# OPTIMIZATION OF GAS TUNGSTEN ARC WELDING PARAMETERS ON PENETRATION DEPTH AND BEAD WIDTH USING TAGUCHI METHOD

Muhammad Ibrahim[1], ShahidMaqsood[1], Rafiullah Khan[2], Muhammad Amjad[2], SakhiJaan[2]

## ABSTRACT

*The objective of this paper is the optimization of the gas tungsten arc welding parameters on penetration depth and bead width. Taguchi L25 orthogonal array was used for the design of experiments. Welding experiments were performed on stainless steel specimens. Pilot experimentations were conducting to define the range of variables. Optimal parameters were determined through signal to noise (S/N) ratio approach. Significant factors have been determined through analysis of variance approach. The results showed that the penetration depth and bead width were increased with increase in current and decrease with increase in torch speed. It was concluded that the arc current is the significant factor for both the response parameters while torch angle is significant only for bead width. The results have been verified through confirmation test for each response parameter.*

**Key Words:** *GTAW, Taguchi, ANOVA, Penetration depth, Bead width*

## INTRODUCTION

Gas tungsten arc welding (GTAW),is a type of arc welding process in which an electrode of non-consumable tungsten material and shielding gas is used forthe generationof arc among the electrode and base metal due to which the base metal is melted[1].

In GTAW different variables like electrode, electrode diameter, arc current, current type, torch angle, arc length, torch speed, shielding gas, shielding gas flow rate etc are used. Bead widths, reinforcement height, penetration depth and fusion zone are the parameters dependent on the settings of these variables during welding[2]. A brief literature review of prominent investigations of GTAW is given in the following paragraphs.

P. K. Giridharanet al[3] conducted experiments on 3 mm thick 304L grade austenite steel to study the parametric effect of pulsed current, torch speed and pulsed current durationparameters on bead width, penetration depth, bead area and aspect ratio of 3 mm thickness 304L grade steel. They observed that the process parameters contribution decreased on response variables i.e. welding speed, pulsed current and pulsed current duration respectively. S.C Juanget al[4] conducted experiments on 304L grade steel of 1.5 mm thickness to study the parametric effect of arc length, torch speed, current and gas flow rate parameters on back and front height and back and front width. Their results showed that the contribution of torch speed,shielding gas flow rate, welding current and arc length, respectively decreased on the weld pool geometry dimensions. UgurEsmeet al[5] conducted experiments on 304L grade steel of 1.2 mm thickness to study the parametric effect of current, arc length, gas flow rate and torch speed parameters on tensile load, bead height, bead width, heat affected zone, penetration area and penetration. Torch speed was the most influential factor on response. The influence of other parameters arc length, current and gas flow rate decreased on response respectively. Y. S. Tarnget al[6]conducted experiments on Aluminum 1.6 mm plate's thickness study theparametric effect, welding speed, arc length, polarity ratio, welding current and filler wire speed parameters on back and front height, back and front width of weld bead. Welding speed was the most significant factor followed by current and polarity ratio. P. Bharathet al[7] conducted experiments on 316 austenitic stainless steel of 3 mm thickness, to study the parametric effect of welding speed, operator, root gap, welding current and electrode parameters on bending strength and tensile strength. Current is significant for bending strength and others factors were insignificant. Welding speed followed by welding current and root gap was significant for tensile strength.

The above literature review reveals that previous studies are only focused on few combinations of GTAW parameters. The literature further reveals that optimization of five process parameters of GTAW i.e arc current, torch angle, arc length, torch speed and shielding gas

1 Department of Industrial Engineering, University of Engineering and Technology, Peshawar, Pakistan
2 Department of Mechanical Engineering, International Islamic University, Islamabad, Pakistan

flow rate each with five levels for stainless steel 304L grade welding has not been investigated till date. The objective of this paper is to apply Taguchi optimization technique to find the optimal results for GTAW simultaneously for the above parameters. The penetration depth and bead width was measured after welding specimens of stainless steel 304L grade. Optimum parameters were determined by Taguchi method. This method was also used in earlier study[3,8-10]. The predicted results were verified through confirmation test and compare with literature. The following section describes experimental details of the studies.

### Experimental Procedure

Base metal austenite stainless 304L chemical composition was determined by spectromaxx analyzer. Specimen of thickness 3 mm was prepared by shearing machine and cleaned with acetone. Tungsten electrode, electrode vertex angle $60^o$, electrode diameter 1.6mm,mean arc voltage 15 V, argon shielding gas and purging gas flow rate 6 L/min were kept constant. Variables range determined through pilot experimentations as shown in table I. After performing welding, power hacksaw was used to cut the transverse section, plane cross-section was achieved by milling machine. Cold work effect produced during transverse cutting was minimized by grinding followed by polishing by silicon carbide abrasive paper to enhance edge flatness. Samples were etched in a mixture of HNO3 and HCl of ratio (1:3) for 3 minutes and then washed by distilled water. Penetration depth and bead width measured and macrographs of samples obtained through Olympus inverted metallurgical microscope Model GX-71. Verified samples macrographs are shown in figure 1 and 2. Highest penetration 2.60 mm and lowest bead width 3.15 mm achieved as shown in table II.

## TAGUCHI METHOD

Taguchi is a mathematical and statistical method using orthogonal array to decrease the number run of experimentation and find the optimum parameters through signal to noise ratio. Larger the better quality characteristic of S/N ratio is used for response parameter penetration depth, smaller the better for response parameter bead width and nominal the better[7,11]. Taguchi L25 orthogonal array was applied in this study to conduct experiments

**Table 1. Control factor with levels**

| Factor Notation | Control Factors | Levels | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| A | Arc Current (Amp) | 55 | 60 | 65 | 70 | 75 |
| B | Torch Speed (mm/min) | 110 | 115 | 120 | 125 | 130 |
| C | Arc length (mm) | 1.4 | 1.7 | 2 | 2.3 | 2.6 |
| D | Torch Angle (Deg) | 60 | 75 | 90 | 105 | 120 |
| E | Shielding Gas Flow Rate (Ltr./min) | 8 | 10 | 12 | 14 | 16 |

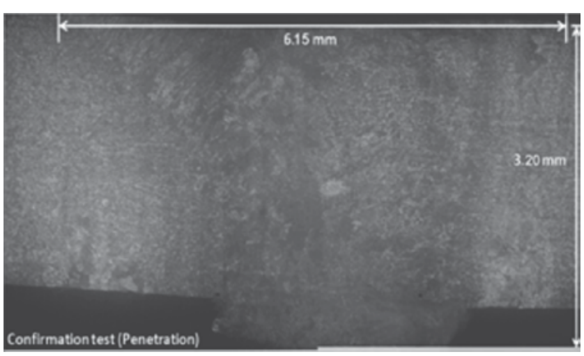


**Fig 1. Confirmation test for penetration depth**

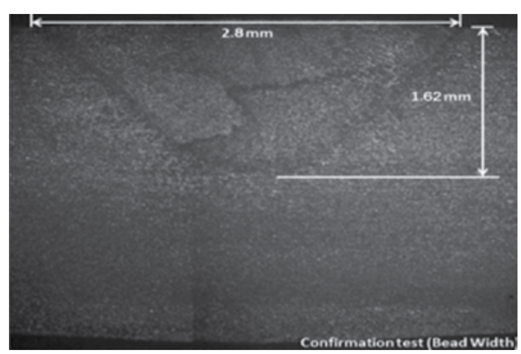


**Fig 2. Confirmation test for bead width**

**Table 2. Orthogonal L_25 table for response**

| TrialNo | A | B | C | D | E | Penetration depth (mm) | Bead Width (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 55 | 1.4 | 110 | 60 | 8 | 1.28 | 3.96 |
| 2 | 55 | 1.7 | 115 | 75 | 10 | 0.98 | 4.65 |
| 3 | 55 | 2 | 120 | 90 | 12 | 1.15 | 4.20 |
| 4 | 55 | 2.3 | 125 | 105 | 14 | 0.82 | 3.50 |
| 5 | 55 | 2.6 | 130 | 120 | 16 | 0.62 | 3.15 |
| 6 | 60 | 1.4 | 115 | 90 | 14 | 1.16 | 4.80 |
| 7 | 60 | 1.7 | 120 | 105 | 16 | 1.21 | 4.20 |
| 8 | 60 | 2 | 125 | 120 | 8 | 1.48 | 3.80 |
| 9 | 60 | 2.3 | 130 | 60 | 10 | 1.10 | 4.30 |
| 10 | 60 | 2.6 | 110 | 75 | 12 | 1.16 | 4.70 |
| 11 | 65 | 1.4 | 120 | 120 | 10 | 1.87 | 4.13 |
| 12 | 65 | 1.7 | 125 | 60 | 12 | 1.28 | 4.44 |
| 13 | 65 | 2 | 130 | 75 | 14 | 0.95 | 5.00 |
| 14 | 65 | 2.3 | 110 | 90 | 16 | 1.69 | 5.55 |
| 15 | 65 | 2.6 | 115 | 105 | 8 | 1.58 | 5.10 |
| 16 | 70 | 1.4 | 125 | 75 | 16 | 2.10 | 4.85 |
| 17 | 70 | 1.7 | 130 | 90 | 8 | 1.55 | 5.50 |
| 18 | 70 | 2 | 110 | 105 | 10 | 1.95 | 5.90 |
| 19 | 70 | 2.3 | 115 | 120 | 12 | 2.00 | 4.55 |
| 20 | 70 | 2.6 | 120 | 60 | 14 | 1.50 | 5.64 |
| 21 | 75 | 1.4 | 130 | 105 | 12 | 2.10 | 4.30 |
| 22 | 75 | 1.7 | 110 | 120 | 14 | 2.60 | 4.80 |
| 23 | 75 | 2 | 115 | 60 | 16 | 2.49 | 5.63 |
| 24 | 75 | 2.3 | 120 | 75 | 8 | 1.70 | 6.95 |
| 25 | 75 | 2.6 | 125 | 90 | 10 | 1.90 | 6.37 |

as shown in table II with their corresponding response parameters. Analysis of variance approach (ANOVA) wasapplied to find the considerablefactors[12].

To find the S/N ratio for penetration depth[13],

$$\eta_L = -10\log_{10}(1/m\sum_{j=1}^{m} 1/z_j^2) \quad (1)$$

To find the S/N ratio for bead width[14],

$$\eta_S = -10\log_{10}(1/m\sum_{j=1}^{m} z_j^2) \quad (2)$$

Where *n*is for number of replications for each experiment and for the response parameter. The obtained S/N ratio for response parameters are shown in table III.

## RESULTS AND DISCUSSION

Figure 3 and 4shows that with increase in current both the response parameters penetration depth and bead width are increased. With increase in arc length bead width is increased and penetration depth is decreased. With increase in torch speed both the response parameters are decreased. With increase in torch angle penetration depthis decreased for some interval and then further increased while bead width is increased for some interval and then decreased. With increase in shielding gas flow rate both the response parameters shows fluctuating results.Penetration depth and bead width are increased with increase in current. The increase of arc current results in the accumulation of high amount of heat in the weld zone. Similarly the heat transfer is affected with

**Table 3. Calculated S/N ratio for responses**

| Trial. No | Penetration depth S/N ratio | Bead width S/N ratio | Trial. No | Penetration depth S/N ratio | Bead width S/N ratio |
|---|---|---|---|---|---|
| 1 | 2.144 | -11.953 | 14 | 4.557 | -14.885 |
| 2 | -0.175 | -13.349 | 15 | 3.973 | -14.151 |
| 3 | 1.214 | -12.465 | 16 | 6.444 | -13.714 |
| 4 | -1.724 | -10.881 | 17 | 3.806 | -14.807 |
| 5 | -4.152 | -9.966 | 18 | 5.800 | -15.417 |
| 6 | 1.289 | -13.624 | 19 | 6.020 | -13.160 |
| 7 | 1.655 | -12.465 | 20 | 3.521 | -15.025 |
| 8 | 3.405 | -11.595 | 21 | 6.444 | -12.669 |
| 9 | 0.827 | -12.669 | 22 | 8.299 | -13.624 |
| 10 | 1.289 | -13.442 | 23 | 7.923 | -15.010 |
| 11 | 5.436 | -12.319 | 24 | 4.608 | -16.839 |
| 12 | 2.144 | -12.947 | 25 | 5.575 | -16.082 |
| 13 | -0.445 | -13.979 | | | |

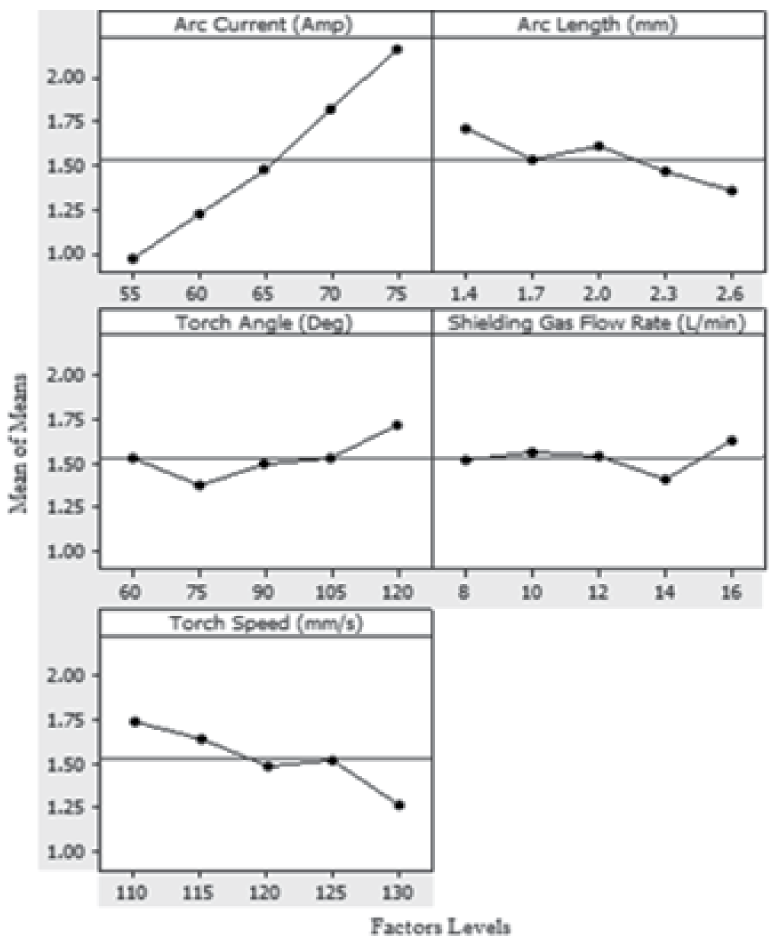


**Fig 3. Plots of effects for means of penetration depth.**

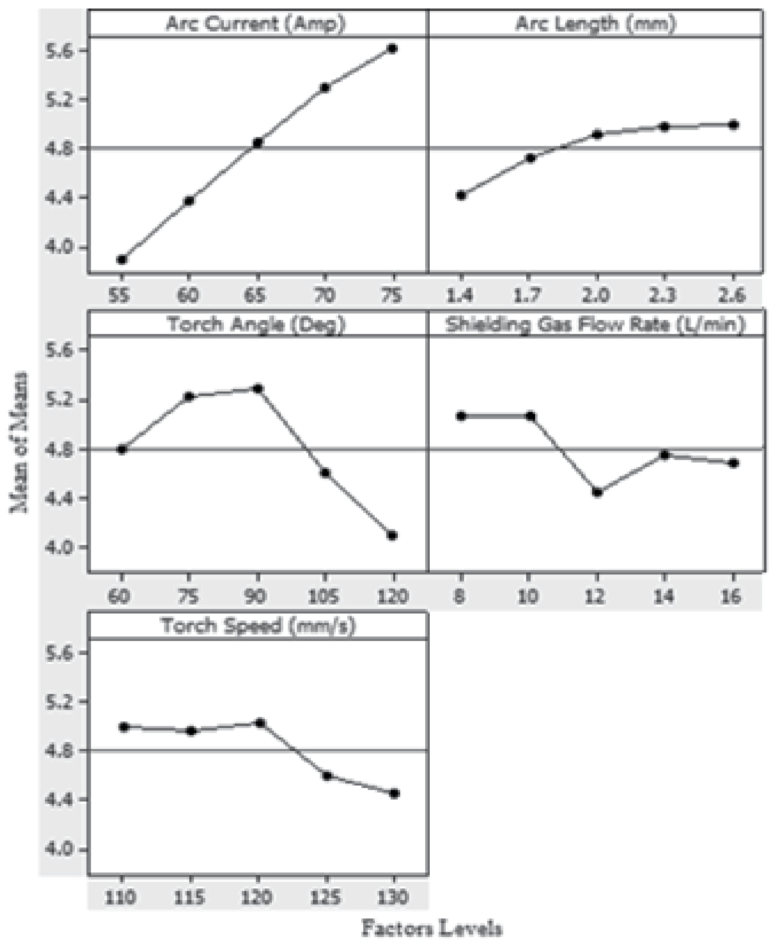


**Fig 4. Plots of effects for means of bead width.**

**Table 4. Analysis of Variance for Penetration depth (mm), using Adjusted SS for Tests**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Arc Current (Amp) | 4 | 4.4503 | 4.4503 | 1.1126 | 12.2 | 0.016 |
| Arc Length (mm) | 4 | 0.3569 | 0.3569 | 0.0892 | 0.98 | 0.508 |
| Torch Speed (mm/s) | 4 | 0.6393 | 0.6393 | 0.1598 | 1.75 | 0.300 |
| Torch Angle (Deg) | 4 | 0.2927 | 0.2927 | 0.0732 | 0.8 | 0.581 |
| Shielding Gas Flow Rate (Ltr./min) | 4 | 0.1247 | 0.1247 | 0.0311 | 0.34 | 0.838 |
| Error | 4 | 0.3643 | 0.3643 | 0.0910 | | |
| Total | 4 | 6.2284 | | | | |

**Table 5. Analysis of Variance for Bead Width (mm), using Adjusted SS for Tests**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Arc Current (Amp) | 4 | 9.5712 | 9.5712 | 2.3928 | 19.9 | 0.007 |
| Arc Length (mm) | 4 | 1.1869 | 1.1869 | 0.2967 | 2.47 | 0.201 |
| Torch Speed (mm/s) | 4 | 1.3519 | 1.3519 | 0.3380 | 2.81 | 0.170 |
| Torch Angle (Deg) | 4 | 4.8449 | 4.8449 | 1.2112 | 10.1 | 0.023 |
| Shielding Gas Flow Rate (Ltr./min) | 4 | 1.4533 | 1.4533 | 0.3633 | 3.03 | 0.154 |
| Error | 4 | 0.4803 | 0.4803 | 0.1201 | | |
| Total | 4 | 18.888 | | | | |

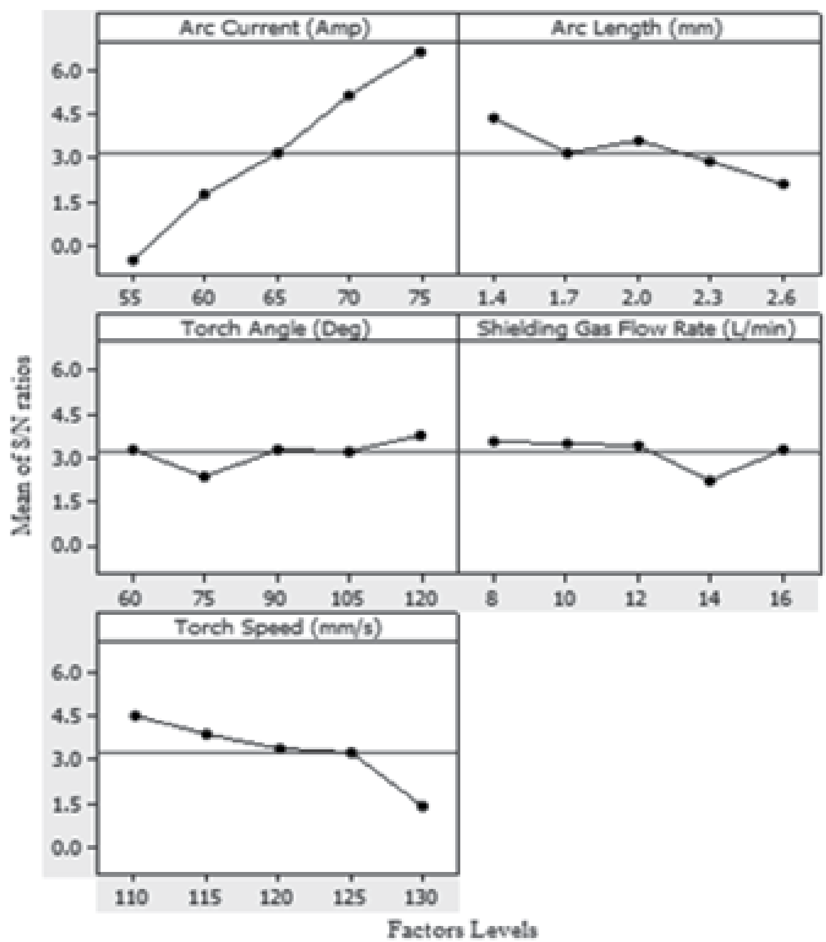


**Fig 5. Plots of effects for S/N ratios of penetration depth**

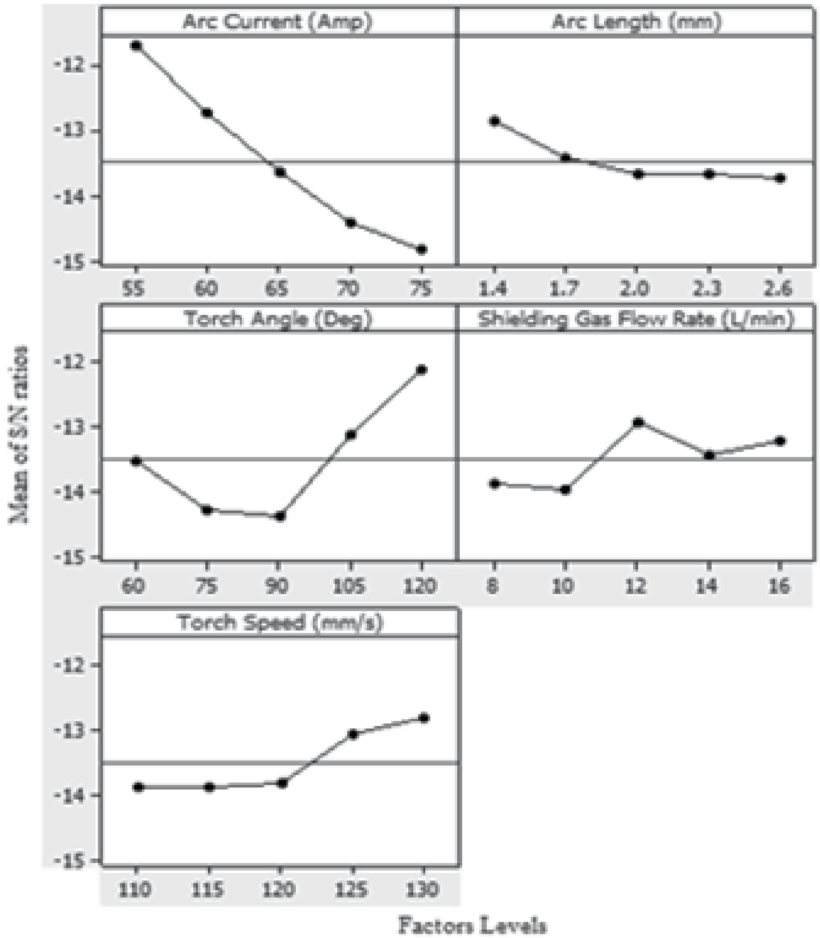


**Fig 6. Plots of effects for S/N ratios of bead width.**

the increase of torch speed, which results in the decrease of penetration depth and bead width. This inference is in conformity with earlier study[14]. ANOVA results show that arc current is the significant factor for penetration depth and for bead width arc current and Torch angle are the significant factorswith a p-value less than 0.05 as shown in table IV and V respectively.Same results have been reported in earlier studyin[15]. The optimum values for penetration depth with the highest S/N ratio by Taguchi method, arc current 55Amp, arc length 1.4mm, torch speed 110 mm/s, torch angle 120$^o$ and shielding gas flow rate of 8Ltr./min as shown in figure 5.

The optimum values for bead width with the highest S/N ratio by Taguchi method, arc current 55Amp, arc length 1.4mm, torch speed 130 mm/s, torch angle 120$^o$ and shielding gas flow rate of 12 Ltr./min as shown in figure 6.

**Confirmation test**

Confirmation test was conducted to validate the obtained optimal results. Therefore confirmation tests for the response parameters penetration depth and bead width conducted with its optimal process parameters. The optimal process parameters predicted S/N ratio obtainedfrom Eq. (3)[16] is 9.948 for penetration depth and -8.542 for bead width.

$$\eta = \eta_k + \sum_{p=1}^{q} \left( \eta_p - \eta_k \right) \tag{3}$$

Where is the predicted S/N ratio, is the 'total mean' of S/N ratio, is the 'mean' of S/N ratio at optimum level and q the number of control factors. Confirmation test experiments values at the optimal settings parameters for the response parameters penetration depth is 3.20mm and for bead width is 2.80mm and their S/N ratios are 10.102 and -8.299 respectively. The S/N ratio values of confirmation tests are improved by 1.5% for penetration depth and 2.9% for bead width.

## CONCLUSION

In this study, five factors with five levels for GTAW have been selected for the experiments. Taguchi L25 orthogonal array has been applied to optimize the response parameters penetration depth and bead width for GTAW process. Optimal parameters have been found for each response parameter. It is found that arc current is the most significant for both the response parameters penetration depth and bead width while torch angle is significant only for bead width. The predicted results were verified through confirmation test and it showed a better agreement among the measured and predicted results.

## REFERENCES


1. *Marlow, Frank, M., 2012, "Welding Know-How: Tips & Techniques for Master Welders", Metal Arts Press, First Edition.*

2. *Zhao, Y., Yang, Q., Huang, J., Zou, J. and Wu, Y., 2016. Droplet transfer and weld geometry in laser welding with filling wire. The International Journal of Advanced Manufacturing Technology, pp.1-9.*

3. *Giridharan, P.K., and Murugan, N., 2009, "Optimization of pulsed GTA welding process parameters for the welding of AISI 304L stainless steel sheets", International Journal of Advanced Manufacturing Technology, Vol. 40, pp. 478–489*

4. *Juang, S.C. and Tarng, Y.S., 2002, "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*

5. *UgurEsme, MelihBayramoglu, YugutKazancoglu and SuedaOzgun, 2009, "Optimization of weld bead geometry in TIG welding process using grey relational analysis and Taguchi method", Materials and technology, Vol. 43, Issue 3, pp. 143–149*

6. *Tarng, Y. S., & Yang, W. H., 1998, "Optimisation of the weld bead geometry in gas tungsten arc welding by the Taguchi method", Intl. Journal of AdvManufTechnol, Vol. 14, pp. 549-554*

7. *Bharath. P, V.G. Sridhar & Senthilkumar, M., 2014, Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique, Procedia Engineering, Vol. 97, pp. 881 – 891*

8. *Yousefieh, M., M. Shamanian, and Arghavan, A.R., 2012, "Analysis of Design of Experiments Methodology for Optimization of Pulsed Current GTAW Process Parameters for Ultimate Tensile Strength of UNS S32760 Welds", Metallogr. Microstruct. Anal., Vol. 1, pp. 85–91*

9. *Kumar, A. & Sundarrajan, S., 2009, "Optimization of pulsed TIG welding process parameters on mechanical properties of AA 5456 Aluminum alloy weldments", Materials and Design, Vol. 30, pp. 1288–1297*

10. *Manikandan M, NageswaraRao M, Ramanujam R, DevendranathRamkumar, Arivazhagan N & Reddy G.M, 2014, "Optimization of the Pulsed Current Gas Tungsten Arc Welding Process Parameters for alloy C-276 using the Taguchi Method", Procedia Engineering, Vol. 97, pp. 767 – 774*

11. *Wang Ji-Min, Hong-Jie Yan, Jie-Min Zhou, Shi-Xuan Li and Guang-Chen Gui,2012, "Optimization of parameters for an aluminum melting furnace using the Taguchi approach", Applied Thermal Engineering, Vol. 33-34, pp. 33-43.*

12. *AykutCanakci, FatihErdemir, TemelVarol and Adnan Patir, 2013, "Determining the effect of process parameters on particle size in mechanical milling using the Taguchi method: Measurement and analysis", Measurement, Vol. 46, pp. 3532–3540*

13. *George Box, 1988, "Signal-to-noise ratios, performance criteria and transformations", Technometrics, Vol. 30 No. 1, pp. 1-17.*

14. *Sudhakaran R., VeLMurugan V., Senthil Kumar K. M., Jayaram R., Pushparaj A., Praveen C. &VenkatPrabhu N., 2011, "Effect of Welding Process Parameters on Weld Bead Geometry and*

*Optimization of Process Parameters to Maximize Depth to Width Ratio for Stainless Steel Gas Tungsten Arc Welded Plates Using Genetic Algorithm", European Journal of Scientific Research, Vol.62 No.1, pp. 76-94*

15. *Mohamed Abu Aesh, 2001, "Optimization of weld bead dimensions in GTAW of Aluminum–Magnesium alloy", Materials & Manufacturing processes, Vol. 16, pp. 725–736*

16. *Romoli, L. and Vallini, R., 2016. Experimental study on the development of a micro-drilling cycle using ultrashort laser pulses. Optics and Lasers in Engineering, 78, pp.121-131.*