Grey Based Taguchi Method for Optimization of TIG Process Parameter in Improving Tensile Strength of S30430 Stainless Steel

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Abstract
Tungsten inert gas welding is popular known welding technique for ferrous & nonferrous. Stainless steel grade 3HQ (S30430) is a specialized wire grade with very wide usage for manufacturer of stainless steel fastener. It has now totally replaced Grade 384 and 305 for heading application. The stable austenitic structure makes 302HQ nonmagnetic, even after substantial cold work, and also results in excellent toughness, even down to cryogenic temperatures. This paper attempts in optimizing the Tungsten Inert Gas (TIG) welding process parameter. The effect of various parameters and their influence is important to determine the strength of welded joint. To obtain a good quality weld, it is therefore, essential to control the input welding parameters. Therefore appropriate selection of input welding parameter is necessary in order to obtain a good quality weld and subsequently increase the productivity of manufacturing industry. This paper present multi objective optimization using grey relation analysis (GRA) for S30430 with TIG process to determine the suitable selection of parameters Experiment were conducted according to Taguchi's design of experiments (DOE) with orthogonal array L9 is used, mathematical model was developed using parameters such as speed (mm/min), current (Amp), voltage (V), depth of penetration (mm). After conducting experiment and collecting data, signal to noise ratio were determined by using Minitab18 and it is used to obtain optimum level for every input parameter.

Keyword- TIG welding, Grey relation analysis (GRA), Taguchi methodology, Signal to Noise ratio, Minitab18.

1. Introduction

In today's scenario welding of thin sheets is being the challenging task in the field of Engineering. The major reason behind this is perfection, which is being the nominal factor considered during the joining process of sheets because, in such joining of plate, two pass and three pass welding cannot be carried out in thin sheets below 4mm, as under welding results in predominant reduction in strength and over weld results in formation of hole. Hence optimization of weld parameter plays a predominant role in joining of thin sheets. This research is to make the thin sheet welding easy and compatible by optimizing the process parameters. Welding is great significant operation in any manufacturing industry [1]. It is absolutely necessary to optimize different welding process parameter, so that industry achieve reliable, productive and good quality product. Nowdays global manufacturing industries are more focused toward R & D. To investigate welding process parameter such as current, voltage, inert gas, pulsed on/off time etc. TIG welding process is commonly used operation for joining of two materials with the application of heat. TIG is also known as Gas Tungsten Arc Welding (GTAW). Arc is maintained between non-consumable electrode and work piece in a protective inert gas atmosphere [2]. The various studies are done to investigate the influence of welding process parameter on tensile strength [3].

2. Taguchi Design of Experiment

Taguchi DOE is a popular statistical technique that provides a proper and efficient methodology for process optimization. Taguchi method allows us improve the consistency of production. Taguchi design recognizes that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factor. Taguchi design tries to identify controllable factor that minimize the effect of noise factor. During experimentation, you manipulate control factor to evaluate variability that occurs and then determine optimal control factor setting, that minimize the process variability. Process designed with this goal produce more consistent output and performance regardless of the environment in which it is used [4]. It is world widely used for product design and process optimization [5-10]. As a result, time as well as cost is reduced considerably.

IOP Conf. Series: Materials Science and Engineering **404** (2018) 012003 doi:10.1088/1757-899X/404/1/012003

Taguchi DOE methodology uses orthogonal array that gives different combinations of parameters and their levels for each experiment. According to this methodology, every parameter is studied with minimal number of necessary experiments only [11].

3. Layout of Experiment

In order to perform experiment for data collection following sequence is followed.

- Selecting the base and filler material.
- Selecting pulsed TIG welding process parameters.
- Finding the upper and lower limits of the identified process parameters.
- Select the appropriate orthogonal array.
- Conduction of the experiments as per the selected orthogonal array.
- Find the optimum condition.

3.1 Selecting base material and there mechanical properties.

S30430 stainless steel sheets of dimension 100 × 150 × 3 mm are welded autogenously with butt joint without edge preparation [12]. The chemical composition of S30430 stainless steel sheet is given in Table1

Table 1: Chemical Composition of base material (wt %)

US DESIGNATION	% Cr	% Ni	% C	% Mn	% Si	% P	% S
S30430	18	8	0.03	2	0.75	0.045	0.03

Table 2: Mechanical Properties of S30430

Tensile strength	Yield Strength	Hardness	Melting Point	Density
564 MPA	241 MPA	B80 HBN	1400-1450 ^{0}C	8 g/cm^3

3.2 Identify the pulsed welding process parameter.

From the literature survey [13-14] and previous work done the most important process parameters which are having greater influence on the weld bead geometry. They are welding speed, welding current, welding voltage and gas flow rate.

3.3 Level of working range

Numbers of experiment has been conducted by varying one of the process parameters and keeping the others constant [13-14]. The working range of the process parameters are shown in Tables 3.

Table 3: Process parameters working range at standoff distance 2mm.

Factor/Process Parameter	Code	Level 1	Level 2	Level 3
Welding current (Amp)	A	140	150	160
Welding voltage (V)	B	24	25	26
Welding speed (mm/min)	C	165	179	193

3.4 Orthogonal array is selected

Process parameters selected for this experiment is three, and the level of each parameter is three. Taguchi orthogonal design of experiment uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment [15]. These standard arrays provide the way to full information of all three factors that affects the process performance. For the present experimental work, three factors with their three levels are used for which the corresponding orthogonal array is L9 as shown in below table.

Table 4: Orthogonal Array L_9 (Minitab18)

Experiment No.	Process Parameter		
	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

3.5 Conduction of experiments

By putting the values of three levels of three parameters in L9 Orthogonal array, the nine set of experiments with different values of parameters and results are obtained as fallows. The S/N ratio help in measuring the sensitivity of quality characteristic to external noise factor which is not under control. Taguchi techniques are experimental design optimization techniques which use standard Orthogonal Arrays (OA) for forming a matrix of experiments. Using an OA to design the experiment helps the researcher to understand the influence of different controllable factors on the quality characteristics and the variations in a fast and economic way. The highest S/N ratio indicates more impact of the process parameter on the performance characteristics. On the basis of characteristic three S/N ratios are available namely lower the better, higher the better and nominal the better. In this paper higher the better is used for maximizing depth of penetration [16].

$$S/N\ Ratio = -10\log 1/n\ [\sum_{i=0} 1/y_i^2]$$

Signal-to Noise ratio (S/N ratio) was first introduced by Sir Michael A Choma. The purpose of the Signal-to-Noise ratio (S/N ratio) is to find which design parameters significantly affect the quality characteristic. In the Taguchi Method the term Signal represents the desirable value (mean) for the output characteristic and the term Noise represents the undesirable value (standard deviation) for the output characteristic. The S/N ratio is defined as n=10log (M.S.D.) Where, M.S.D is the mean square deviation for the output characteristic. To obtain optimal welding performance, higher the better quality characteristic can be taken and S/N ratio is calculated for each experiment.
Where n is the repetition of output response in the same trial and is the response.

Table 5: Experimental Results

Experimental No.	A	B	C	Penetration	S/N Ratio
1	140	24	165	5.4	14.6479
2	140	25	179	5.2	14.3201
3	140	26	193	5.0	13.9794
4	150	24	179	5.3	14.4855
5	150	25	193	5.1	14.1514
6	150	26	165	5.4	14.6479
7	160	24	193	5.3	14.4855
8	**160**	**25**	**165**	**6.9**	**16.7770**
9	160	26	179	6.4	16.1236

Table 6: Response Table for Signal to Noise Ratios (Larger is better)

Level	Welding current (amp)	Welding voltage (v)	Welding speed (mm/min)
1	14.32	14.54	15.36
2	14.43	15.08	14.98
3	15.80	14.92	14.21
Delta	1.48	0.54	1.15
Rank	1	3	2

Table 7: Response Table for Mean

Level	Welding current (amp)	Welding voltage (v)	Welding speed (mm/min)
1	5.2	5.333	5.9
2	5.267	5.733	5.633
3	6.2	5.600	5.133
Delta	1.0	0.400	0.767
Rank	1	3	2

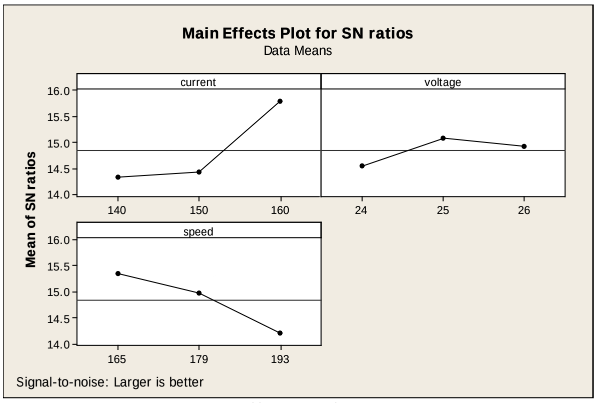

Fig1: Main Effect plot for S/N Ratio

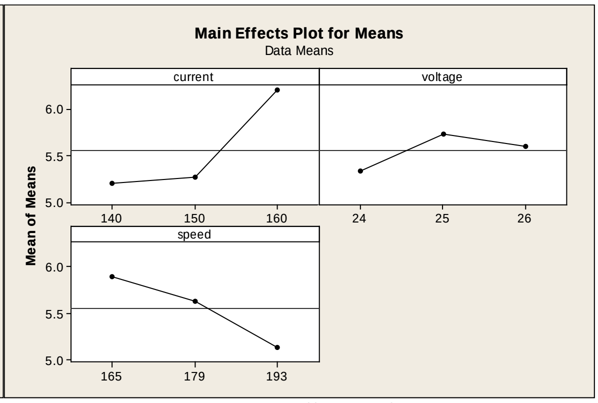

Fig2: Main Effect plot for Mean

4. ANOVA Approach

Analysis of variance (ANOVA) is a method for testing the hypothesis that there is no difference between two or more population means. ANOVA is a hypothesis testing technique used to test the equality of two or more population (or treatment) means by examining the variances of samples that are taken.

Table 8: Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adjss	AdjMS	F	P	% contribution
Current	2	4.0708	4.0708	2.0354	6.71	0.130	56.46
Voltage	2	0.4649	0.4649	0.2325	0.77	0.566	6.45
Speed	2	2.0671	2.0671	1.0335	3.41	3.41	28.67
Error	2	0.6066	0.6066	0.3033			
Total	8	7.2094					

5. Integration of Taguchi method Grey Relation Analysis

In the grey relation analysis experimental results were first normalized and then grey relation coefficient was calculated from normalized experimental data to express the relationship between desired and actual experimental data. Then the grey relation grade was computed by averaging the grey relation coefficient corresponding to each process response [17].

5.1. Grey relation generation(GRA)

In Grey Relation Analysis when the range of the sequence is large or the standard value is enormous, the function of the factor is neglected [18]. However, if the factor goal and direction are different, grey relation might produce incorrect results. There preprocess of the data which are related to a group of sequence which is called grey relational generation. Experimental results are normalized in the range between zero to one. The normalization is done three different ways:-

Larger the better $x_i^*(K) = \frac{x_i^0(k) - min\, x_i^0(k)}{max\ x_i^0(k) - min\, x_i^0(k)}$ …………………...... (1)

Smaller the better $x_i^*(K) = \frac{max\ x_i^0(k) - \ x_i^0(k)}{max\ x_i^0(k) - min\, x_i^0(k)}$ …………………….. (2)

Where $x_i^*(K)$ = value after data preprocessing, $max\ x_i^0(k)$ & $min\, x_i^0(k)$ are max. & min value of $x_i^0(k)$ SNRA$x_i^0(k)$ = 14.6479, $max\ x_i^0(k)$ = 16.7770, $min\, x_i^0(k)$= 13.9794, i = 1,2,3…………..m
k =1,2,3…………..n, m = no. experimental data

Table 9: Normalization of experimental data

Sample No.	Penetration (mm)
Reference Sequence	1
1	0.2389
2	0.12178
3	0
4	0.1809
5	0.06148

6	0.6685
7	0.06848
8	1
9	0.7664

5.2. Grey Relation coefficient

After pre-processing, a grey relation coefficient can be calculated with the preprocessed sequence. It expresses the relationship between ideal and actual normalized experimental results. Grey relation coefficient can be expressed as

$$\xi_i\ (k) = \frac{\Delta \min + \ \xi\Delta\ \max}{\Delta_{oi}\ (k)\ +\ \xi\Delta\ \max}$$

Taking ξ= 0.5, Δ max =1, Δ min = 0, $\Delta 1 = 1 - 0.23891 = 0.76109$

Table 10: Grey Relation coefficient of each performance characteristic

Sample No.	Grey Relation Coefficient	Grey Relation Grade	Rank
1	0.3964	0.3964	4
2	0.362786	0.362786	6
3	0.3333	0.3333	9
4	0.3790	0.3790	5
5	0.34757	0.34757	8
6	0.601322	0.601322	3
7	0.349279	0.349279	7
8	1	1	1
9	0.68157	0.68157	2

Table 11: Analysis of Variance for Grey Relation Grade

Source	DF	Seq SS	Adjss	AdjMS	F	P	% contribution
Current	2	0.15890	0.15890	0.07945	5.63	0.151	38.670
Voltage	2	0.06594	0.06594	0.03297	2.34	0.300	16.04
Speed	2	0.15786	0.15786	0.07893	5.59	0.152	38.417
Error	2	0.02822	0.02822	0.01411			
Total	8	0.41091					

6. Result & Discussion

In this research article, L_9 orthogonal array is used to investigate the influence of welding process parameter, welding current found to be the most crucial factor that effect the process characteristic. By using statistical technique ANOVA, that will assesses the contribution of each parameter. The statistical software Minitab 13 is used to investigate the significance contribution of each parameter. It has been found that experiment no. 8 has the optimum parameter setting for better control of the process characteristics. By using Grey Relation Analysis integrated with Taguchi Method, higher Grey Relation Grade (GRG) will have better multiple responses; Rank 1 is given to higher GRG. Comparing the results obtained from both the method *i.e* taguchi & GRA is has been found that welding current is most crucial parameter which affects the performance characteristics followed by welding speed and welding voltage. In Taguchi experiments, we always want to maximize the S/N ratios and the means were maximized when the Current was 160Amp, voltage 25 Volt and welding speed was 165 mm/min based on these results, we should set the factor at the calculated value.

Table 12: Response Table for levels

Welding Current	Level 1	160 Amp
Welding Voltage	Level 3	25 Volt
Welding speed	Level 2	165 mm/min

So, on the basis of these results we can say that Tensile Strength of stainless steel will be higher when we will use Current at 160A, 25 Voltage and Welding speed 165 mm/min. So these are optimum welding parameters on which we can attain the higher tensile strength of Stainless Steel S30430 welds.

7. Future Scope

Different techniques are used for investigation of processes and process parameter. The most common techniques is trial and error method based experiment, it is time consuming and uneconomical. The results obtained is verified by various other optimization techniques is used to get optimum results *i.e* Genetic Algorithm (GAs), fuzzy logic, Artificial Neural Network (ANN), Finite Element Method (FEM).

8. Acknowledgement

I would gratefully acknowledge to, Dr.S.Alam, Integral University, Lucknow, Uttar Pradesh, India, for providing research facility & guidance, I also thankful to Dr. Ishtiyaq Ahmad, NIT-Raipur, Chhattisgarh, India, for their consistent help in writing this research paper.

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