MULTI OBJECTIVE OPTIMIZATION OF WELD BEAD GEOMETRY IN TIG WELDING PROCESS THROUGH GREY FUZZY INFERENCE SYSTEM

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Abstract

Todays welding technology focusses in the maximizing productivity and cost effectiveness of welded structures in major industries.ss316 stainless steel alloy is gainig importance in welding industries due to its extensive applications in manufacturing of Exhaust manifolds furnace parts ans heat exchangers.In this paper the current study deals with investigation of optimal weld bead parameter for minimizing weld bead and maximzing the weld bead parameters.Taguchis,L_{27} orthogonal array couple with grey relational analysis is used for the parametric optimisation of weld bead parameters,some uncertainity observed in the final solution is overcomed with the use of grey fuzzy logic approach. The results are analyzed through ANOVA and verified by means of a confirmation experiment The experimental trails are performed on SS316 stainless steel alloy, it is used for the butt joint formation with same stainless steel as the filler material .The experiment is conducted using L_{27} orthogonal array.The current ,voltage and gasflow rate are selected as the control factors and experiments were conducted. The present work focuses on the minimization of the weld width and maximization of weld penetration. The measurement of the weld bead width and penetration is made by the travelling microscope. The optimization of the weld bead parameter is made by grey relational analysis coupled with fuzzy logic using MATLAB. The grey relational analysis is employed to solve the multiresponse problem for obtaining optimum levels of the control factors. The graph is employed by Minitab software under taguchi analysis design .

keywords: TIG welding, grey relation analysis, fuzzy logic, travelling microscope

1. Introduction:

SS316 stainless steel alloy is a chromium-nickel-molybdenum austenitic stainless steel developed to provide improved corrosion resistance to Alloy 304/304L in moderately corrosive environments. It is often utilised in process streams containing chlorides and halides. The addition of molybdenum improves general corrosion and chloride pitting resistance. TIG welding is refered in this work because of its versatility, the high quality weld it delivers as well as the ability of the process to work at low currents and to add filler materials when required, makes it an ideal process for both thin materials as well as for root runs in the one sided welding of thicker plate and pipe sections.

Bead geometry (bead height and width) and penetration(depth and area) are the important characteristics of a weldment. The weld bead width is the maximum width of the weld metal diposited. Weld bead width is directly proportional to arc current, welding voltage and electrode diameter and indirectly proportional to the welding speed. The bead width increases with increase in current until it reaches a critical value and decreases with an increase in welding current.Weld bead penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. the more the penetration, the less is the number of welding passes required to fill the weld joint which results in higher production rate. Penetration decreases with decrease in the welding speed because the time during which the arc force is allowed to penetrate into the metals surface decreases. The Bead geometry is shown in Fig 1.

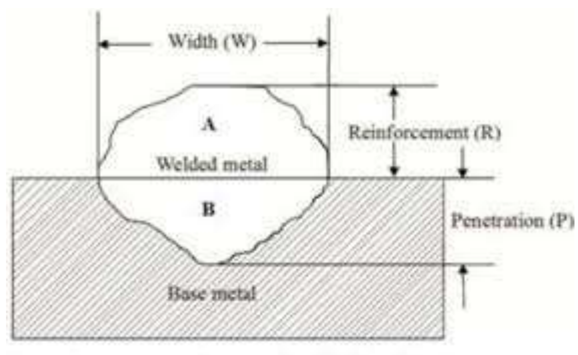

Fig1: Weld Bead Geometry

Jayashree P K, SS Sharma, Raviraj Shetty, Ashish Mahatod and Gowrishankar M C[1]in this paper they focused to determine the favorable welding conditions for Tungsten Inert Gas (TIG) welding of 6061Al alloy based on Taguchi's design of experiments. Hence the concentration is on experimentally identifying the effect of the different welding parameters on hardness and weld bead geometry at weld zone under different welding condition obtained by L9 Orthogonal array using Taguchi's design of experiments. A. Balaram Naik and A. Chennakeshava Reddy[2] purpose was to increase the tensile strength, hardness and depth of weld by varying the parameters such as current, time, speed, variation of oxide fluxes, electrode diameter and gas flow rate. The Mat lab software is used for analyzing results and it shows that neural network coupled with Taguchi method and Anova is an effective method for optimizing the weld quality of material. Sriramoju Avinash, Yelamasetti Balram, B. Sridhar Babu and G. Venkatramana[3] they did an investigation on PCGTA welding process was used for joining of two dissimilar plates, steel grade 304 and Monel 400, by employing ERNiCrMo-3 as filler. Taguchi method was employed for designing and analyzing experimental results for improving the welding quality characteristics. For designing of process parameters an L-9 orthogonal array is used for optimizing the mechanical properties and heat affected region of base metals. The GRA has been performed for optimization of factors by considering multiresponse variables simultaneously. Analysis of variance has also been performed to perceive the significance effect of the parameters on welding characteristics of the weldments. D.S. Nagesha and G.L. Datta[4] in this paper they explained an integrated method with a new approach using experimental design matrix of experimental designs technique on the experimental data available from conventional experimentation, application of neural network for predicting the weld bead geometric descriptors and use of genetic algorithm for optimization of process parameters. The properties of the welded joints are affected by a large number of welding parameters. Modeling of weld bead shape is important for predicting the quality of welds. In an attempt to model the welding process for predicting the bead shape parameters (also known as bead geometry parameters) of welded joints, modeling and optimization of bead shape parameters in tungsten inert gas (TIG) welding process has been tried in the present work. Multiple linear regression technique has been used to develop mathematical models for weld bead shape parameters of TIG welding process, considering the effects of main variables as well as two factor interactions. Also by using the same experimental data, an attempt has been made to predict the bead shape parameters using back-propagation neural network. To optimize the process parameters for the desired front height to front width ratio and back height to back width ratio, genetic algorithmic approach has been applied. Swarup S. Deshmukh, Vijay S. Jadhav and Ramakant Shrivastava[5] have focused on optimization of process parameters of EDM and its modified versions like WEDM, MicroEDM and PMEDM using Taguchi method and Grey relational analysis and hence, only such research works are included in this review. Where the Taguchi method and Grey relational analysis method is used to optimizing process parameters of EDM; that were published in the last 15 years since 2003. The review work on such large extent was not tried earlier by considering this optimization process for EDM and its modified versions and hence this review work may become ready information at on a place and help researchers to decide their direction of research. C.B Maheswaran, R. Jayendra Bharathi, S. Paul joshuac and Arun Kumar Srirangan[6] they study attempts to find the optimal level of parameters for multi performance characteristics in laser welding of incoloy 800HT using Grey-Fuzzy algorithm. Incoloy 800HT, which comes under the family of austenitic nickelchromium-based super alloys exhibits good strength, excellent resistance to carburization and oxidation in high-temperature exposure. This alloy has been considered as a prominent material for fourth generation nuclear power plants. Laser welding has proved to be advantageous due to its characteristics such as narrow fusion zone, low heat input, concentrated heat intensity and the ability to align the beam to a specific position with respect to joint line. Taguchi L9 experiment was used to perform laser welding on incoloy 800HT. The input parameters chosen were the welding speed, focal position and laser power. The output performance characteristics were the hardness, toughness and ultimate tensile strength. To improve the quality of the weld, the optimal combination of laser welding parameters was chosen using grey relational analysis and grey fuzzy logic approach offers improved Grey-Fuzzy reasoning grade and has less uncertainties when compared with grey relational technique. Analysis of variance (ANOVA) was used to find percentage contribution of the laser welding parameters and found that welding speed was the most influential factor in welding of incoloy 800HT.Sudhir Kumar and Rajender[7] in this research they worked on AISI 1018 mild steel samples have been welded in V-butt joint configuration using MIG welding. The design of experiment is Taguchi based Orthogonal Array (L9). Effect of process parameters such as current, voltage and preheat temperature has been studied and welds are examined using X-ray radiographic tests. Weld quality has been assessed in terms of tensile properties of weldments such as ultimate tensile strength and percentage elongation. Process parameters have been optimized using grey based Taguchi methodology. Further, analysis of variance has been done to ascertain the influence of input parameters on response parameters. Experimental results show that to achieve optimum ultimate tensile strength and percentage elongation of weldments, preheat temperature turns out to be the most effective input parameter followed by welding current and voltage. A mathematical model has been developed using multiple regression equations. In the end, a confirmatory experiment with optimized parameters from the analysis has also been performed to confirm the results. Punitha Chamarthi and RajeshNagadolla[8] in this paper they did a investigation on optimization of turning parameters on Aluminum hybrid metal matrix composites were studied using grey integrated fuzzy. AA6082/SiC/Gr hybrid MMC were prepared using liquid metallurgy route, and CNC turning was employed for machining the composites. L9 array was used as DOE, and a mathematical relationship was established between process parameter levels and the outcomes. The key objectives of this investigation is to analyze the effect of process variables i.e., cutting speed, feed, and depth of cut on minimizing surface roughness and maximizing material removal rate. Grey integrated fuzzy was used for multi-objective optimization.

2Methodology

2.1Selection of material

The stainless steel 316 plates are arranged to form a butt joint ,they have a thickness of 5mm,and the chemical composition of the SS316 is given below in Table 1

Table 1 : Chemical composition of ss316 metal

Elements	Fractional size	Metric and imperial sizes
	Composition wt%	
Chromium	16.0 to18.0	17.0 to 19.0
Nickel	11.0 to 14.0	12.5 to 15.0
Molybdenum	2.00 to 3.00	2.50 to 3.00
Manganese	2.00 max	2.00 max
Silicon	0.75 max	1.00 max
Carbon	0.035 max	0.030 max
Sulphur	0.030 max	0.015 max

2.2 Taguchi based design of Experiments

Taguchi L_{27} orthogonal array matrix has been selected with three different levels for conducting the experimental work of Welding process. The different conditions of the various process parameters used for the experimental study along with their levels are presented in **table 2**

Table2: Input process parameters and their values

parameters	level 1	level 2	level 3
Current(I)(amps)	76	245	318
Voltage(V)(volts)	9	13	25
gas flow rate(gfr)(mm^3/min)	10	12	15

2.3 Welding and measurement

In the welding of ss316 pieces tungsten inert gas welding instrument is used with filler materials ss316 and shielding gas is argon.

The experimental set up was designed to provide linear movement, the sectioning of the welded material is done by abrasive jet cutting. The abrasive jet cutting is a process in which very fine abrasive particles are blasted over the target materials at high pressures and it produces fine edges. In our Experiment ss316 stainless steel of dimensions (163×341) mm is cut into 32 individual piecesof dimensions (40×80× 5)mm and these 32 individual pieces are Welded to form 27 joints as shown in figure 1. the TIG welding equipment is shown in figure 2.

Figure 1: - work pieces after welding

Figure 2: - TIG welding Equipment

The work pieces after welding were machined with the help pf abrasive water jet machining and the weld pieces bead shape parameters were measured with help of travelling microscope.

The Table 3 shows the depth of Depth of penetration (D.O.P), bead width (B.W) for weldments which are obtained from the experimental result

Table 3: - Experimental results with process parameters

S.NO	Current (amps)	Voltage (volts)	Gas flowrate (mm^3/min)	D.O.P (mm)	B.W (mm)
1	76	9	15	4.18	4.96
2	318	9	15	3.66	11.61
3	76	25	15	2.98	6.4
4	76	25	10	0.54	4.62

5	318	25	10	1.93	12.11
6	318	13	10	4.74	5.25
7	245	25	12	3.83	9.21
8	245	13	12	3.34	16.21
9	76	13	12	1.74	7.23
10	318	9	12	0.9	7.65
11	76	9	10	0.54	2.88
12	318	13	15	4.4	7.42
13	76	9	12	0.54	4.92
14	318	25	12	0.77	9.45
15	245	25	15	1	7.23
16	245	9	10	0.9	6.92
17	76	25	12	1.26	4.14
18	318	13	12	2.76	6.95
19	245	9	12	5	8.2
20	245	9	15	3.63	6.5
21	318	25	15	1.01	9.25
22	76	13	10	2.6	4
23	245	25	10	0.8	8.63
24	76	13	15	3.9	5.24
25	245	13	12	0.59	7.65
26	318	9	10	2.3	7.15
27	245	13	15	2.91	7.29

3.**Result and Discussions:**

3.1 Grey Relational Analysis:

In the grey relational method, all the experimental data about the bead geometry such as bead width and penetration is normalised. normalisation can be defined as the arrangement of the given output data in the range of zero to one.

For the normalisation of the given data there are two relations mainly used for the bead penetration larger the better criteria is used, which is expressed as

$$x_i^*(k) = \frac{x_i(k) - min x_i(k)}{max x_i(k) - min x_i(k)} \quad (1)$$

Then for the bead width smaller the better criteria is used, which is expressed as

$$x_i^*(k) = \frac{max\ x_i(k) - x_i(k)}{max x_i(k) - min x_i(k)}$$

(2)

Where $x_1(k)$is the value after the normalisation is done min $y_1(k)$ is the minimum value of the response or the output, $y_1(k)$ is the y^{th} response in the column , similarly max $y_1(k)$ is the maximum value in that response column. The grade of the grey relation is developed in order to create the degree of closeness between the 27 sequence values. The grey relational can be calculated by

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{min}}{\Delta_i(k)+\zeta\Delta_{max}} \quad (3)$$

Where Δ_1 = (1- $x_1(k)$) the difference between the absolute value of grey relational coefficient is defined as the deviation of the corresponding response ,and Δ_{max} is the maximum value from the deviation response column similarly Δ_{min} is the minimum value from the deviation response column.

The average of the grey relational coefficient is defined which is

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (4)$$

The Grey relational analysis values are evaluated and shown in Table4

Where

i =1, ...m; k = 1, ...n.

m is number of experimental data items, n is the number of parameters

Table4: Grey relational values

S.no	NPC	NWC	DEVP	DEVW	RELCP	RELCW	GRG
1	0.816	0.843	0.183	0.156	0.731	0.762	0.078
2	0.699	0.345	0.300	0.654	0.624	0.432	0.327
3	0.547	0.735	0.452	0.264	0.524	0.654	0.132
4	0	0.869	1	0.130	0.333	0.792	0.065
5	0.311	0.307	0.688	0.692	0.420	0.419	0.346
6	0.941	0.822	0.058	0.177	0.895	0.737	0.088
7	0.737	0.525	0.262	0.474	0.655	0.512	0.237
8	0.627	0	0.372	1	0.573	0.333	0.5
9	0.269	0.673	0.730	0.326	0.406	0.605	0.163
10	0.080	0.642	0.919	0.357	0.352	0.582	0.178
11	0	1	1	0	0.333	1	0
12	0.865	0.659	0.134	0.340	0.787	0.594	0.170
13	0	0.846	1	0.153	0.333	0.765	0.076
14	0.051	0.507	0.948	0.492	0.345	0.503	0.246
15	0.103	0.673	0.896	0.326	0.357	0.605	0.163
16	0.080	0.696	0.919	0.303	0.352	0.622	0.151
17	0.161	0.905	0.838	0.094	0.373	0.841	0.047
18	0.497	0.694	0.502	0.305	0.498	0.620	0.152
19	1	0.600	0	0.399	1	0.556	0.199
20	0.692	0.728	0.307	0.271	0.619	0.648	0.135
21	0.105	0.522	0.894	0.477	0.358	0.511	0.238
22	0.461	0.915	0.538	0.084	0.481	0.856	0.042

23	0.058	0.568	0.941	0.431	0.346	0.536	0.215
24	0.753	0.822	0.246	0.177	0.669	0.738	0.088
25	0.011	0.642	0.988	0.357	0.335	0.582	0.178
26	0.394	0.679	0.605	0.320	0.452	0.609	0.160
27	0.531	0.669	0.468	0.330	0.516	0.601	0.165

NPC: Normalised penetration coeffecient.

NWC: Normalised gasf low rate coeffecient.

DEVP: Deviation of penetration.

DEVW: Deviation of gas flow rate.

RELCP: Relation coeffecient of penetration.

RELCW: Relation coeffecient of width.

GRG: Grey relation grade.

3.2 Grey Fuzzy logic:

In grey relational the first step is to perform normalization of the experimental values ,this process normalized brings down the values in the range of 0 to 1. Data pre processing converts the original experimental values to asset of comparable sequence. The second step is to calculate the grey relational coefficient based on the normalized experimental data to represent relation between the desired and actual experimental data, then the grey relational grade is computed by fuzzy logic in MATLAB.

Steps for grey-fuzzy-logic method

The experimental values of Bead penetration, and Bead width are normalized in the range of 0to1.

Grey relational coefficient (GRC) of each response is calculated.

Then fuzzy-logic system is applied. The fuzzifier uses the membership functions to fuzzify GRC of each performance characteristic.

Fuzzy rules (if-then control rules) are generated and finally defuzzifier converts fuzzy predicted value into a GFRG.

Optimal setting of machining parameters with the help of main effective plots for GRG is finally evaluate.

3.2Fuzzy logic:

In this analysis, two inputs and one output (GFRG) fuzzy-logic system is used. The inference engine (Mamdani fuzzy inference system) performs fuzzy reasoning with fuzzy rules for generating a fuzzy value. These fuzzy rules are shown in the form of 'if-then' control rule. Grey relational coefficients for Bead Width, Depth of Penetration are inputs to the fuzzy logic system. The linguistic membership function for instance Low, Medium and High are used to represent the grey relational coefficients (GRC) of input variables Bead Width, Depth of Penetration Likewise, the output grey relational grade is being represented by the membership functions such as are lowest(LS), very low(V.L), low(L), medium(m), medium high(M.H), high(H), most high(M.H),highest(HS). The Input membership functions, which is used in this work, is shown in Figs. 3 and 4 A total of 25 numbers of fuzzy rules are used for this purpose. The rule-based fuzzy-logic reasoning is shown in Fig. 5. Maximum–minimum compositional operation by tracking the fuzzy reasoning yields a fuzzy output. At last, the defuzzifier converts the fuzzy predicted values into a GRFG by using MATLAB (R2020a) fuzzy logic toolbox.

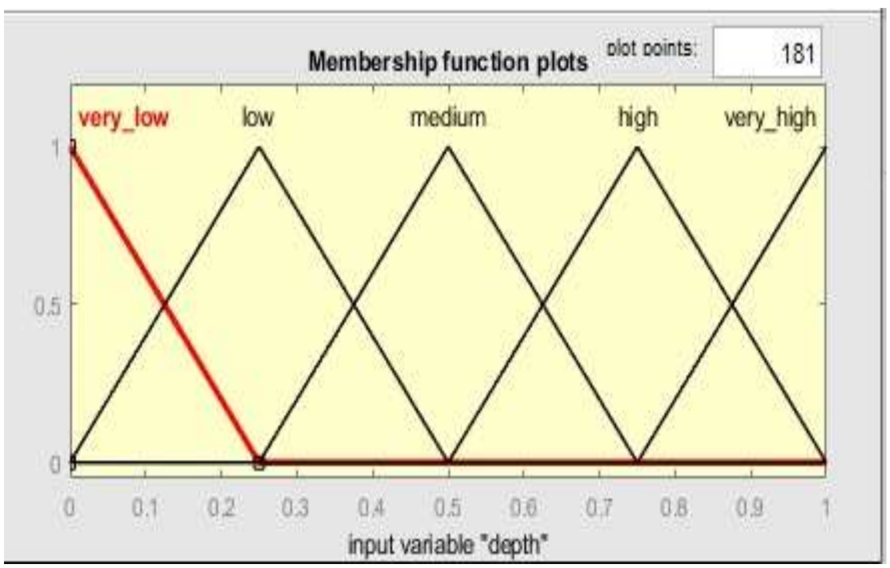

Figure 3: Input membership functions

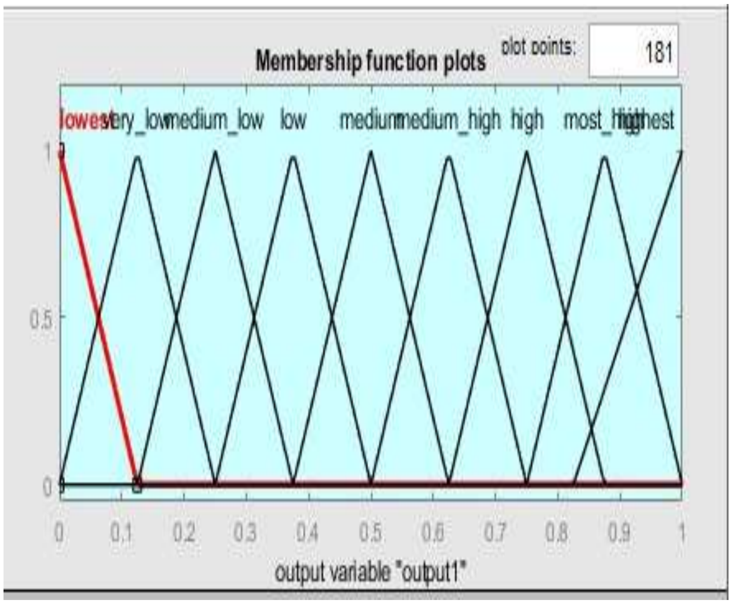

Figure 4: Output membership fuctions

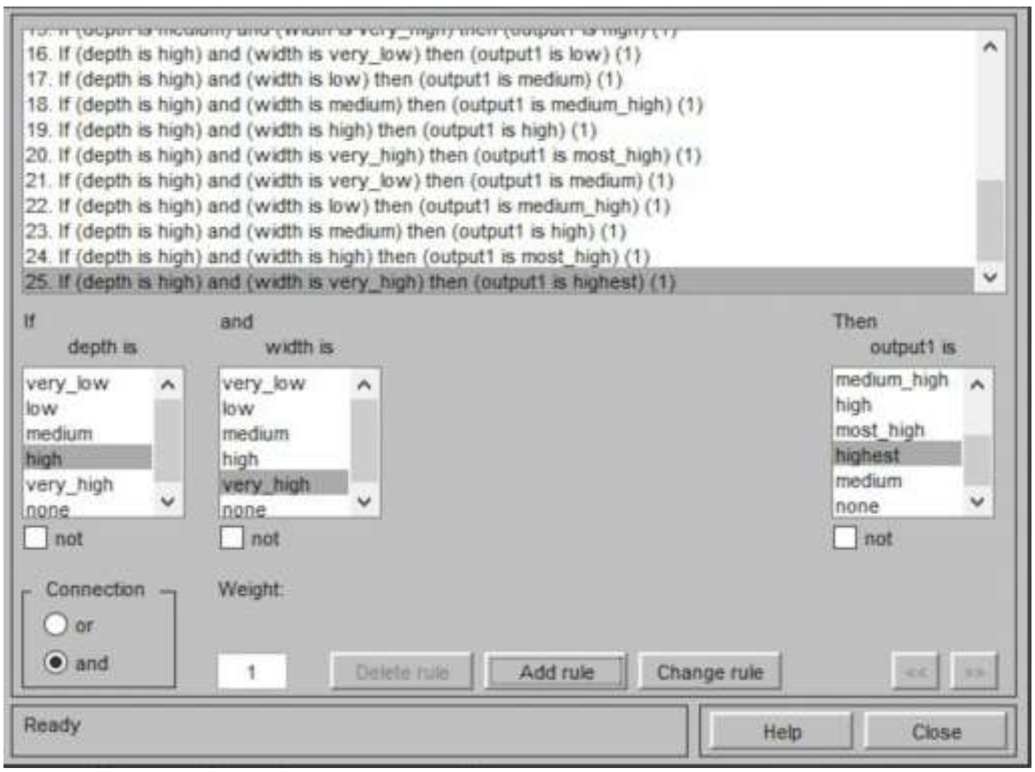

Figure5: Fuzzy rules

Figure6: GFRG values evaluation

3.3Analysis of means (ANOM)

Analysis of Means is applied on GFRG values to obtain optimal process parameters of TIG Welding process. In our study Taguchi L_{27} orthogonal array design of experiment (D.O.E) is used thus it is probable to find which welding parameter influences the Bead Width and Depth of Penetration the most at various levels. Usually Higher is the mean value of GFRG better is the Multi response. A graph is plotted for the comparison of GFRG and GRG is shown in the figure 7. In TIG Welding process parameters are identified by Increasing the Depth of penetration Penetration and Decreasing the Bead Width.

Table5: Rank comparison between GRG AND GFRG

GRG	RANK	GFRG	RANK
0.078	22	0.803	2
0.327	3	0.585	13
0.132	19	0.614	10
0.065	24	0.576	15
0.346	2	0.404	27
0.088	20	0.832	1
0.237	6	0.648	9
0.5	1	0.521	18
0.163	13	0.504	19
0.178	9	0.478	22

0	27	0.67	8
0.170	11	0.734	5
0.076	23	0.558	17
0.246	4	0.428	26
0.163	13	0.489	21
0.151	17	0.492	20
0.047	25	0.613	11
0.152	16	0.559	16
0.199	8	0.789	3
0.135	18	0.692	6
0.238	5	0.439	25
0.042	26	0.675	7
0.215	7	0.452	24
0.088	20	0.764	4
0.178	9	0.473	23
0.160	15	0.586	12
0.165	12	0.585	13

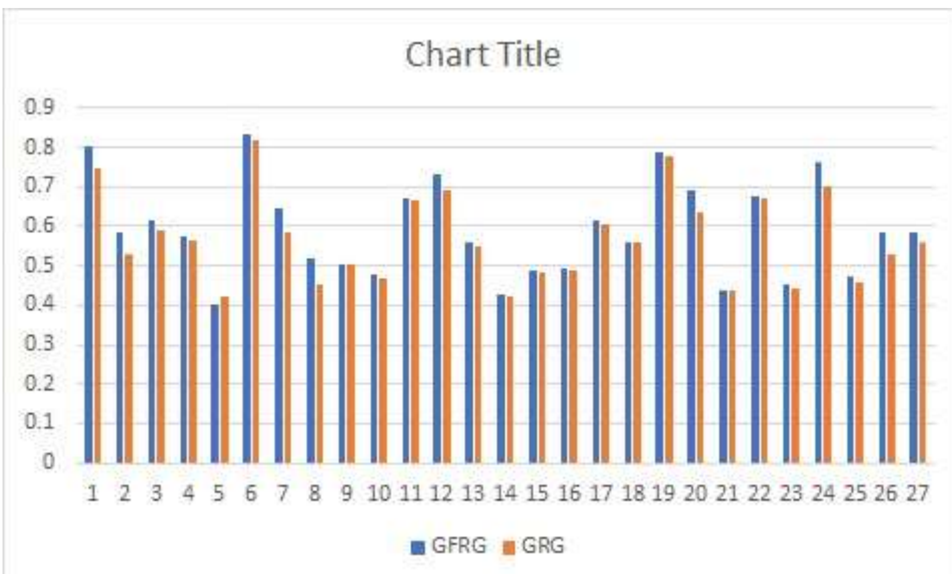

Figure 7: comparison of GFRG and GRG

3.4 Main effects plot for Means

Main effective plot is to examine Differences between levels means for one or more factors Usually Higher is the mean of means value dominant is the control factor or the process parameter as shown in figure 8. According to the figure A_1, B_2, C_3 implies Current at level 1, Voltage at level 2, and gas flowrate at level 3 are the most dominant factor in TIG Welding process.

figure7:Main effects plot for means

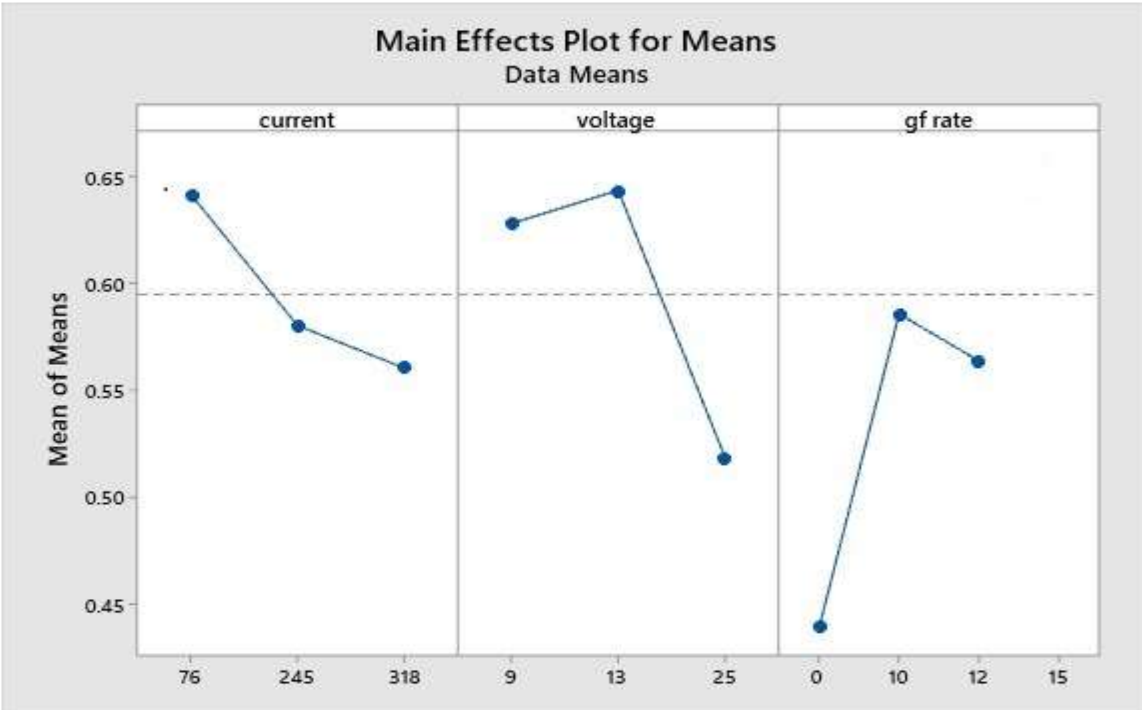

Table8: analysis means between the input parameters and output GFRG

levels	Current	Voltage	Gas flowrate
1	0.6419	0.6281	0.4390
2	0.5805	0.6438	0.5859
3	1.5606	0.5181	0.5638
4			0.6583
Delta	0.0813	0.1256	0.2193
Rank	3	2	1

Among A_1, B_2, C_3 gas flow rate is the most dominating which influences the process followed by Voltage(V) and Current(I).

Conclusion:

- In our study Taguchi L_{27} orthogonal array of experiments was performed for optimising our process parameters in TIG welding. Noise factors(those factors which are not in control of ours) that are Bead width and Depth of penetration where optimised simultaneously different controlled factors (Those factors which are control in ours) are taken current at three different levels(I_1, I_2, I_3), voltage at three different levels (V_1, V_2, V_3), gas flow rate at three different levels(F_1, F_2, F_3) .

- Grey relation analysis was employed for obtaining optimal process parameters but in order to decrease the variance and uncertainity among the grey relational analysis is coupled with fuzzy logic to obtain GFRG (grey fuzzy reasoning grade).
- The GFRG with highest value for optimised weld parameters are I_3, V_2, F_2 implies current 318, voltage 13, gas flowrate 10 is best condition for our experiment, From the mean plot of GFRG , we found that the most dominant parameter in these process of optimization of TIG welding are gas flow rate, followed by voltage and current respectively.

References:

[1] Balla Srinivas,D.S.S Ravi Kiran"Experimental investigation to optimize toolperformance in high speed drilling",Journal of the Brazilian Society of MechanicalSciences and Engineering.

[2]. D.S.S Ravi Kiran "Optimization of machining parameters in drilling of Aluminium-6082using Taguchi method coup;ed with grey relational analysis", International Journal of management Technology and Engineering

[3] Process parameter optimization in TIG welding of AISI 4340 low Alloy Steel welds by Genetic Algorithm-D.vijayan and V. seshagiri Rao-2018.

[4] Evaluating mechanical and metallurgical properties of gas tungsten arc welded AA 5059 aluminium alloy joints-N.babu,U.natarajan, R.Malayalamurthi.-27/06/2019.

[5] Adaptive Neuro-Fuzzy Inference System (ANFIS)-based models for predicting the Weld Bead Width and Depth of Penetration from the Infrared Thermal image of the Weld pool-L.Subashini, M.vasudevan-08/09/2011.

[6] Intelligent Modelling Using Adaptive Neuro Fuzzy Inference System (ANFIS) for Predicting Weld Bead Shape Parameters During A-TIG Welding of Reduced Activation Ferritic-Martentic(RAFM) Steel S.Vishnuvardhan, N.Chandrasekhar, M.Vasudevan, T.Jayakumar-22/11/2012.

[7] Process parameter selection for optimizing the weld pool geometry in the tingsten inert gas welding of stainless steel-S.C. juang, Y.S. Tarang-05/11/2000.

[8] Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints-subodh kumar,A.S. sahi-03/03/2011.

[9] Experimental investigation of the effect of hydrogen in argon as a shielding gas on TIG welding og austentic stainless steel.- Ahmed Durgutlu-30/07/2003.

[10] Experimental investigating for Welding Aspects of stainless steel 310 for the processof Tig Welding-V. Anand rao, Dr.R. Deivanathan-05/06/2008.

[11] Optimization of weld bead geometry in TIG welding process using grey relation analysis and Taguchi method-Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu,Sueda Ozgun-17/02/2009.