run.

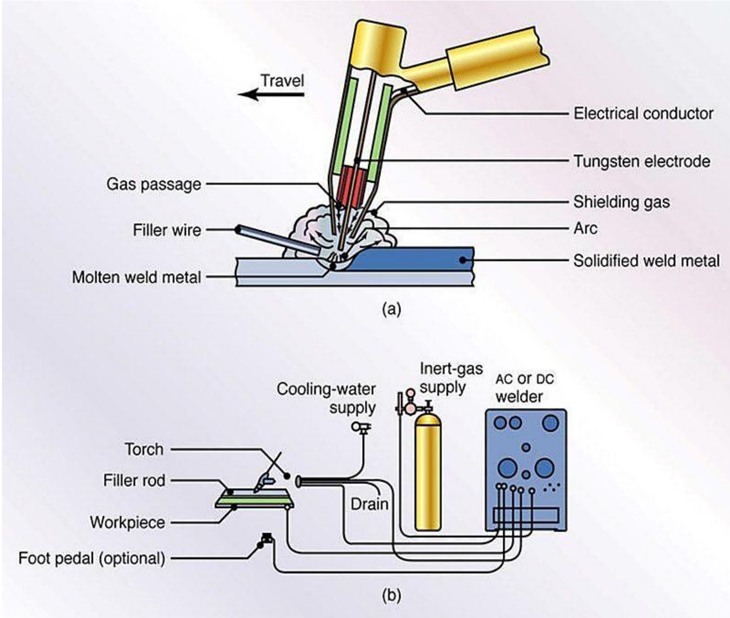

Figure 1: Working principle of TIG Welding. (created by the authors).

1.2 Weld Quality is Affected by Following Process Parameters in TIG Welding

Following are the various parameters that affect the quality of the Weld in the TIG welding process.

1.2.1 Direct Current of Welding

Specifically TIG welding for Stainless Steel material, the Direct Current is used with polarity electrode negative. The intensity of direct current in TIG welding affects the rate of deposition, weld size and penetration.

1.2.2 Voltage

For an electrical breakdown of the gas, arc voltage discharge plays a very important role, it produces an electrical discharge of current through the air in a non-conductive medium generating visible light of plasma. The Arc voltage depends upon the thickness of metal, type of joints, type of electrode used, type of shielding gas used and position of welds.

1.2.3 Speed of Welding

Welding speed is related to the time and distance covered in the welding process, it will give the actual length on which weld metal is deposited by the welding process. It can be calculated for any specific welding process.

2 Literature Survey

MIG welding is used in many industries. A consumable metal electrode is used in MIG welding. It is desired to get a good quality weld, good weld strength, and minimum cost of welding, there are some input parameters in MIG welding which play an important role. For getting a good quality weld it is very difficult to select optimal process parameters. Amit et al., 2015) The author has justified the most popular welding process ie the author has studied different welding parameters like supplied voltage, and direct welding current and studied their effect on strength of the weld joint.

MIG welding parameters are very important parameters that affect the weld quality, productivity and cost to a larger extent. The welding parameters which affect weld quality are the current for welding, the voltage of welding, the flow rate of shielding gas, the feed rate of wire, etc. All these parameters effects on strength of weld in Steel material. DOE method can optimize the parameters and gives the best-suited parameters which are required for desired weld quality. The DOE analysis gives importance to the process parameters which will affect the quality and strength of the weld. Taguchi technique will give us the plan for experimentation for getting the required data. In this paper, the author has studied various methods for optimizing process parameters and knowing the welding properties of different materials by considering orthogonal array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA). Labesh et al. (2017) studied these results to find out optimal parameters based on maximum tensile strength.

3 Design of Experiment (DOE): an Effective Technique

Design of Experiments is first used by Fisher (1920). Fisher was from England and studied the various effect of input parameters simultaneously on the test specimen. For economic purposes, Taguchi's approach can be used for overcoming problem-solving with optimized process parameters. Labesh et.al. (2017), DOE is used to consider various parameters at various levels within the acceptable range to get the best result and with minimum variation with respect to optimum values.

3.1 Importance of DoE

- Reduced Numbers of trials for experimentation.
- Easy Identification of control variables that have a significant effect on product performance.
- Process parameters can be easily found.
- Process parameters and performance parameters can easily determine on a Qualitative basis.
- Reduced Experimental error.

3.2 Finding Range of various Levels

In Labesh et al. (2017), several experiments were carried out by varying one process parameter and by keeping one constant value of the remaining process parameters. Table I shows process parameters along with their working range.

Table 1: Working Range Of Process Parameters (CREATED BY AUTHORS)

Variables	Units	Levels		
		1	2	3
Direct Welding Current (A)	Amp	120	150	180
Supplied Voltage (V)	Volts	20	22	24
Speed of Welding (G)	M/Min	4	5	6
Gas Flow Rate	L/Min	8	9	10

Process parameters are selected with a suitable Orthogonal Array, for this experiment three process parameters will affect weld quality and we have selected level three for each parameter. In Taguchi method special array is used which is called orthogonal arrays (OA), these orthogonal arrays are used for experimentation and provide all necessary information of three process parameters selected which affect the process performance. In this experimental work, we have considered three levels and their respective factors to form the L9 array.

3.3 Taguchi Methodology

Taguchi has developed a method of Optimization that is the most effective tool for designing different manufacturing systems (Amit et al. 2015). The suitable orthogonal array is developed based on experiments carried out which are the designed experiments, for optimum process parameters, variance is on the lower side. Taguchi method will provide us the integration for optimizing the process by using a suitable design of experiments (DOE) (Kamaleshwar et.al., 2017). By using Taguchi's method we can the optimum number of experiments and their related (S/N) ratios for this we can use an orthogonal array (OA). By considering mean values of Ultimate Tensile stress (UTS) Ranking and Delta values are calculated, see Table 6.

3.4 Selection of S/N Ratio Conditions

According to Modanloo et.al. (2016), it is very useful to find out optimal process parameter settings by using the Taguchi method, it's a statistical measure of performance evaluation. Dr. Taguchi has introduced the S/N ratio for determining performance parameters to predict control parameters that are most suitable for noise. In the S/N ratio mean and variable are considered for the analysis. In simple words, it is the ratio of the mean and the standard deviation. This S/N ratio can be determined by considering the conditions such as nominal is best (NB), lower the better (LB), and higher the better (HB). Weld penetration depth and Heat Affected Zone (HAZ) are taken into account in this research, as HAZ width will let us know the quality of the weld. Considering the Higher the better (HB)one can determine the depth of penetration parameter. We can determine the S/N ratio by using lower the better (LB) and higher the better (HB) conditions.

Condition 1:- By using Larger is a better condition.

$$S/N = -10 * \log(\Sigma(1/Y^2)/n) \quad (1).$$

Condition 2:- By using Smaller is a better condition.

$$S/N = -10 * \log(\Sigma(Y^2)/n) \quad (2),$$

Where Y = factor level combination response; n= Response number in the factor level combination.

S/N= Signal to Noise Ratio.

4 Experimental Layout

Experimentation is carried out for collecting the data which requires a particular sequence for which information of base and filler material along with its optimum welding process parameters are essential inputs. (Yang WH et.al., 1998)Appropriate limits will be fixed for minimum and maximum values of process parameters along with a suitable orthogonal array from standard Taguchi's method of optimization so that the experimentation can be conducted accordingly (Referring Figure 4) for getting optimum outputs. Referring to Figure 2 and Figure 3.

4.1 Chemical and Physical Properties of Test Specimen

Two plates of 302HQ grade stainless steel material of Size 25X4 mm, length 100mm are welded together with a butt joint in 1G position having specific Chemical and Mechanical properties which are considered are highlighted in Tables 2 and 3.

Table 2: Chemical Composition For 302hq Grade Stainless Steel (% Of Weight) (CREATED BY AUTHOR)

Steel Grade	C	Mn	Si	P	S	Cr	Ni	Cu
302HQ	0.03	2	1	0.045	0.03	19	10	4

Table 3: 302hq Grade Stainless Steel Mechanical Properties. (CREATED BY AUTHORS)

Tensile Strength	Yield Strength	Hardness	Melting point	Density
520MPa	220MPa	80HRB	14000C -14500C	8027 kg/m3

4.2 Experimentation

In this experiment, an Orthogonal array of matrix L9 (3*3) is designed by Taguchi's method (Davis et.al., 1978) which are giving nine conditions for experimentation is obtained (Table 4). The parameters are considered constant during experimentation and are listed in Table IV. Using this data experimentation is carried out and the results are tabulated, the Signal to Noise ratios (S/N) for each experiment can be determined by referring to Table 5.

Table 4: L9 Orthogonal Array For Experimental Layout.

Direct Welding Current (A)	Gas Flow Rate (L/Min)	Supplied Voltage (V)	Speed of Welding (G) (M/Min)
120	8	20	4
120	9	22	5
120	10	24	6
150	8	20	5
150	9	22	6
150	10	24	4
180	8	20	6
180	9	22	4
180	10	24	5

Table 5: S/N Ratio Main Effect Plot. (CREATED BY AUTHORS)

Direct Welding Current (A)	Gas Flow Rate (L/Min)	Supplied Voltage (V)	Speed of Welding (G) (M/Min)	UTS (N/mm2)	S/N Ratio (from Equation 1)
120	8	20	4	400.05	52.04
120	9	22	5	454.25	53.14
120	10	24	6	427.75	52.62
150	8	20	5	437.16	52.51
150	9	22	6	434.78	52.76
150	10	24	4	434.33	52.75
180	8	20	6	324.37	48.58
180	9	22	4	420.33	52.47
180	10	24	5	436.83	52.80

Table 6: Response Table For Mean. (CREATED BY AUTHORS)

Level	Direct Welding Current (A)	Supplied Voltage (V)	Speed of Welding (G) (M/Min)	Gas Flow Rate (L/Min)
1	427.3	350.2	418.2	423.9
2	435.4	436.5	442.7	367.3
3	356.9	433	358.6	428.4
Delta	79.3	78.2	79.1	61.1
Rank	1	3	2	4

Table 7: Range For Confirmatory Test. (CREATED BY AUTHORS)

Direct Welding Current (A)	Supplied Voltage (V)	Speed of Welding (G) (M/Min)	Gas Flow Rate (L/Min)
120	22	5	9

Table 8: Results From Confirmatory Test. (CREATED BY AUTHORS)

UTS (N/mm2)	S/N Ratio
454.25	53.1459

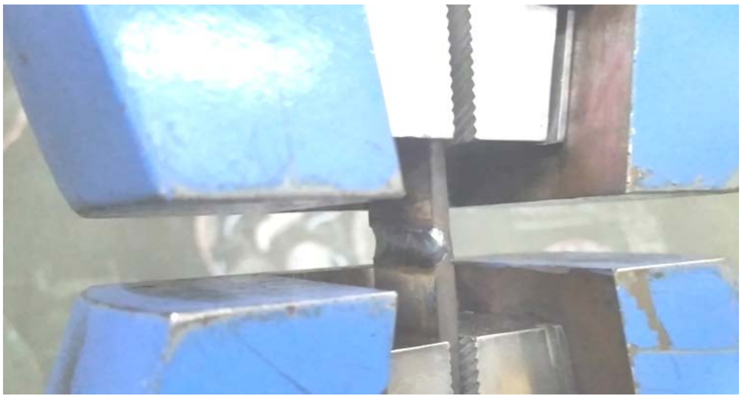

Figure 2: Tensile Test 1 Plate Size 25X4 mm, length 100mm S30430. (created by authors).

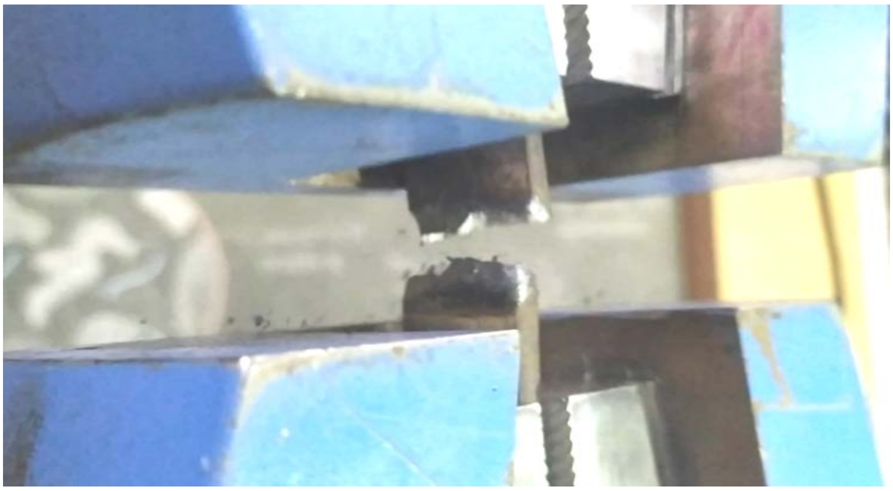

Figure 3: Specimen failure under Tensile Loading (created by authors).

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Tensile Test Report

Machine Model	: M 100	Test File Name	: OMK1MS_2020.Utm
Machine Serial No	: 2017/12	Date	: 23/01/2020 03:15 PM
Customer Name	: Mech Dept	Customer Address	: MIT PAUD ROAD
Lot No.	:	Test Type	: Tensile
Order No.	:	Heat No.	:

Input Data

Specimen Shape	: Flat	
Specimen Type	: Mild Steel	
Specimen Description	: Sample 1 MS Welded Joint	
Specimen Width	: 25	mm
Specimen Thickness	: 4	mm
G. L. for % Elong	: 100	mm
Pre Load Value	: 0	kN
Max. Load	: 100	kN
Max. Elongation	: 1000	mm
Speciman Cross-Section Area	: 100.000	mm2

Output Data

Load At Yield	: 25.928	kN
Elongation At Yield	: 3.400	mm
Yield Stress	: 259.28	N/mm2
Load at Peak	: 32.437	kN
Elongation at Peak	: 4.381	mm
Tensile Strength	: 324.370	N/mm2
Load At Break	: 2.745	kN
Elongation At Break	: 5.181	mm
Breaking Stregth	: 27.450	N/mm2
% Reduction Area	: - - -	%
% Elongation	: 2.00	%

Load Vs. Elongation

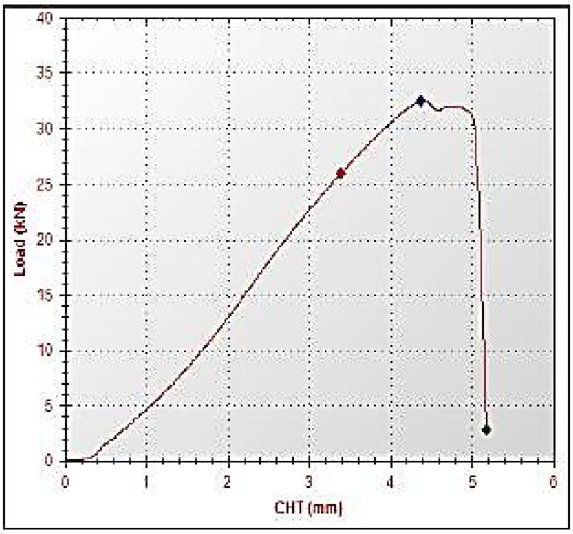

Figure 4: Test Report on UTM (created by authors)

5 Results and Discussions

5.1 Effect on Current (A)

Current will have a massive effect on weld quality and is the most prominent parameter in the rest of the parameters. For a direct current of 120Ampere (referring to Table 7), we will get the maximum Signal to Noise (S/N) ratio of 53.1459 with a corresponding ultimate tensile strength value of 454.25(N/mm2). (Referring to Tables 5 and 8)

5.2 Effect on Voltage (V)

Voltage is an essential parameter but not affected the most, when the voltage value is 22 Volts (Referring Table VII) we will get a maximum Signal to Noise (S/N) ratio of 53.1459 with a corresponding ultimate tensile strength value of 454.25 N/mm^2. (Referring to Tables 5 and 7).

5.3 Effect on the Speed of Welding

When the signal-to-noise (S/N) ratio is maximum ie 53.1459 Speed of welding is kept at 5 (M/min) (referring to Table 7) for which we get maximum ultimate tensile strength of 454.25(N/mm^2). (Referring to Tables 5 and 8)

5.4 Effect on Gas Flow Rate

At the maximum value of signal-to-noise (S/N) ratio of 53.1459 the gas flow rate is 9(L/Min) (Referring Table 7) which also shows the maximum ultimate tensile strength of **454.25(N/mm^2).** (Referring to Tables 5 and 8).

6 Conclusion

From the actual experiment conducted and the results obtained one can conclude that the voltage applied for welding, direct welding current, optimum speed of welding, rate of shielding gas flow, etc. are very essential control parameters for the TIG welding process. The welding current is the most prominent and important process parameter which affects not only the quality of the weld but also effects on the other performance parameters. Parameter optimization has been done to find the optimum parameters for better response and gives minimum residual stresses. The Taguchi method is very effective for optimizing process and performance parameters by conducting minimum experimentation. It also shows that the Ultimate Tensile Strength (UTS) of the weld which is obtained in Figure 4 will give the optimal level for each process parameter.

TIG welding process can be used for welding similar and dissimilar ferrous and non-ferrous metals and is widely used in industrial applications. In TIG welding Low Heat Affected Zone is prominent along with no slag as no flux is being used. Weld bead geometry determines weld quality in TIG welding. In the TIG Welding method, process parameters can be optimized without experiment also different DOE methods can be used for optimization. Finite Element Analysis can also use. In Taguchi's DOE method we will make use of an Orthogonal Array to conduct the experiments. The Process parameters such as welding voltage, direct welding current and flow rate of gas are considered for experimentation with that one can extend the experimental test by considering the filler wire diameter. The helium leak testing and ultrasonic testing methods which are non-destructive methods are used widely for considering the performance of welded joints and also used for penetration of the welded joint. By developing DOE and Finite Element Analysis models we can analyze the effect of process parameters on performance parameters such as tensile strength and weld pool geometry and one can compare the actual results obtained by conducting the actual experiments.

7 Availability of Data and Material

All information is included in this study.

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