Process Parameter Optimization in ARC Welding of Dissimilar Metals

Lenin N., Sivakumar M. and Vigneshkumar D.
Department of Mechanical Engineering, National Engineering College,
Kovilpatti, Tamilnadu, India.
E-mail: n.lenin@gmail.com

Abstract

Welding is a basic manufacturing process for making components or assemblies. Recent welding economics research has focused on developing the reliable machinery database to ensure optimum production. In this paper, the optimization of welding input process parameters for obtaining greater weld strength in the manual metal arc (MMA) welding of dissimilar metals like stainless steel and carbon steel is presented. The Taguchi method is adopted to analyze the effect of each welding process parameter on the weld strength, and the optimal process parameters are obtained to achieve greater weld strength. Experimental results are provided to illustrate the proposed approach.

Keywords: Dissimilar metals welding, MMA welding, Taguchi method, optimal parameters, Tensile strength of the weld

1. Introduction

In high pressure boilers, alloy materials are used for making the super heater and economizer. The cost of alloy steel is very high and hence, in order to reduce the cost, the alloy steels may be combined with carbon steel. Hence, cost reduction is the main objective together with a better quality weld, so we use dissimilar metals welding.

A better quality weld in dissimilar metal welding is obtained by optimizing the process parameters because they play a vital role in deciding the weld strength. Some important parameters are welding current, welding voltage, welding speed, arc length, etc. These parameters can be selected based on screening experiments. The actual number of experiments has been minimized by using an orthogonal array and experiments have to be conducted. Once these parameters are optimized, then a perfect weld, i.e. good weld strength, can be achieved.

2. Taguchi method for the optimization of process parameters

Optimization of process parameters is the key step in the Taguchi method [1] for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e. lower-the better, higher-the-better and nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic [1-4], a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the higher S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

3. Dissimilar metals joining by MMA welding process

In the manual metal arc (MMA) welding process, a 3.15 mm diameter consumable stainless steel 304 Grade electrode is used to strike an electric arc with the base metal. The heat generated by the electric arc is used to melt and join the base metal. In this study an MMA welding machine is used to weld the base plates of 304 Stainless Steel and Low Carbon Steel. The chemical composition of Stainless steel is given in Table 1 and for Low carbon steel is given in Table 2. Two plates of size 125 mm x 100 mm x 4 mm are tacked together to form a weld pad of 250 mm x 100 mm.Welding is carried out in the down hand position and beads are laid along the weld pad centerline to form a butt joint. The plates are allowed to cool to room temperature, after the completion of welding.

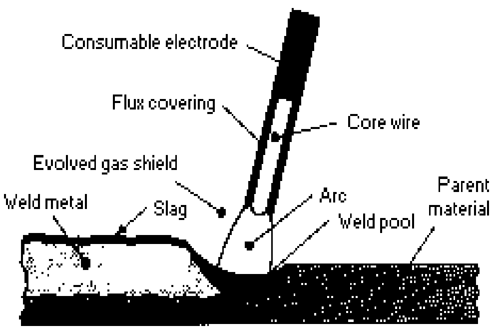

Figure 1 Dissimilar metals welding process

Table 1 Chemical composition of Stainless steel 304 in wt%

Mtrl	C	Mn	S	P	Si	Cu	Ni
%	0.0195	1.7153	0.00086	0.0282	0.2884	0.1731	9.1355

Ti	Cr	Mb	V	Tu	Al	Fe
0.004	19.2703	0.0776	0.1189	0.036	0.006	68.923

Table 2 Chemical composition of Low carbon steel in wt%

Mtrl	C	Mn	S	P	Fe
%	0.15	0.6	0.055	0.055	99.14

To evaluate the quality of the MMA welds, a measurement of the tensile strength is performed by using an ultimate tensile testing (UTM) machine. The tensile strength of the weld has a higher-the-better quality characteristic. After welding, the joints are sliced in transverse direction to prepare the specimens for the purpose of measuring the tensile strength of the weld.

4. Optimal selection of process parameters using Taguchi method

In this section, the use of the Taguchi method [1-3] to determine the process parameters in the MMA welding of stainless steel, and low carbon steel is reported step-by-step. Optimal welding process parameters with greater weld strength are determined and verified.

4.1 Orthogonal array Experiment

In the present study, three 3-level process parameters i.e. welding current, welding voltage and welding speed are considered. The values of the welding process parameters are listed in Table 3. The ranges and levels are fixed based on the screening experiments. The interaction effect between the parameters is not considered. The total degrees of freedom of all process parameters are 8. The degrees of freedom of the orthogonal array should be greater than or at least equal to the degrees of freedom of all the process parameters. Hence, L_9 (3^3) Orthogonal array was chosen which has 8 degrees of freedom. This is shown in Table 4.

Table 3 Process Parameters and their Levels

Symbol	Process Parameter	Level 1	Level 2	Level 3
A	Welding speed (mm/min)	353	250	207
B	Welding current (amps)	100	80	60
C	Welding voltage (volts)	30	28	26

Nine Experiments are conducted based on the orthogonal array, instead of 27 possibilities.

Table 4 Experimental layout (L_9 (3^3) Orthogonal array)

Expt. number	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

4.2 Loss function and its S/N ratio

As discussed earlier, the weld strength belongs to the higher-the-better quality characteristic. The loss function of the higher-the-better quality characteristic can be expressed as:

$$L_{ij} = \frac{1}{n} \sum \frac{1}{y_{ijk}^{2}} \quad \text{---- (1)}$$

where L_{ij} is the loss function of the *i* th quality characteristic in the *j*th experiment, n the number of tests, and y_{ijk} the experimental value of the *i*th quality characteristic in the *j*th experiment at the *k*th test.

The loss function is further transformed into the S/N ratio. In the Taguchi method the S/N ratio is used to determine the deviation of the quality characteristic from the desired value. The S/N ratio n_j in the *j*th experiment can be expressed as:

$$\mathbf{n_j = -10 \log (L_{ij})} \qquad \text{---- (2)}$$

The effect of each welding process parameter on the S/N ratio at different level can be separated out because the experimental design is orthogonal.

4.3 Analysis of Variance (ANOVA)

The purpose of ANOVA [1-3] is to investigate which welding process parameters significantly affect the quality characteristics. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic.

5. Results and Discussion

The tensile strength of the dissimilar welded plates is measured in the Universal Testing Machine (UTM) and the result is shown in Table 5. The center portions of the welded specimens are cut down with a width of 20 mm in order to hold it in the UTM.

Table 5 Experimental observations

Expt. number	Tensile strength (N/mm^2)
1	115.5
2	98.5
3	68.5
4	105.5
5	115.5
6	125
7	112.5
8	98.5
9	42.5

The corresponding S/N ratio for the nine experiments is shown in Table 6.

Table 6 Experimental Results

Experiment Number	S/N ratio(db)
1	41.25164
2	39.86872
3	36.71381
4	40.46505
5	41.25164
6	41.9382
7	41.02305
8	39.86872
9	32.56778

The mean S/N ratios for the three parameters at three levels are calculated. This is shown in Table 7.

Table 7 Mean S/N ratio for the parameters

Level	Factor A	Factor B	Factor C
1	39.278058	40.913246	39.258608
2	41.218296	40.32969	35.872938
3	37.819851	37.073263	37.90121

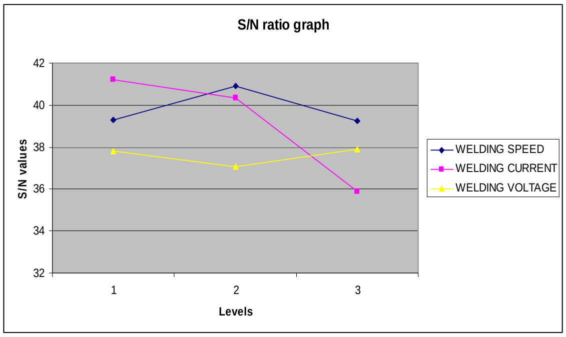

Figure 2 S/N Ratio Graph for Dissimilar Metals Welding

Based on S/N ratio results, the welding process parameters with greater tensile strength are welding speed at level 2, welding current at level 1 and welding voltage at level 1.

5.1 Analysis of Variance (ANOVA)

The purpose of the ANOVA is to investigate which welding process parameter has significantly affected the tensile strength. The results of ANOVA are shown in Table 8.

Table 8 Results of the ANOVA

Symbol	Degrees of freedom	Sum of squares	Mean square	% Contribution
A	2	1492.167	746.0833	26.84236
B	2	1755.5	877.75	31.57942
C	2	1429.167	714.5833	25.70906
Error	2	882.1667	441.0833	15.86916
Total	**8**	**5559**		

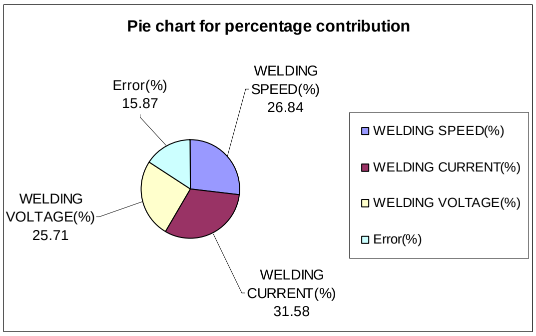

Figure 3 Percentage contributions of parameters

From the ANOVA result, the percentage contribution of the welding current is more, compared with the other welding parameters.

5.2 Confirmation test

The final step is to predict and verify the improvement of quality characteristic using the optimal level of the welding process parameters. The 3 experiments for the optimal inputs, i.e. welding speed at level 2, welding current at level 1 and welding voltage at level 1, are conducted to obtain the tensile strength of 112 N/mm^2. From that, the optimal inputs determine the greater tensile strength of the weld.

6. Microstructure and Hardness analysis

6.1 Effect of heat input on hardness

The hardness of weld metal in Weld Zone (WZ), Heat Affected Zone (HAZ) and Base Metal (BM) has been determined using hardness testing machine. The Brinell a hardness values are measured and compared for different thickness. The hardness values for different heat inputs are compared.

In a 4 mm thickness plate, it is found that with an increase in the welding current, heat input per unit length of the weld increases, which lowers the cooling rate of the weldment. The hardness value decreases, when the heat input increases along the weld zone. The weld zone showed a higher hardness than the Heat Affected zone. In a 2mm thickness plate, the hardness in the weld zone is higher than the heat affected zone. With an increment in the heat input, the hardness along the weld zone is increased. The spatial hardness distribution showed evidence of heat affected zone softening.

6.2 Effect of Heat Input on Microstructure

The microstructure of weld metal has been examined by using a metallurgical microscope and BIOVIS materials plus software. The magnification of the microscope is 100x. CCD camera with reduction lens has the magnification of 10x. The grain size, density and volumetric percentage of different phases have been determined. Microstructures of the BM, HAZ and WZ are compared in Figures 4, 5 & 6 and the analysis result is presented in Table 9.

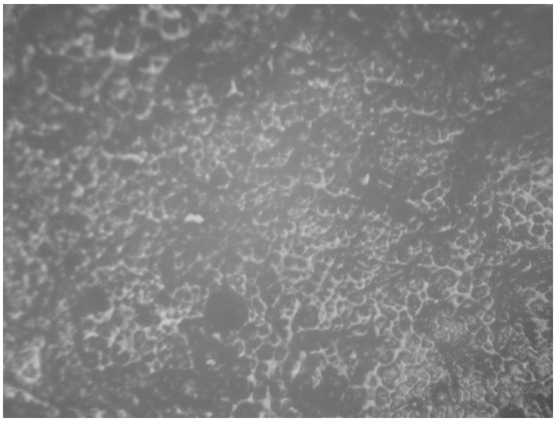

Figure 4 Microstructure on the Base Metal (BM) region for the heat input per unit length of 0.188 kJ/mm

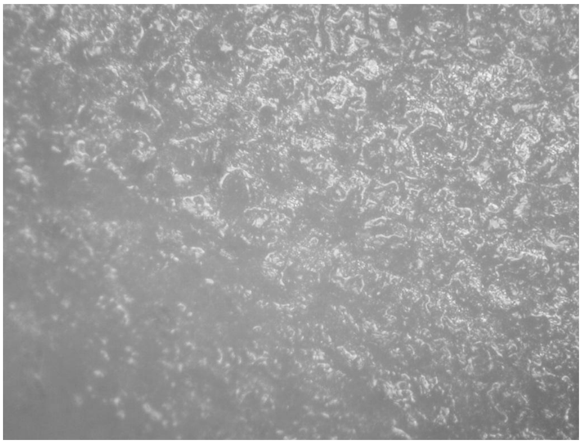

Figure 5 Microstructure on the Heat affected Zone (HAZ) region for the Heat input per unit length of 0.188 kJ/mm

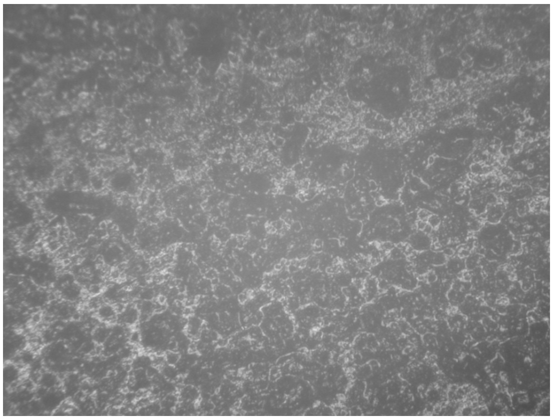

Figure 6 Microstructure on the Weld Zone (WZ) for the heat input per unit length of 0.188 kJ/mm

Table 9 Microstructural analysis

Parameter	HAZ	WZ
Pearlite	68.30187	72.28199
Ferrite	31.69813	27.71801
Grain size	14.5	14.5

Micro structural analysis is made on a small volume of welded zone and heat affected zone of the test specimen. Pearlite and Ferrite phases appear in the microstructure analysis. It was found that the pearlite percentage was always higher than the ferrite in both weld and heat affected zones. The hardness value is lower in the heat affected zone than the weld zone because the percentage of ferrite is higher in the heat affected zone. The higher amount of ferrite influences the softening of the heat affected zone.

7. Conclusion

In this paper, the optimization of the process parameters for MMA welding of stainless steel and low carbon steel with greater weld strength has been reported. The higher-the-better quality characteristic is considered in the weld strength prediction. The Taguchi method is adopted to solve this problem. The experimental result shows that the weld strength is greatly improved by using this approach.

8. References

[1] S. C. Juang and Y. S. Tarng, Process Parameter Selection for Optimizing the Weld Pool Geometry in the Tungsten Inert Gas Welding of Stainless Steel, Journal of Materials Processing Technology, Vol. 122, pp. 33-37, 2002.

[2] A. Kumar and S. Sundarrajan, Process Parameter Selection for the Optimum Weld Pool Geometry in the TIG Welding of Aluminium Alloy

Using Taguchi Method, International Welding Symposium, WE07, 2005.

[3] Y. S. Tarng, H. L. Tsai, S. S. Yeh, Modeling, Optimization and Classification of Weld Quality in TIG Welding, International Journal of Machine Tool and Manufacture, Vol. 39, pp. 1427-1438, 1999.

[4] M. Nataraj and V. P. Arunachalam, A Novel Design Approach for Quality Improvement of Centrifugal Pump Using Taguchi's Robust Design Concept, AIMTDR Conference, VIT, 2005.

[5] S. Murugan, T. P. S. Gill, P. V. Kumar, B. Raj and M. S. E. Bose, Numerical Modeling of Temperature Distribution During Multi Pass Welding of Plates, Journal of Science and Technology of Welding and Joining, Vol. 5, No. 4, pp. 208-214, 2000.

[6] F. M. Hosking, J. J. Stephen and J. A. Rejent, Intermediate Temperature Joining of Dissimilar Metals, Journal of Science and Technology of Welding and Joining, Vol. 3, No. 3, pp. 127-136, 2000.

[7] N. A. McPherson, T. N. Baker and D. W. Millar, A Study of the Structure of Dissimilar Submerged Arc Welds, Journal of Metallurgical and Materials Transactions B, Vol. 29 A, pp. 55-62, 1998.

[8] A. S. Shahi, Sahib Sartaj Singh, Nitin Singla, Sunil Pandey and Tarun Nanda, Prediction of UTS and Toughness Properties of SAW Welded Joints, Proceedings of the Symposium of Joining of Materials, SOJOM, WRI, WMB-1, pp. 1-12, 2004.

[9] S. R. Koteswara Rao, P. Nagaraju, M. Kamaraj and K. Prasad Rao, Modeling the Thermo-Mechanical Treatment of AA 2219 GTA Welds Using ANOVA, Proceedings of the Symposium of Joining of Materials, WEA-4, pp. 1-9, 2004.

[10] N. Murugan and P. K. Palani, Optimization of Bead Geometry in Automatic Stainless Steel Cladding by MIG Welding Using a Genetic Algorithm, IE (I) Journal-PR, Vol. 84, pp. 88-97, 2004.

[11] S. Subramanian, D. R. White, J. E. Jones and D. W. Lyons, Experimental Approach to Selection of Pulsing Parameters in Pulsed GMAW, Welding Research Supplement, pp. 167S-172S, 1999.

[12] Rowlands H., Anthony J., Knowles G., An Application of Experimental Design for Process Optimization, TQM Magazine, Vol. 12, pp. 78-83, 2000.

[13] Douglas C. Montgomery, Arizona State University, Design and Analysis of Experiments, 4th Edition, John Wiley and Sons, New York, 2001.

[14] Phillip J. Ross, Taguchi Techniques for Quality Engineering, 2nd Edition, Mc Graw Hill, 1996.

[15] Charles R. Hicks, Fundamental Concepts in Design of Experiments, 3rd Edition, CBS College Publications, New York, 1982.

[16] O. P. Khanna, A Text Book of Welding Technology, Dhanpat Rai Publications, 1997.

[17] Giachino, Weeks and Johnson, Welding Technology, 2nd Edition, American international Society, 1977.