PARAMETRIC OPTIMIZATION OF TIG WELDING PARAMETERS USING TAGUCHI METHOD FOR DISSIMILAR JOINT

(Low carbon steel with AA1050)

J.Pasupathy, V.Ravisankar

Abstract— Tungsten Inert Gas welding (TIG) process is an important component in many industrial operations. The TIG welding parameters are the most important factors affecting the quality, productivity and cost of welding. This paper presents the influence of welding parameters like welding current, welding speed on strength of low carbon steel on AA1050 material during welding. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of dissimilar joint and optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicted values with the experimental values to confirm its effectiveness in the analysis of strength.

Index Terms— TIG welding, optimization, orthogonal array, S/N ratio

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1 INTRODUCTION

TUNGSTEN Inert Gas welding is one of the most widely used processes in industry. The input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect arc can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, welding speed and distance between the electrode and workpiece. These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility. Ugur Esme [45] an investigation of the effect and optimization of welding parameters on the tensile shear strength in the resistance spot welding (RSW) process-conducted experimental studies under varying electrode forces, welding currents, electrode diameters, and welding times. K. Kishore, P. V. Gopal Krishna, K. Veladri and Syed Qasim Ali [17] worked on welding of materials like steel and is still critical and ongoing. Sourav Datta, Ajay Biswas, Gautam Majumdar [39] worked on Sensitivity Analysis. It has been carried out to check the case sensitiveness of relation importance of different bead geometry parameters imposing predominant effect on the optimal parametric combination. P K Palani, Dr N Murugan, [31] designed the DOE using Taguchi approach can significantly reduce time required for experimental investigations [29,37,39]. In this investigation, Taguchi's orthogonal arrays were used to conduct the experiments to find the contributions of each factor and to optimize the parameter settings.

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2 TAGUCHI'S DESIGN METHOD

Taguchi Technique is applied to plan the experiments. The Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly and at low cost. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the combination of Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Signal-to-Noise Ratio

There are 3 Signal-to-Noise ratios of common interest for optimization

(i) Smaller-The-Better:

$n = -10 \, Log_{10}$ [mean of sum of squares of measured data]

(ii) Larger-The-Better:

$n = -10 \, Log_{10}$ [mean of sum squares of reciprocal of measured data]

(iii) Nominal-The-Best:

$$n = 10 \, Log_{10} \frac{\text{square of mean}}{\text{variance}}$$

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2.1 Work Material:

1mm thick Low carbon steel and 2mm thick AA1050 aluminium alloy were used. The dimensions of the work piece, length 300 mm, width 150mm. For selection of workpiece, reference of the procedure handbook of Arc Welding & Welding Process Technology by P. T. Houldcroft is referred. This experiment, TIG welding is done using Lincoln machine, Polarity: Direct Current Electrode Negative [DCEN], Welding current, welding speed and distance of electrode from workpiece are 130, 135, 140Amps, 3.2, 3.5, 3.8mm/sec and 2.3, 2.4, 2.5mm respectively, Voltage 16V, Frequency 60Hz, The arc distance, electrode type, electrode size and electrode tip angle were 2.4mm, EWTh-2, 3mm in diameter and Vertical respectively. Pure argon gas with 20L/min was used for preventing oxidation of molten steel.

Table 1: welding parameters and their levels

Symbol	Welding parameters	Level 1	Level 2	Level 3
I	Welding current	130	135	140
S	Welding speed	3.2	3.5	3.8
D	Distance of electrode from the workpiece	2.3	2.4	2.5

2.2 L9 Level Taguchi Orthogonal Array

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Below Table No.2 shows L9 Orthogonal array from Table1.

Table 2: L9 orthogonal array

Expt. No.	Process Parameters		
	Welding current	Welding Speed	Distance
1	1	1	1
2	1	2	2
3	1	3	3
5	2	2	3
6	2	3	1
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

3. Analysis of S/N Ratio

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. Therefore, the S/N ratio to the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. In S/N ratio, S is defined as

$$S = -10 \log (M.S.D.)$$

where, M.S.D. is the Mean Square Deviation for the output characteristic.

To obtain optimal welding performance, higher-the better quality characteristic for strength must be taken. The M.S.D. for higher-the –better quality characteristic can be expressed as,

$$M.S.D = \sum 1/P_i2$$

Where, P_i is the value of penetration.

Table3: Experimental result for strength and S/N ratio:

Ex No	Welding current (amps)	Welding speed (mm/sec)	Distance of electrode from workpiece (mm)	Strength (MPa)	S/N ratio
1	130	3.2	2.3	34.68	12.11
2	130	3.5	2.4	40.35	2.57
3	130	3.8	2.5	39.06	5.99
4	135	3.2	2.4	25.9	14.89
5	135	3.5	2.5	55.55	8.26
6	135	3.8	2.3	19.95	11.74
7	140	3.2	2.5	43.23	11.59
8	140	3.5	2.4	14.69	3.94
9	140	3.8	2.3	34.47	9.24

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for strength is shown in Table No.4 as below

Table 4: S/N response table for strength

Symbol	Welding parameters	Mean S/N Ratio		
		Level 1	Level 2	Level 3
I	Welding current	6.89	11.623	8.257
S	Welding speed	12.863	4.917	8.9
D	Distance	9.263	8.9	8.607

4. ANOVA (Analysis Of Variance)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SS_T from the total mean S/N ratio n_m can be calculated as,

$$SS_T = \sum (n_i - n_m)^2$$

Table 5: Result of analysis of variance for strength

Factor	*Sum of square*	*DOF*	*Var*	*F*	*Result*	*Significance*
I	35.600	2	17.800	14.9213	0.9860	*Yes*
S	94.728	2	47.364	39.7043	0.9977002	*Yes*
D		*Pooled (or) Poored*				
Error	4.772	4	1.193			
Total	135.100	8	*At least 95% confidence*			

5. Conformation Test

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design pa-

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rameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as

$$\acute{\eta} = \eta_m + \sum_{i=1}^{n} (\eta_i - \eta_m)$$

where η_m is total mean of S/N ratio, η_i is the mean of S/N ratio at the optimal level, and n is the number of main welding parameters that significantly affect the performance. The comparison of the predicted strength with actual strength using the optimal parameters is shown in table 6. Good agreement between the predicted and actual penetration being observed.

Table 6: Result of the conformation test

	Initial welding parameters	Optimal welding parameters	
		Prediction	Experiment
Level	A3B3C2	A2B1C1	A2B1C1
Strength	30.96	59.35	61.37
S/N ratio	8.307	15.909	16.45

6. Conclusion

Taguchi optimization method was applied to find the optimal process parameters for strength. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified for the effectiveness of the Taguchi optimization method. The experiment value that is observed from optimal welding parameters, the strength is 61.37MPa. & S/N ratio is 16.45.

References

[1] Banovic. S. W, DuPont J. N, and Marder. A. R, "Dilution and micro segregation in dissimilar metal welds between super austenitic stainless steel and nickel base alloys", Science and Technology of Welding and Joining, Vol. 7 No. 6, pp. 374 – 384, 2002.

[2] Blewett R.V., "Welding aluminium and its alloys, A review of applications and requirements", Welding & metal fabrication, pp.449-454, 1991.

[3] Borrisutthekul, R., T. Yachi, Y. Miyashita and Y. Mutoh, "Suppression of intermetallic reaction layer formation by controlling heat flow in dissimilar joining of steel and aluminum alloy", Mater. Sci. Eng. A., pp 108-113, 2007.

[4] Bozzi. S, Etter. A. L, Baudin. T, Robineau. A, and Goussain. J. C, "Mechanical behavior and Microstructure of Aluminium – Steel sheets joined by FSSW", Hindawi publishing corporation, Texture, Stress and Microstructure, Vol 2008, Article ID 360617, 8 pages, 2008.

[5] Çalik. A, Karakaş M. S, and Varol. R, "Fatigue Behavior of Electron Beam Welded Dissimilar Metal Joints", Welding Research, Vol. 91, 50-52-s, 2012.

[6] DebRoy. T, and Bhadeshia. H. K. D. H, "Friction stir welding of dissimilar alloys – a perspective" Science and Technology of Welding and Joining, Vol. 15, No4, pp. 266-270, 2010.

[7] Edmilson Otoni Correa, "Weldability of Iron Based Powder Metal Alloys Using Pulsed GTAW Process", Arc welding, www.intechopen.com, pp 109-126, 2011.

[8] Esther T, Stephen A, "Friction Stir Welding of Dissimilar Materials – Statistical Analysis of the Weld Data", Proceeding of IMECS 2012, Vol. II, 2012.

[9] Faidy. C, Martin. G, Chapuliot. S, Kayser. Y, Safa. N, Cipierre. MF, Gilles. P, Keinanen. H, Laukkanen. A, Sherry. A, Lidbury. D, Wintle. J., Taylor. N, Youtsos. A, Lenkey. G, "Assessment of aged piping dissimilar metal weld integrity (ADIMEW)", Proceedings of FISA 2003 Conference, Luxembourg, 2003.

[10] George A. Young, John G. Banker, "Explosion Welded, Bi-Metallic Solutions to Dissimilar Metal Joining", Proceedings of the 13th Offshore Symposium, Texas, 2004.

[11] Göbel. G, Kaspar. J, Herrmannsdörfer. T, Brenner. B, Beyer. E, "Insights into intermetallic phases on pulse welded dissimilar metal joints", 4th International Conference on High Speed Forming, pp. 127-136, 2010.

[12] H.J. Park, D.C. Kim, M.J. Kang, S. Rhee; "Optimisation of the wire feed rate during pulse MIG welding of Al sheets." Journal of Achievements in Materials and Manufacturing Engineering Volume 27, by International OCSCO world.

[13] Hitoshi Ozaki, Muneharu Kutsuna, Shigeyuki Nakagawa and Kenji Miyamoto, "Laser Roll Welding of Dissimilar Metal Joint of Zinc Coated Steel and Aluminium Alloy", II W Doc. IV – pp. 906 –909, 2001.

[14] Hui-Chi Chen & Andrew J. Pinkerton & Lin Li, "Fibre laser welding of dissimilar alloys of Ti-6Al-4V and Inconel 718 for aerospace applications", Int J Adv Manuf Technol, pp. 2791-2793, 2010.

[15] Indira Rani M., Marpu.R.N., A.C.S.Kumar, "A study of process parameters of friction stir welded aa 6061 aluminum alloy in o and t6 conditions", ARPN Journal of Engineering and Applied Sciences, Vol. 6, No. 2, pp. 61-66, 2011.

[16] Jyoti Prakash, S.P.Tewari, Bipin Kumar Srivastava, "Shielding Gas for Welding of Aluminium Alloys by TIG/MIG Welding-A Review" Vol.1, Issue.2, pp. 690-699, 2003.

[17] K. Kishore, P. V. Gopal Krishna, K. Veladri and Syed Qasim Ali; " Analysis of defects in gas shielded arc welding of AISI1040 steel using Taguchi method." ARPN Journal of Engineering and Applied Sciences, Vol 5, No.1.

[18] K.Y. Benyounis, A.G. Olabi; "Optimization of different welding processes using statistical and numerical approaches – A reference guide." Advances in Engineering Software 39 (2008) 483–496

[19] Kankanala, Anusha; James, Jon; Bouchard, John; Northover, Shirley and Yescas, Miguel, "Measurement of residual stresses in a dissimilar metal welded pipe". In MECA SENS VI, pp. 7 -9, 2011.

[20] Katayama. S, "Laser welding of Aluminium alloys and dissimilar metals", Welding International, Vol. 18 [8]. pp. 618 – 625, 2004.

[21] Krishnaprasad. K, Raghu V. Prakash,, "Fatigue Crack Growth Behavior in Dissimilar Metal Weldment of Stainless Steel and Carbon Steel" World Academy of Science, Engineering and Technology 32, pp. 873-879, 2009.

[22] Lee, K.J. and S. Kumai, "Characterization of intermetallic compound layer formed at the weld interface of the defocused laser welded low carbon steel/6111 aluminum alloy lap joint". Mater. Trans., pp. 1178-1185, 2006.

[23] Lee, K.J., S. Kumai and T. Arai, "Interfacial microstructure and strength of steel to aluminum alloy lap joints welded by a defocused laser beam". Mater. Trans., pp. 1847-1856, 2005.

[24] Metzger G.E Aug "Gas tungsten Arc welding of a powder metallurgy aluminum alloy" Welding journal, pp.297-302, 1992.

[25] Mir Sadat Ali, Ch.Srinivasa Rao, "Study of mechanical properties in a weld bead of dissimilar metals", International Journal of Engineering

International Journal of Scientific & Engineering Research Volume 4, Issue ƕƔƕǅƔ - ÖÝÌÔÉÌÙıĺƔƕƔƗ
ISSN 2229-5518

Science and Technology (IJEST), Vol. 3 No. 5, pp. 4411-4416, 2011.

[26] Miyashita, Y., I. Nakagawa, J.Q. Xu, Y. Mutoh, M. Akahori and H. Okumura, "Laser welding of dissimilar metals joint aided by unsteady thermal convection boundary element method analysis". Q. J. Jap. Weld. Soc., pp. 16-24, 2005.

[27] Mueller. S, Volpone. L. M, "Friction Stir Welding of Steel Aluminium sandwich panels", Welding International, pp. 699-705, 2007.

[28] Muhamad Tehyo, Prapas Muangjunburee and Somchai Chuchom, Friction stir welding of dissimilar joint between semi-solid metal 356 and AA 6061-T651 by computerized numerical control machine", Songklanakarin J. Sci. Technol., pp 441-448, 2011.

[29] N.B. Mostafa, M.N. Khajavi; "; Optimisation of welding parameters for weld penetration in FCAW" Achievements in Materials and Manufacturing Engineering Vol. 16 ISSUE 1-2 May-June 2006

[30] Nelson. T. W, Lippold. J. C. Mills. M. J, "Nature and Evolution of the Fusion Boundary in Ferritic-Austenitic Dissimilar Weld Metals, Part 1 — Nucleation and Growth", Welding Research Supplement, pp. 329-337-s, 1999,

[31] P K Palani, Dr N Murugan, "Modeling of Heat Input in Stainless Steel Cladding using Taguchi's Design of Experiments" IE(I) Journal-MC, Vol. 87, January 2.

[32] P.Sathiya, Swati, V.Manaswini, Anubha Singh Bhadauria and Snigdha Lakra; " Optimizing The Gas Metal Arc Welding Parameter Of Super Austenitic Stainless Steel By Grey Based Taguchi's Method"

[33] Rathod, M.J. and M. Kutsuna, "Joining of aluminum alloy 5052 and low-carbon steel by laser roll welding. Weld. J., pp. 16-26S, 2004.

[34] Rattana Borrisutthekul, Pusit Mitsomwang, Sirirat Rattanachan Yoshiharu Mutoh, "Feasibility of Using TIG Welding in Dissimilar Metals between Steel/Aluminum Alloy", Energy Research Journal 1, pp. 82-86, 2010.

[35] Saperstein Z.P and Eyring C.L. "Fracture strength microstructure of welds in 2014aluminum", Welding journal. pp. 90-94, 1968.

[36] Saurav Datta & Asish Bandyopadhyay & Pradip Kumar; "Application of Taguchi philosophy for parametric optimization of bead geometry and HAZ width in submerged arc welding using a mixture of fresh flux and fused flux"

[37] Serdar Karaoglu and Abdullah Seçgin; "Sensitivity analysis of submerged arc welding process parameters" journal of materials processing technology, volume 202 (2008) 500–507.

[38] Shubhavardhan RN, Surendran S, "Friction Welding to Join Dissimilar Metals" International Journal of Emerging Technology and Advanced Engineering, Vol 2, Issue 7, pp. 200-211, 2012.

[39] Sourav Datta, Ajay Biswas, Gautam Majumdar; "Sensitivity analysis for relative importance of different weld quality indicator influencing optimal process condition of Submerged Arc Welding using Gray based Taguchi Method" The International Journal for Manufacturing science & production, Vol. 10 No. 2 2009

[40] Sun Yufeng, Fujii Hidetoshi, Takada Yutaka, Tsuji Nobuhiro, Nakata Kazuhiro, Nogi Kiyoshi, "Microstructure and Hardness distribution of Friction Stir Welded 1050 Al and IF Steel with different original grain sizes", Transactions of JWRI, Vol.38, No.2, 2009.

[41] Sunwoo A.J., Morris J.W, "Microstructure and properties of aluminum alloy2090 weldments", Annual American Welding Society Meeting, pp. 262-268, 1989.

[42] Thaiping Chen, "Process parameters study on FSW Joint of dissimilar metals for Aluminium – Steel", Journal of Material Science, pp. 2573 – 2580, 2009.

[43] Theron. M, VanRooyen. C, Ivanchev. L.H, "CW ND: YAG Laser welding of dissimilar sheet metals", Paper# 803.

[44] Tucker M.S. and Philips, "The influence of cooling rates on microstructure and strength of2014 Al-alloy weld", Welding Journal pp.82-86. Feb 1968.

[45] Ugur r Esme; "Application of Taguchi method for the optimization of resistance spot welding process." The Arabian Journal for Science and Engineering, Volume 34, Number 2B