Experimental Investigation of Combined TIG-MIG Welding for 304 Stainless Steel Plates

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Abstract. The current research work is based on combine effect of TIG & MIG welding to achieve desirable mechanical properties. The stainless steel 304L plates were selected for welding. Current, Voltage and gas flow rate were taken as input parameters to study the response (hardness and width of weld bead). The experiments were conducted with the help of a full factorial design. The increase in gas flow rate decreases the hardness of the weld bead as well as increases the bead width to some extent. Non-dominated Sorting Genetic Algorithm was used to optimize the responses. Sixteen non-dominated solutions were obtained. The welding current, voltage and gas flow rate should be maintained at approximately 200A, 24V and 15-17 l/min respectively for the best hardness and bead width value.

Keywords: TIG-MIG Welding, Hardness, Weld bead width, Current, Voltage, Gas flow rate

1. Introduction
Welding is widely used due to its high productivity and relatively low cost in the manufacturing industry. MIG welding has high efficiency while the TIG welding has high quality of weld. The combined TIG-MIG welding has high efficiency as well as high quality of weld. This also enhances toughness of weld metal at lower cost. The strength can be improved by combined TIG-MIG welding, which is an important approach in the fabrication industry. The study of Tusek (1996) and Lucas (1997) proposed that in a high-speed MIG/MAG welding instability like spatter and weld bead roughness was present. Moreover, the defect like undercut was easily found. Further study of Meng et al. (2014) revealed that proper distance between MIG and TIG torch should always be maintained in case of hybrid TIG-MIG welding of mild steel.

Quite a few modifications in the fabrication technique were proposed by earlier researchers to achieve better strength and productivity. It was found by Eboo (1979) that a laser beam stabilizes the welding current and arc voltage. It also reduces the arc column resistance and helps to reduce the depth to width ratio of the weld in the laser-MIG hybrid welding process. Choi et al. (2006) were utilized a hybrid laser and GMAW process to control the weld bead hump formation. It was observed that the bead humping could be suppressed by sufficient laser heat input. Roepke et al. (2010) were studied the effect of laser power, arc power and laser arc separation on microstructure in hybrid laser arc welding.
Acicular ferrite was formed in weld metal microstructure with rise in arc power and laser arc separation. Huang and Zhang (2010) demonstrated a laser enhanced GMAW process. It was tried to generate detaching force and produce spray transfer at continuous welding current. Ding et al. (2015) focused on TIG–MIG hybrid welding of magnesium alloys and ferritic stainless steels having a Cu interlayer of different thickness. They proposed that joining ferritic stainless steel and magnesium alloys is economic and helps to reduce the weight of automobiles. Moreover, increase in Cu. Interlayer increases the tensile strength. Bunaziv et al. (2016) focused on Fiber laser-MIG hybrid welding of aluminium alloys. According to them, using argon as a shielding gas gives the better tensile strength of the weld as compared to a mixture of helium and argon. Moreover with trailing MIG torch set-up in hybrid plasma-MIG welding, partial penetration was achieved resulting in poor weld strength. Chen et al. (2014) developed an improved model of the heat source for the hybrid TIG-MIG welding process. Hosseini et al. (2016) focused on the nitrogen loss and its effects on the microstructure of a duplex stainless steel in multipass TIG welding. It was revealed that there was a decrement in nitrogen content 0.28 wt% to 0.17 wt% and 0.10wt% after four respective passes for the low and high input welds.

In the past three decades, a number of innovative suggestions were given by researchers. Chen et al. (2014) suggested to further analyse the interaction of the two arcs during TIG-MIG hybrid welding. The combined TIG-MIG welding is a process that gives us good strength and better productivity. But the process is a bit difficult to control. At the same time, welders find it difficult to hold two torches. Therefore, a slightly different process has been developed to achieve the feasibility as well as productivity without sacrificing the strength of the welded sample. The root was welded by using TIG welding to achieve better control and strength. Another pass of welding was done using MIG welding to achieve better productivity. From the above literature review, it was evident that less concentration was given on welding thicker plates. Therefore, it was decided to conduct the experiment on 10mm thick stainless steel plate. The design of experiment (DOE) was conducted for the optimization of the input parameters. Hardness and strength of the welded samples were tested.

2. Experimentation
2.1. Materials and Consumables
The research work was carried out on 304L stainless steel plates of 10mm thickness for welding. The test workpiece were cut using plasma cutting into sizes 60mm×50mm as shown below in figure 1. The filler wire should have nearly similar chemical composition for 304L stainless steel. Filler wire of 308L was selected to provide sufficient filling during welding.

![Plasma cutting of the stainless steel plate](image1)

![Rockwell Hardness Testing Machine](image2)

![Plates with 60˚ V-groove](image3)

![Welded plates after the root welding](image4)
2.2. Measurement of Responses
Hardness of weld bead was measured with the help of a Rockwell Hardness Testing Machine as shown in figure 2. Vernier Caliper was used to measure bead width. It is measured in mm.

2.3. Welding Set-up
MIG welding was done by using Auto K-400 thyristorised MIG/MAG power source manufactured by Esab India Limited while the power source manufactured by Technology Promoters Pvt. Limited was utilized for TIG welding. A wire feed unit was also used to feed the filler wire at a constant rate.

2.4. Experimental Procedure
The plates to be welded needs to be clamped properly so that the welding can be performed properly and effectively. To achieve the welding effectively 60° V-grooves were made on the plates prior to welding as shown below in figure 3. The combined TIG-MIG welding is a process in which the specimens were welded in at least two passes. The root was welded by using TIG welding in this research work. Figure 4 shows the welded plates after the first pass of TIG welding. After the root welding, another pass of welding was done by using GMAW process. Top surface of the weld was ground prior to MIG welding to remove oxides and dust particles which may hinder a good quality weld. Finally another pass of welding was done by using MIG welding. The welded samples are shown below in figure 5.

![Figure 5: Stainless steel plates after the welding](image)

2.5. Design of Experiment
There are many input parameters in welding. Three important welding parameters like current, voltage & gas flow rate were selected for analysis. The study is mainly based on hardness (H) and bead width (B). Three input factors (P) & three levels (L) of machining parameters were chosen in this study. Twenty seven ($L^P=3^3=27$) experiments were conducted with the help of full factorial design. The welding parameters and their levels are shown in Table 1. Table 2 shows the design matrix along with observations.

| Welding Parameters | Symbol | Unit       | Levels          |
|--------------------|--------|------------|-----------------|
| Current            | C      | Ampere     | 140 170 200     |
| Voltage            | V      | Volt       | 18 21 24        |
| Gas flow rate      | G      | litre/minute | 15 20 25       |
Table 2: Design matrix along with observations

| S. No. | Current, C (ampere) | Voltage, V (volt) | Gas flow rate, G (litre/minute) | hardness, H (C scale) | Bead Width, B (mm.) |
|--------|---------------------|------------------|---------------------------------|------------------------|---------------------|
| 1      | 140                 | 18               | 15                              | 98.33                  | 11.080              |
| 2      | 140                 | 18               | 20                              | 97.00                  | 12.030              |
| 3      | 140                 | 18               | 25                              | 96.33                  | 14.360              |
| 4      | 140                 | 21               | 15                              | 98.00                  | 13.220              |
| 5      | 140                 | 21               | 20                              | 98.00                  | 13.560              |
| 6      | 140                 | 21               | 25                              | 97.00                  | 14.500              |
| 7      | 140                 | 24               | 15                              | 91.66                  | 13.988              |
| 8      | 140                 | 24               | 20                              | 93.00                  | 14.780              |
| 9      | 140                 | 24               | 25                              | 95.00                  | 14.880              |
| 10     | 170                 | 18               | 15                              | 93.00                  | 12.580              |
| 11     | 170                 | 18               | 20                              | 90.00                  | 12.912              |
| 12     | 170                 | 18               | 25                              | 88.00                  | 13.750              |
| 13     | 170                 | 21               | 15                              | 98.00                  | 13.540              |
| 14     | 170                 | 21               | 20                              | 94.00                  | 15.600              |
| 15     | 170                 | 21               | 25                              | 95.00                  | 14.220              |
| 16     | 170                 | 24               | 15                              | 97.00                  | 15.260              |
| 17     | 170                 | 24               | 20                              | 95.00                  | 15.390              |
| 18     | 170                 | 24               | 25                              | 96.33                  | 14.500              |
| 19     | 200                 | 18               | 15                              | 93.00                  | 14.030              |
| 20     | 200                 | 18               | 20                              | 83.00                  | 14.040              |
| 21     | 200                 | 18               | 25                              | 81.00                  | 13.700              |
| 22     | 200                 | 21               | 15                              | 93.33                  | 14.420              |
| 23     | 200                 | 21               | 20                              | 95.66                  | 16.200              |
| 24     | 200                 | 21               | 25                              | 86.00                  | 15.452              |
| 25     | 200                 | 24               | 15                              | 98.00                  | 16.700              |
| 26     | 200                 | 24               | 20                              | 97.50                  | 17.260              |
| 27     | 200                 | 24               | 25                              | 95.50                  | 16.200              |

3. Result and Discussion

Figure 6: Main effect plot for Hardness, H

Figure 7: Main effect plot for Bead Width, B

Figure 6 shows the variation of weld bead hardness with current, voltage and gas flow rate. It was observed that the weld bead hardness decreased with increase in current and gas flow rate. The grain refinement takes place with rise in current. It was observed that too much of gas flow rate causes turbulence and hinders a quality weld. The hardness was increased up to certain limit and then it was decreased with rise in voltage.
Figure 7 shows the main effect plot of weld bead width with current, voltage and gas flow rate. The bead width increases with increase in current and voltage. The heat input and metal deposition rate increases with rise in current. The arc length increases with rise in voltage. But, it increases first and then decreases with rise in gas flow rate.

4. Optimization of Responses

Minitab software was used for the analysis of experimental data. Two quadratic equations were obtained using response surface methodology separately. The final response equations 1 and 2 for Bead Width (B) and Hardness (H) are as follows:

\[
B = -21.3 - 0.0585C + 1.56V + 1.731G + 0.000302C^2 - 0.0246V^2 - 0.01592G^2 + 0.00205CV^2 - 0.0249V^2G + 0.000202C^2G - 0.0249V^2G
\]  

\[
H = 163.2 - 0.612C - 0.52V - 0.85G - 0.00330C^2 - 0.1934V^2 + 0.0092G^2 + 0.04259CV - 0.01232CG + 0.1065VG
\]  

Figure 8: Pareto-optimal front for objectives Bead Width and Hardness

| S. No. | C       | V          | G          | B         | H         |
|-------|---------|------------|------------|-----------|-----------|
| 1     | 199.9997| 23.999829  | 15.000171  | 16.84934 | 98.85346  |
| 2     | 199.9996| 23.999813  | 17.272298  | 16.93028 | 97.80575  |
| 3     | 199.9996| 23.999813  | 17.272298  | 16.93028 | 97.80575  |
| 4     | 199.9997| 23.999829  | 15.000171  | 16.84934 | 98.85346  |
| 5     | 199.9998| 23.999503  | 15.416109  | 16.87626 | 98.65437  |
| 6     | 199.9999| 23.99973   | 15.068961  | 16.85416 | 98.82031  |
| 7     | 199.9998| 23.999356  | 16.697146  | 16.92515 | 98.06174  |
| 8     | 199.9955| 23.999724  | 15.580319  | 16.88556 | 98.57684  |
| 9     | 199.9924| 23.999028  | 15.373975  | 16.87315 | 98.67365  |
| 10    | 199.9996| 23.999824  | 17.170076  | 16.93017 | 97.85085  |
| 11    | 199.9947| 23.998909  | 16.830501  | 16.92676 | 98.0012   |
| 12    | 199.9985| 23.999479  | 16.226797  | 16.91323 | 98.27579  |
| 13    | 199.9919| 23.999572  | 16.028704  | 16.90619 | 98.36725  |
| 14    | 199.9926| 23.997908  | 16.388688  | 16.91714 | 98.20047  |
| 15    | 199.9687| 23.997834  | 16.525357  | 16.92086 | 98.13852  |
| 16    | 199.9992| 23.999606  | 17.021494  | 16.92934 | 97.91662  |
Matlab software was used for multi-objective optimization with the help of Non-dominated Sorting Genetic Algorithm (NSGA). The objective functions are given below.

Objective 1= -Bead Width (B)

Objective 2= -Hardness (H)

Figure 8 shows the pareto-optimal solution front. The choice of one solution over the other depends on the requirement of the process engineer. Ranking and sorting of solutions have been done in the NSGA-II algorithm. 16 non-dominated solutions were obtained. Table 3 represents Pareto-optimal solution set and corresponding variable settings.

5. Conclusions
Combined TIG-MIG welding process was applied to weld 304L10mm thick stainless steel plates. Increase in gas flow rate decreases the hardness of the weld bead. But, the increase in gas flow rate increases the bead width to some extent. It has also been found experimentally that too much of gas flow rate causes turbulence and hinders a quality weld. For the best Hardness and bead width value, the welding current and voltage should be maintained at approximately 200A and 24V respectively. The gas flow rate can be kept in the range of 15-17 l/min.

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