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Parametric Optimization of TIG welding on UNS S31603 using Genetic Algorithm

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Abstract —*Tungsten Inert Gas (TIG) welding with filler wire addition is a candidateprocess for welding of UNS S31603/316L austenitic stainless steel. In GTAW, the qualityof the weld is characterized by the weld-bead geometry as it influences the mechanicalproperties and its performance during service. This work focuses on the development ofregression model and optimization using Genetic Algorithm for determining the optimum/near-optimum TIGprocess parameters for obtaining the optimum weld-bead geometry during welding of 316Lstainless steel. Parameters selected for study were Welding current, Shielding Gas Flow, Filler Rod Diameter and the response selected was Aspect Ratio. Using the experimental data generated on the influence of process variableson weld-bead geometry, regression models correlating the weld-bead shape parameterswith the process parameters has been developed using Regression Method. ANOVA Analysis was done to obtain the significant parameters. Percent contribution of various parameter found was Shielding gas flow 43.52%, Filler rod diameter 31.09%, Welding current 22.13%. Experimental validation of the model was also performed. The optimum result obtained from Genetic algorithm was welding current 80A, Shielding gas 8l/min, Filler rod diameter 1.6mm and Aspect ratio of 2.228.*

Keywords-*TIG welding, Genetic algorithm, Aspect ratio, regression, ANOVA.*

I. INTRODUCTION

Tungsten Inert Gas (TIG) is an arc welding processthat produces coalescence of metals by heating themwith an arc between a nonconsumable electrode and basemetal. In TIG welding the quality of weld are characterized by its width to depth ratio i.e. Aspect Ratio. Aspect Ratio of a welded joint should be minimum for better quality welds. The weld area is protected from atmosphere with a shieldinggas generally Argon or Helium or sometimes mixture of Argon and Helium. A filler metalmay also feed manually for proper welding. GTAW most commonly called TIG weldingprocess was developed during Second World War. With the development of TIG weldingprocess, welding of difficult to weld materials e.g. Aluminium and Magnesium becomepossible. The use of TIG today has spread to a variety of metals like stainless steel, mildsteel and high tensile steels, Al alloy, Titanium alloy.

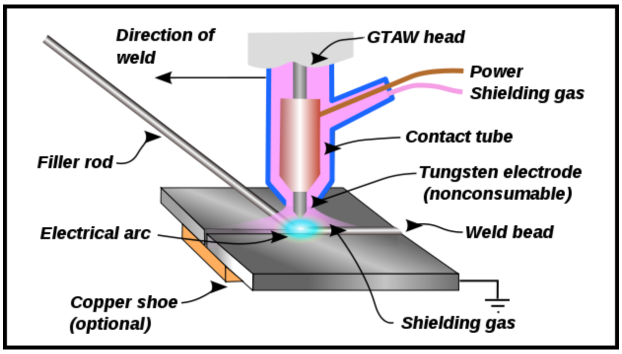

Fig. 1: Principle of TIG Welding

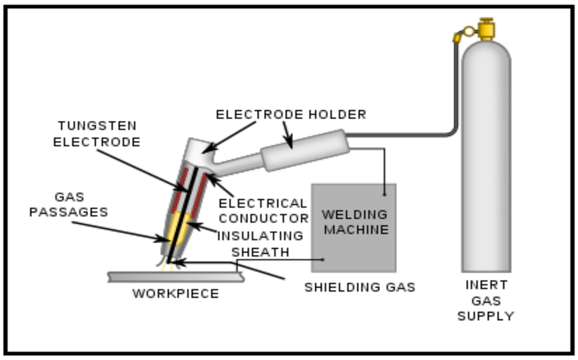

Fig. 2: Schematic Diagram of TIG Welding System

The TIG welding process is best suited for metal plate of thickness around 5- 6 mm. Thicker material plate can also be welded by TIG using multi passes which results in highheat inputs, and leading to distortion and reduction in mechanical properties of the basemetal. In TIG welding high quality welds can be achieved due to high degree of control inheat input and filler additions separately. TIG welding can be performed in all positionsand the process is useful for tube and pipe joint. The TIG welding is a highly controllableand clean process needs very little finishing or sometimes no finishing. This weldingprocess can be used for both manual and automatic operations. The TIG welding processis extensively used in the so-called high-tech industry applications such as: Nuclear industry, Aircraft, Food processing industry, Maintenance and repair work, Precision manufacturing industry, Automobile industry.

II. LITERATURE REVIEW

AlirezaYazdipour, Mohammad Reza Ghaderi et al.(2014)[3] has focused onoptimization of weld bead of GTAW in terms of Bead width (Minimize), Depth ofPenetration (Maximize). The input parameters are welding current (I), arc voltage (V),welding speed (S), and arc length (L). TIG welding experiments are carried out by varyingthe arc length in a range of 3– 5 mm, the arc voltage in a range of 13.7–17.2 V, the weldingcurrent in a range of 160–220 Amps, and the welding speed in a range of 150–250 mm/min.A correlation was developed using regression analysis to gain a relationship betweenoptimization parameters and an output variable. The adequacy of the proposed model wastested for both GA and ICA, and results show good conformability of the developed modelto the real process. The percentage errors related to penetration and width are found to beequal to 3.15 and 6.64 %, respectively, for GA, and 2.9 and 4.35 %, respectively, for ICA.**G. Magudeeswaran, Sreehari R. Nair, L. Sundar et al.(2014)[4]** has studied the weldbead in the form of aspect ratio i.e. width to depth ratio of Activated TIG welding. Theinput parameters were Electrode gap, Travel speed, Current and Voltage. L9 (34) OA with4 columns and 9 rows was used for carrying out readings. Results obtained from ANOVAare: electrode gap is the most significant factor on aspect ratio with contribution of 53.99%,followed by current with contribution of 27.62%. The voltage and travel speed areinsignificant with contribution of 14.55% and 3.82% respectively. The optimum weldingparameters are found to be electrode gap of 1 mm, travel speed of 130 mm/min, current of140 A, and voltage of 12 V. The aspect ratio is found to be 1.24 for the joints fabricatedusing the optimized process parameters and is well within the acceptable range to avoidsolidification cracking.**N. Kiaee, M. Aghaie-Khafri et al.(2014)[5]** has studied parameters namely current,welding speed and shielding gas flow rate on Tensile strength and Hardness using RSM.Applying RSM, simultaneous effects of welding parameters on tensile strength andhardness were obtained through two separate equations. Empirical relation for tensilestrength. HAZ hardness and weld hardness was obtained. The adequacy of the developedrelationship was tested using the analysis of variance technique (ANOVA). Tensilestrength has maximum value of 528MPa can be obtained at the current of 127 A, gas flowrate of 16 l/min and welding speed of 9 cm/min. Maximum value of 213 HV for HAZhardness is achieved at the current of 150 A, gas flow rate of 15 l/min and welding speedof 13 cm/min. Besides, at the welding speed of 9 cm/min, HAZ hardness value of greaterthan 186 HV is never obtained. The maximum value of 230 HV for weld hardness can begained at the current of 150 A, gas flow rate of 15 l/min and welding speed of 13 cm/min,hardness values greater than 205 HV for weld metal may not be obtained at the weldingspeed of 9 cm/min. The optimum value obtained were current of 130 A, welding speed of9.4 cm/min and gas flow rate of 15.1 l/min.**A. Ravisankar, Satish Kumar Velaga et al.(2014)[7]** has studied the temperaturedistribution and residual stresses for a GTAW circumferential butt joint of AISI 304stainless steel using numerical simulation. For evaluation of weld induced residual stresses,the analysis of heat source fitting was carried out with heat inputs ranging from 200 to 500J/mm to arrive at optimal heat input for obtaining proper weld penetration and heat affectedzone (HAZ). The heat source analysis revealed the best choice of heat input as 300 J/mm.The residual stresses on the inner and outer surfaces, and along the radial direction werecomputed. Increase in temperature distribution as well as longitudinal and circumferentialresidual stresses was observed with the increase in weld speed and power. There was noeffect of weld speed and power on radial stress.**E. Rastkerdar, M. Shamanian et al.(2013)[15]** has used Taguchi method as a design ofexperiment technique to optimize the pulsed current gas tungsten arc welding (GTAW)parameters for improved pitting corrosion resistance. A L9 (34) orthogonal array of theTaguchi design was used, which involves nine experiments for four parameters as peakcurrent (P), base current (B), percent pulse-on time (T), and pulse frequency (F) with threelevels was used. ANOVA showed that the percent pulse-on time has the highest influenceon the pitting corrosion resistance (50.48%) followed by pulse frequency (28.62%), peakcurrent (11.05%) and base current (9.86%). The optimum conditions were found as 170 A,85 A, 40%, and 6 Hz for P, B, T, and F factors, respectively.**M. Yousefieh, M. Shamanian et al.(2012)[18]** has studied the effect of hardness and thetoughness of pulsed current gas tungsten arc welding. The output parameters were pulsecurrent, background current, % on time, and pulse frequency. Each parameter was variedat three different levels. The pulse current is found to be the most significant factor for boththe hardness and the toughness of welds by percentage contribution of 71.81 for hardnessand 78.18 for toughness. The % on time (21.99%) and the background current (17.81%)had also the next most significant effect on the hardness and the toughness, respectively.The optimum conditions within the selected parameter values for hardness were found aspulse current (100 A), background current (70 A), % on time (40%), and pulse frequency(1 Hz), while for toughness they were found as pulse current (120 A), background current(60 A), % on time (60%), and pulse frequency (5 Hz).

III. EXPERIMENTATION

The TIG welding machine that is to be used for carrying out experimental runs is MaCHTTIG300 Inverter welder machine, DC type. It has a digital display for current. This machine is dual machine that can be used for both Arc welding and TIG welding. It has acurrent range of 20-300A. This machine fulfills the necessary parameters and levels that isrequired for experiments. Location Ansari Fabricator,Plot no. H/5/1,Phase-1, GIDC Chhtral,Kalol, Gandhinagar.

The Material used is 300 series of Austenitic Stainless Steel i.e. UNS S31603/AISI 316L. 316L is an extra low-carbon variation of Type 316 with a 0.03% maximum carbon contentthat eliminates carbide precipitation due to welding. Weld annealing for this material isonly required in high stress applications otherwise not.

Element	Carbon	Silicon	Sulphur	Phosphorous	Manganese	Nickel	Chromium	Molybdenum
% weight	0.027	0.420	0.001	0.025	1.430	10.200	16.820	2.040

Table 1: Chemical composition

The parameters and their levels used for research are given in Table 2. Tungsten electrode used for performing welding is 2% ceriated tungsten electrode. The experiments are performed on plate of size 50mmX30mmX5mm. The Aspect Ratio was measured at Divine Laboratory Service, Ahmedabad. Test Method was ASME Sec IX-2013.

- **Input Parameter**

Parameters	Level 1	Level 2	Level 3
Welding Current (A)	80	95	110
Shielding Gas Flow (l/min)	4	6	8
Filler Rod Diameter (mm)	1.6	2.0	2.4

Table 2: Input Parameters

- **Response/Output Parameter** : Aspect Ratio (width to depth ratio)

Aspect ratio is ratio of Bead width to the Depth of Penetration. Aspect Ratio is a response that has to be minimized. Minimum bead width and maximum depth of penetration isdesirable for the welding joints.

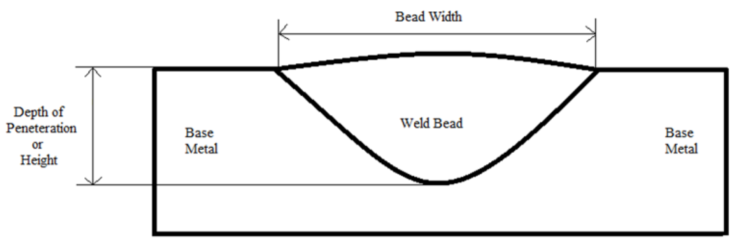

Fig. 3: Section of Welded Joint

IV. RESULTS, DISCUSSIONS AND ANALYSIS

DOE was used to define the experimental runs. Full Factorial method was used, various runs are shown below in Table 3. Experimental and predicted values of Aspect Ratio in shown in below Table 3.

Std Order	Welding Current (A)	Shielding Gas Flow (l/min)	Filler Rod Diameter (mm)	Aspect Ratio Experimental	Aspect Ratio Predicted
1	80	4	1.6	2.1691	2.3442
2	80	4	2	2.6223	2.3754
3	80	4	2.4	2.0613	2.4355
4	80	6	1.6	2.5265	2.4419
5	80	6	2	2.9548	2.5226
6	80	6	2.4	2.5787	2.6466
7	80	8	1.6	1.9278	2.2280
8	80	8	2	2.0848	2.3582
9	80	8	2.4	2.8493	2.5459
10	95	4	1.6	2.6110	2.5605
11	95	4	2	2.7314	2.5860
12	95	4	2.4	2.4447	2.6403
13	95	6	1.6	2.4571	2.6619
14	95	6	2	2.5049	2.7339

Std Order	Welding Current (A)	Shielding Gas Flow (l/min)	Filler Rod Diameter (mm)	Aspect Ratio Experimental	Aspect ratio Predicted
15	95	6	2.4	2.9807	2.8492
16	95	8	1.6	2.7911	2.3932
17	95	8	2	2.2967	2.5118
18	95	8	2.4	2.5381	2.6881
19	110	4	1.6	2.1493	2.3025
20	110	4	2	2.2988	2.3223
21	110	4	2.4	2.4749	2.3708
22	110	6	1.6	2.5296	2.6856
23	110	6	2	2.7406	2.7491
24	110	6	2.4	2.7070	2.8557
25	110	8	1.6	2.4236	2.6402
26	110	8	2	3.1915	2.7473
27	110	8	2.4	2.6463	2.9120

Table 3: Experimental and Predicted Values of Aspect Ratio.

Below figure are some of the sections of welded joints. Fig. 4 is at Welding Current: 110A, Shielding Gas flow: 4 l/m, Filler Rod Diameter: 2.4 mm. Fig 5 is at

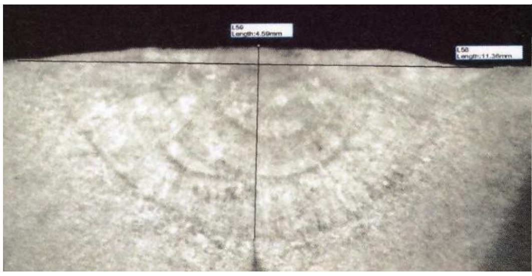

Fig.4: Section

Fig. 5: Section

A. Analysis of Variance (ANOVA)

ANVOA is a method most widely used for determining significant parameters on response and measuring their effects. ANOVA is a statistically based, objective decision-making tool for detecting any differences in theaverage performance of groups of items tested. ANOVA helps in formally testing the significance ofall main factors and their interactions by comparingthe mean square against an estimate of theexperimental errors at specific confidence levels.

Statistically, there is a tool called an F test, named after Fisher, to see which designparameters have a significant effect on the qualitycharacteristic. In the analysis, the F-ratio is a ratio ofthe mean square error to the residual error, and istraditionally used to determine the significance of afactor.The P-value gives the significance level. ANOVA table for parameters is given below in Table 4. MINITAB 17 was used to obtain ANOVA table. From the table it is found that all the factors are significant, confidence level was 95%. Shielding gas flow was most significant factor with 43.52% contribution, after that Filler rod diameter as 31.09% and Welding current at 22.13%.

Source	DF	SS	MS	F-Value	P-Value	%contribution
Welding Current	2	0.5156	0.25780	68.02	0.0001	22.13%
Shielding Gas Flow	2	1.0139	0.50695	133.76	0.0001	43.52%
Filler Rod Diameter	2	0.7243	0.36215	95.55	0.0001	31.09%
Error	20	0.0759	0.00379			3.26%
Total	26	2.3297				100

Table 4: ANOVA

B. REGRESSION ANALYSIS

By the means of regression in MINITAB 17, a model correlating process parameters and response was generated. Analysis of variance was used to find the significant factors which is shown in Table 5. The factors found significant were: Welding current (A), Shielding gas flow (B), Filler rod diameter (C), A^2, AB, A^2B, AB^2, ABC, BC^2. Residual plot for Aspect ratio is shown in Fig. 6.

Aspect Ratio = -16.1 + 0.403***A**+ 2.33***B** - 0.169***C** - 0.00229*$\mathbf{A^2}$- 0.0487 **A*B** + 0.000309*$\mathbf{A^2B}$- 0.000487*$\mathbf{AB^2}$- 0.00024***ABC** + 0.0225*$\mathbf{BC^2}$

Source	DF	SS	MS	F-Value	P-Value	
Regression	16	2.10842	0.131776	5.95	0.0349	
Welding Current-A	1	0.21698	0.216982	9.80	0.0107	Significant
Shielding Gas Flow-B	1	0.33129	0.331289	14.97	0.0031	Significant
Filler Rod Diameter-C	1	0.16723	0.167234	7.56	0.0205	Significant
A^2	1	0.22587	0.225866	10.20	0.0096	Significant
B^2	1	0.04198	0.041983	1.89	0.1992	Not Significant
C^2	1	0.00712	0.007122	0.32	0.5841	Not Significant
AB	1	0.18345	0.183447	8.29	0.0164	Significant
AC	1	0.00918	0.009184	0.41	0.5364	Not Significant
BC	1	0.00009	0.000088	0.00	1.0000	Not Significant
A^2B	1	0.26307	0.263073	11.89	0.0062	Significant
A^2C	1	0.05313	0.053129	2.40	0.1524	Not Significant
AB^2	1	0.19948	0.199477	9.01	0.0133	Significant
ABC	1	0.28184	0.281841	12.73	0.0051	Significant
AC^2	1	0.00284	0.002837	0.13	0.7259	Not Significant
B^2C	1	0.00883	0.008826	0.40	0.5413	Not Significant
BC^2	1	0.11604	0.116042	5.24	0.0451	Significant
ERROR	10	0.22133	0.022133			
Total	26	2.32975				

Table 5: ANOVA for Regression analysis

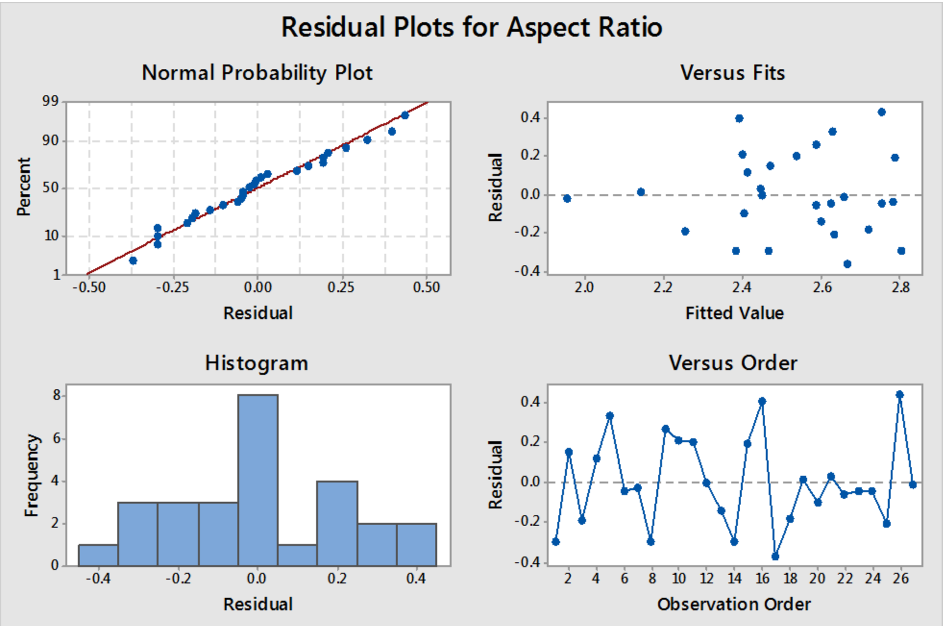

Fig. 6: Residual plot for Aspect Ratio.

Experimental validation of the model was also done using the values other than the experimental values and was found to be ±8%.

C. GENETIC ALGORITHM

A genetic algorithm is a search algorithm based on natural selection and the mechanisms of population genetics[20].Genetic algorithm is a computerized search and optimizationalgorithm based on the mechanics of natural genetics and natural selection. According tothe concept of survival of the fittest, the fittest individuals of any population have thehighest probability to reproduce and survive to the next generation, thus improvingsuccessive generations. However, inferior individuals also have meager chances to surviveand reproduce. Genetic algorithm is a population-based search technique used to solve bothlinear and nonlinear problems by exploring all regions of the stated space and range[9].Reproduction is the first operator applied on a population. In this process, individual stringsare copied into a separate string called the 'mating pool' according to their fitness values,i.e. the strings with a higher value have a higher probability of contributing one or moreoffspring in the next generation[9]. Reproduction operator is also known as selectionoperator.

After reproduction, the population is enriched with good strings from the previous generation but does not have any new string. A crossover operator is applied to thepopulation to hopefully create better strings. The total number of participative strings incrossover is controlled by the crossover probability, which is the ratio of total stringsselected for mating and the population size. The crossover operator is mainly responsiblefor the search aspects of genetic algorithm[9]. Mutation ensures no important genetic material is lost[20].Mutation is the occasionalrandom alteration of the value of a string position. This means changing 0 to 1 or vice versaon a bit-by-bit basis.The population size is one of the most important parameters that plays a significant role inthe performance of the genetic algorithms. The population size dictates the number ofindividuals in the population. Larger population sizes increase the amount of variationpresent in the initial population at the expense of requiring more fitness evaluations.Fitness function is required for evaluation.

GA optimization toolbox was used to obtain the optimum results. The parameters selected for optimization were Population Size: 100, Selection Function: Roulette, Fitness Scaling: Rank, Elite count: 0.2, Generation: 100, Crossover rate: 0.8, Mutation rate: 0.01. The optimum values of parameters found were welding current 80A, Shielding gas flow 8l/min, Filler rod diameter of 1.6mm. Optimum value of Aspect Ratio found was 2.2280.

V. CONCLUSIONS

This paper has presented an investigation on the optimization TIG welded joint of SS 316L. Input parameters selected for study were Welding current, Shielding gas flow, Filler rod diameter and the response was Aspect ratio. The level of importance of the welding parameters on the Aspect ratio is determined by using ANOVA. Regression analysis was done and the model was optimized using Genetic algorithm optimization toolbox. Experimental validation of the model was also performed. Various conclusions obtained were:

- Percent contribution of various parameter found was Shielding gas flow 43.52%, Filler rod diameter 31.09%, Welding current 22.13%
- Experimental validation of regression model showed error was in range of $\pm$8%.
- Genetic Algorithm has given optimum result at lowest value of welding current, filler rod diameter and highest value of Shielding gas flow.
- The optimum values of parameters found were welding current 80A, Shielding gas flow 8l/min, Filler rod diameter of 1.6mm.
- Optimum value of Aspect Ratio found was 2.2280.

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