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# PARAMETRIC OPTIMIZATION OF WELDING PROCESS OF LOW CARBON STEEL (AISI 1019) BY USING TAGUCHI'S APPROACH

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***Abstract*: Generally, there is a lack of comparative study regarding the performance of the optimization methods, in other words for a given optimization problem which method would suit better. Literature survey reveals that Taguchi approach is the best suited to improve mechanical properties of weldment, therefore Taguchi approach is selected to optimize the welding parameters for MIG and TIG welding of low carbon steel (AISI 1019). The main aim of the project work is to obtain an optimal value of MIG and TIG welding process parameters (such as voltage, current, and welding speed for MIG welding and Peak current, base current, pulse frequency for TIG welding) resulting in an optimal value of notch tensile strength, impact toughness and hardness when welding low carbon steel (AISI 1019) sheet of 3.15 mm and less than 3 mm thickness. The Fractional factorial experimentation approach was used to study the impact of welding parameters on the notch tensile strength, impact toughness and hardness of the weldment. An estimate of mean of the optimum values with confidence interval of 90% was calculated for notch tensile strength, impact toughness and hardness. These results were confirmed by further experiments with three repetitions for notch tensile strength, impact toughness and hardness. The results indicate that the selected process parameters significantly affect the welding characteristics. The future scope of this project can be analyse and compare the parameters with the existing conditions and the predicted conditions and can be preceded for other types of welding. This literature survey shows the correlation between the input parameters and the output variables, and also presents the optimization of the different welding processes through the mathematical models.**

***Keywords:* Low carbon steel AISI 1019, ANOVA, Regression analysis, S/N ratios, MINITAB software.**

## I. LITERATURE REVIEW

The gas metal arc welding is increasingly employed for fabrication in many industries. The process is versatile, since it can be applied for all position welding; it can be easily automated and can easily be integrated into the robotized production centers, since for each welding condition (base material, electrode material and diameter, shielding gas type, etc.) there is an optimum parameter combination. Also, robotics and automated applications are demanding greater consistency from the welding process, which in turn necessitates more insights into the effects that operating parameters have on weld bead shapes and extent of fusion. Taking the above facts into consideration, Palani and Murugan [1] have reviewed the various aspects of parameters and their selection to obtain good quality welds and concluded that only a very few had used design of experiments to carry out their experiments for selecting the parameters and to study their effect on weld metal properties.

Ganjigatti et al. [13] have investigated to establish relationships between the process parameters and responses for 'bead-on-plate'-type MIG welding process using the statistical regression analysis carried out on the data collected as per full-factorial design of experiments (DOE). The chosen input parameters in this study are as follows: welding speed, welding voltage, wire feed rate, gas flow rate, nozzle-to-plate distance, torch angle, and the responses considered are: bead height, bead width, and penetration. Two levels are considered for each of the six input process parameters, so that $2^6 = 64$ combinations of input process parameters are considered for full-factorial DOE.

## II. PROJECT OBJECTIVE

Industries are fabricating compressor tanks and petroleum valve parts using low carbon steel (AISI 1019) sheet of 3.15 mm thickness. At present, in some small scale industries, MIG and TIG welding parameters are set to the approximate values based on worker experience (not exact values of voltage, current, and welding speed for MIG welding and peak current, base current, pulse frequency for TIG welding), and it was also found that proper joint spacing and distance from nozzle to work piece parameters is not maintained during welding process.

Fig.1. Compressor Tank

  

Fig.2. Petroleum Valve Part

Figure 1 and 2 shows the compressor tank and a petroleum valve part where maximum defect occurs due to variations of welding parameters. By this project, optimization of welding parameters can be predicted so that the welding strength, hardness, life of welding can be increased.

## III. PROBLEM IDENTIFICATION AND METHODOLOGY

This section describes the methodology behind the work and is as follows. Initially experiments are designed and conducted as planned. Taguchi's approach is used to design the experiments. Analysis of variance is used to calculate the percentage contribution of each parameter and means analysis is used to optimize the parameters. Regression analysis is used to express notch tensile strength, toughness and harness in terms of the process parameter. Finally the confirmation experiments are conducted to make sure that the optimized levels of each parameters result in the optimum value of welding characteristics (response).

Fig.3. Existing condition specimen

Figure 3 shows the existing condition of the work piece where the defect of welding (crack formation) can be seen clearly from the front side and backside view of the specimen.

## IV. SELECTION OF CONTROL FACTORS

The control factors can be identified using different tools. One of those is cause and effect diagram provided by Ishikawa. The C-E diagram to obtain quality parts in welding is constructed.

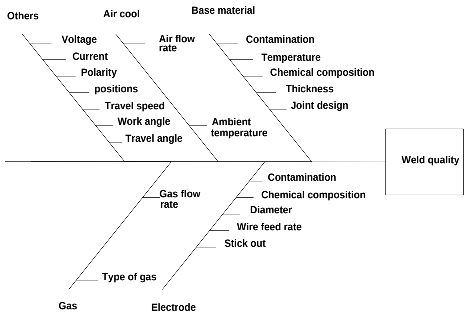


Fig.4. Ishikawa cause-effect diagram for welding process

Figure 4 shows the various welding parameters affecting the quality, hardness and strength of welding. From Ishikawa cause –effect diagram the various process parameters has been selected to increase the hardness, strength and quality of welding.

| Welding | Factors | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| MIG | Voltage (A) | Volt | 18 | 22 | 26 |
| | Current (B) | Amps | 75 | 105 | 135 |
| | Welding speed (C) | mm/ min. | 250 | 330 | 410 |
| TIG | Peak current(D) | Amps | 180 | 190 | 200 |
| | Base current(E) | Amps | 60 | 65 | 72 |
| | Welding speed(F) | mm/ min. | 120 | 140 | 150 |
| | Pulse frequency (G) | Hz | 2 | 4 | 6 |

Table.1. Working range of the process parameters for MIG and TIG welding

Table 1 shows the working range of the selected process parameters for MIG welding and TIG welding. In MIG welding the factors like Voltage, Current, Welding speed has been selected and In TIG welding the factors like Peak current, Base current, Welding speed has been selected.

| Welding | S.No | Process parameters | Existing welding parameters |
|---|---|---|---|
| MIG | 1 | Electrode used : ER70S-6 | ER70S-6R |
| | 2 | Filler rod diameter : 0.8 mm | 0.95mm |
| | 3 | Position : Flat | Flat |
| | 4 | Stick out | 24mm |

  

| | | | |
|---|---|---|---|
| | | : 14 mm | |
| | 5 | Gas flow rate : 10 lpm | 12lpm |
| | 6 | Joint spacing : 1.58 mm | 2.05mm |
| TIG | 7 | Shielding gas flow rate :10 lpm | 10lpm |
| | 8 | Purging gas flow rate :5 lpm | 5.02lpm |
| | 9 | Filler rod diameter : 3.15 mm | 3.25mm |

Table.2. Constant process parameters for MIG and TIG welding

Table 2 shows the Constant process parameters for MIG and TIG welding like selection of electrode, filler rod, and position of welding, gas flow rate, and material used for filler rod and electrode.

## V. SELECTION OF ORTHOGONAL ARRAY

In the present investigation, the Taguchi method was employed to optimize the process parameters for maximizing the mechanical properties. The number of process parameters considered under this study is three, and the level of each parameter is three. The degrees of freedom of all the three parameters are seven and interactions were not considered. Hence, L9 orthogonal array is selected. Each condition of the experiment was repeated twice to reduce the noise/error effects. The detail of the selected orthogonal array is presented in table 3.

| Experiment 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 |
| | | | |

Table.3. L9 orthogonal array for MIG welding and TIG welding

Table 3 shows the L9 orthogonal array selection and the number of experiments conducted for MIG welding and TIG welding.

## VI. BASE MATERIAL AND ELECTRODE MATERIAL FOR WELDING

Base material: Low carbon steel (AISI 1019)
Electrode material: Copper coated mild steel
Diameter of electrode: 0.8 mm
Electrode grade: ER70S-6
Size of base material: 250mmx150mmx3.15mm

## VII. EXPERIMENTAL PROCEDURE

The base metal sheets of dimension 250×150×3.15 mm have been prepared and butt joints were made using the experimental layout.

The weld joint is completed in a single pass. Specimens for tensile testing (both plain and notched specimens) were taken at the middle of all the joints and machined to ASTM E8 standards [10].Tensile test was conducted using a universal testing machine and the properties related to the base metal are obtained but not the weld metal. Hence, notch tensile test is conducted to reveal the weld metal properties. The specimen for impact test was made as per ASTM A370 standards [10] and the test was conducted on a Charpy impact test machine. Specimens for hardness tests were taken at the middle of all the joints. Hardness tests were carried out on the welded samples with a load of 100Kgf using a Rockwell hardness tester (table 4). The quality characteristics, i.e. notch tensile strength, impact toughness and hardness of the weldment were evaluated for all the trials and then statistical analysis of variance (ANOVA) was carried out. Based on the ANOVA, the contribution of each process parameter influencing the quality characteristic was evaluated.

Fig.5. Plain tensile test specimen - Fails at base metal

Figure 5 shows the testing specimen where the specimen frequently fails. The front side view is shown .The crack formation of the specimen can be clearly seen from the front view.

| Scale | Indenter | Load (kgf) | Applications |
|---|---|---|---|
| B | 1/16" ball | 100 | Aluminum alloys, Copper alloy, Unhardened steel etc., In rolled, Dracan, Extruded (or) cast metal. |

Table. 4. Scale selection table for Rockwell hardness

Table 4 indicates the selection of scale type for testing process in welding. Here B scale is selected because the maximum load applied for welding process is 100 kgf. So B scale has been selected

  

| Welding | Notch tensile strength (MPa) | | | Impact toughness (J) | | | Hardness (HRB) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Trial 1** | **Trial 2** | **Average** | **Trial 1** | **Trial 2** | **Average** | **Trial 1** | **Trial 2** | **Average** |
| MIG | 365 | 368 | 366.5 | 40 | 41 | 40.5 | 83 | 81 | 82 |
| TIG | 417 | 432 | 424.5 | 82.5 | 76.2 | 79.35 | 87 | 85 | 86 |

Table. 5. Mechanical properties of low carbon steel (AISI 1019) welds as per existing welding parameter

From the table 5 ,the existing parameters of the welding and the notch tensile strength, impact toughness, hardness of low carbon steel (AISI 1019) has been calculated and shown.

## VIII. EXPERIMENTAL SETUP

Gas Tungsten Arc Welding (GTAW) is frequently referred to as TIG welding. TIG welding is a commonly used high quality welding process. TIG welding has become a popular choice of welding processes when high quality, precision welding is required.


**(i)**

**(ii)**

**(iii)**

Fig.6. TIG welding equipment

From the figure 6 (i), (ii), (iii) shows TIG welding equipment where an arc is formed between a non-consumable tungsten electrode and the metal being welded. Gas is fed through the torch to shield the electrode and molten weld pool. If filler wire is used, it is added to the weld pool separately.

Fig.7. Tensile test specimen (GTAW)

Figure 7 shows the testing specimen before welding. The specimen is cut and kept for GTAW welding process.To perform gas metal arc welding, the basic necessary equipment is a welding gun, a wire feed unit, a welding power supply, an electrode wire, and a shielding gas supply.

Fig.8. MIG welding equipment showing welding gun and wire feed unit

Figure 8 shows the wire feed unit supplies the electrode to the work, driving it through the conduct and on to the contact tip. Most models provide the wire at a constant feed rate, but more advanced machines can vary the feed rate in response to the arc length and voltage. Some wire feeders can reach feed rates as high as 30.5 m/min (1200 in/min), but feed rates for semiautomatic GMAW typically range from 2 to 10 m/min (75–400 in/min).

Fig.9. Tensile test specimen (GMAW)

Figure 9 shows the testing specimen before welding. The specimen is cut and kept for GMAW welding process.

## IX. RESULTS AND DISCUSSION

The optimization of process parameters using the Taguchi method permits evaluation of the effects of individual parameters independent of other parameters on the identified quality characteristics, i.e., notch tensile strength (NTS), impact toughness and hardness.

Table 6 shows the welding process had been carried out based on the selection of OAs and as per the design of experimentation process. For MIG and TIG welding process for the different levels the different experiments had been carried out and the results were tabulated as per DOE. The notch tensile strength, Impact toughness and hardness had been calculated for the welded specimen. The average of values had been listed for each welding process.

  

| **Welding** | **Specimen ID** | **Notch tensile strength (MPa)** | | | **Impact toughness (J)** | | | **Hardness (HRB)** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Trial 1** | **Trial 2** | **Average** | **Trial 1** | **Trial 2** | **Average** | **Trial 1** | **Trial 2** | **Average** |
| MIG | S1 | 209 | 217 | 213 | 37 | 39 | 38 | 68 | 72 | 70 |
| TIG | S1 | 254 | 266 | 260 | 42 | 48 | 45 | 78 | 82 | 80 |
| MIG | S2 | 260 | 256 | 258 | 39 | 40 | 39.5 | 85 | 83 | 84 |
| TIG | S2 | 269 | 272 | 270.5 | 43 | 48 | 45.5 | 86 | 92 | 89 |
| MIG | S3 | 308 | 296 | 302 | 43 | 41 | 42 | 91 | 93 | 92 |
| TIG | S3 | 298 | 309 | 303.5 | 52 | 53 | 52.5 | 95 | 96 | 95.5 |
| MIG | S4 | 266 | 268 | 267 | 38 | 40 | 39 | 95 | 93 | 94 |
| TIG | S4 | 312 | 322 | 317 | 46 | 51 | 48.5 | 98 | 94 | 96 |
| MIG | S5 | 320 | 318 | 319 | 44 | 42 | 43 | 86 | 86 | 86 |
| TIG | S5 | 385 | 388 | 386.5 | 40 | 52 | 46 | 92 | 89 | 90.5 |
| MIG | S6 | 369 | 373 | 371 | 40 | 42 | 41 | 83 | 79 | 81 |
| TIG | S6 | 394 | 398 | 396 | 52 | 59 | 55.5 | 96 | 91 | 93.5 |
| MIG | S7 | 309 | 327 | 318 | 39 | 41 | 40 | 85 | 89 | 87 |
| TIG | S7 | 382 | 385 | 383.5 | 43 | 45 | 44 | 89 | 90 | 89.5 |
| MIG | S8 | 379 | 375 | 377 | 41 | 40 | 40.5 | 79 | 81 | 80 |
| TIG | S8 | 398 | 390 | 394 | 51 | 49 | 50 | 91 | 94 | 92.5 |
| MIG | S9 | 408 | 416 | 412 | 42 | 42 | 42 | 90 | 88 | 89 |
| TIG | S9 | 452 | 448 | 450 | 50 | 48 | 49 | 95 | 92 | 93.5 |

Table.6. Mechanical properties of low carbon steel (AISI 1019) welds as per DOE for MIG and TIG welding

| **Factor** | **DOF** | **Sum of squares** | **Mean squares** | **F cal.** | **F t.** | **Inference** | **Percent contribution** |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 18656.56 | 9328.28 | 9923.70 | 9 | Significant | 57.32 % |
| Current | 2 | 13762.89 | 6881.45 | 7320.69 | 9 | Significant | 42.28 % |
| Welding speed | 2 | 118.23 | 59.11 | 62.88 | 9 | Significant | 0.35% |
| Error | 2 | 1.88 | 0.94 | - | - | - | - |
| Total | 8 | 32539.56 | - | - | - | - | - |

Table.7. ANOVA table for notch tensile strength for MIG welding

F cal.: Calculated F value
Ft.: Table F value

Table 7 shows the ANOVA table for notch tensile strength for MIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

| **Factor** | **DOF** | **Sum of squares** | **Mean squares** | **F cal.** | **Ft.** | **Inference** | **Percent contribution** |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 20865.52 | 9852.03 | 9753.05 | 9 | Significant | 76.32 % |
| Current | 2 | 15352.52 | 7531.57 | 8370.53 | 8 | Significant | 53.28 % |
| Welding speed | 2 | 218.23 | 82.54 | 86.58 | 9 | Significant | 0.58 % |
| Error | 2 | 1.98 | 0.98 | - | - | - | - |
| Total | 8 | 36438.25 | - | - | - | - | - |

Table.8. ANOVA table for notch tensile strength for TIG welding

F cal.: Calculated F value
Ft.: Table F value

  

Table 8 shows the ANOVA table for notch tensile strength for TIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

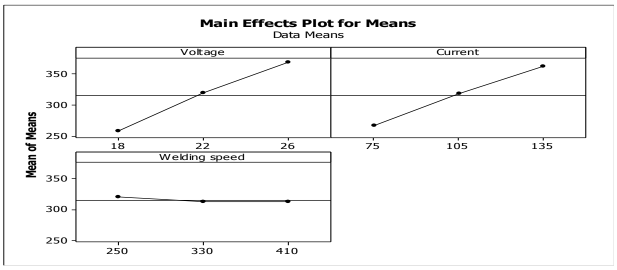


Fig.10. Effect of process parameters on notch tensile strength

Figure 10 shows the plots for the data means along x-axis and the mean of means along Y axis. From the figure 10 and the ANOVA table 7 and 8 the optimum values of notch tensile strength has been predicted for the welding process.

## X. OPTIMUM CONDITION FOR NOTCH TENSILE STRENGTH

1. From Table 7 and 8, voltage and current are found to be most significant factor.
2. From figure 10, it is clear that 26 volts, 135 amps and 250 mm/min are best. Therefore the optimum condition is $A_3B_3C_1$ for MIG welding.
3. It is clear that 185 amps, 72 amps and 150 mm/min are best. Therefore the optimum condition is $A_1B_3C_3$ for TIG welding.

| Factor | DOF | Sum of squares | Mean squares | F cal. | F t. | Inference | Percent contribution |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 2.39 | 1.19 | 2.29 | 9 | Insignificant | 6.8% |
| Current | 2 | 11.56 | 5.78 | 11.12 | 9 | Significant | 36.48% |
| Welding speed | 2 | 5.72 | 2.86 | 5.50 | 9 | Insignificant | 7.95% |
| Error | 2 | 1.04 | 0.52 | - | - | - | - |
| Total | 8 | 20.71 | - | - | - | - | - |

Table.9. ANOVA table for impact toughness for MIG welding

Table 9 shows the ANOVA table for impact toughness for MIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

| Factor | DOF | Sum of squares | Mean squares | F cal. | F t. | Inference | Percent contribution |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 4.73 | 2.34 | 4.64 | 7 | Insignificant | 10.54% |
| Current | 2 | 21.32 | 6.46 | 24.43 | 9 | Significant | 52.13% |
| Welding speed | 2 | 8.54 | 4.64 | 8.24 | 8 | Insignificant | 12.57% |
| Error | 2 | 3.21 | 0.84 | - | - | - | - |
| Total | 8 | 37.8 | - | - | - | - | - |

Table.10. ANOVA table for impact toughness for TIG welding

Table 10 shows the ANOVA table for impact toughness for TIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

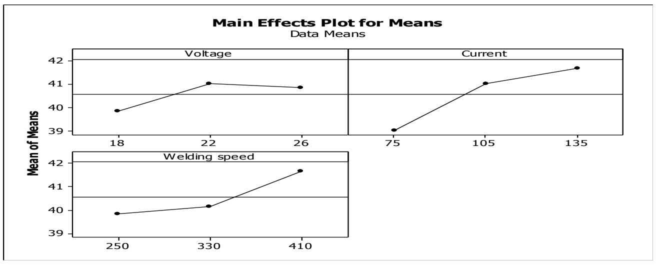


Fig.11. Effect of process parameters on impact toughness

Figure 11 shows the plots for the data means along X-axis and the mean of means along Y axis. From the figure 11 and the ANOVA table 9 and 10 the optimum values of impact toughness has been predicted for the welding process.

## XI. OPTIMUM CONDITION FOR IMPACT TOUGHNESS

1. From Table 9 and 10, current is found to be most significant factor.
2. From figure 11 it is clear that 22 volts, 135 amps and 410 mm/min are best. Therefore the optimum condition is $A_2B_3C_3$
3. It is clear that 198 amps, 70 amps and 120mm/min are best. Therefore the optimum condition is $A_3B_2C_1$ for TIG welding

Table 11 shows the ANOVA table for hardness for MIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

| Factor | DOF | Sum of squares | Mean squares | F cal. | F t. | Inference | Percent contribution |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 68.89 | 34.44 | 4.24 | 9 | Insignificant | 15.54% |
| Current | 2 | 59.52 | 29.76 | 3.66 | 9 | Insignificant | 13.29% |
| Welding speed | 2 | 272.89 | 136.44 | 16.78 | 9 | Significant | 64.39% |
| Error | 2 | 16.25 | 8.13 | - | - | - | - |
| Total | 8 | 417.55 | - | - | - | - | - |

Table.11. ANOVA table for hardness for MIG welding

| Factor | DOF | Sum of squares | Mean squares | F cal. | F t. | Inference | Percent contribution |
|---|---|---|---|---|---|---|---|
| Voltage | 2 | 84.89 | 45.52 | 8.52 | 8 | Insignificant | 27.28% |
| Current | 2 | 87.52 | 38.48 | 4.83 | 9 | Insignificant | 20.53% |
| Welding speed | 2 | 341.89 | 150.51 | 19.42 | 9 | Significant | 72.12% |
| Error | 2 | 24.54 | 12.43 | - | - | - | - |
| Total | 8 | 538.84 | - | - | - | - | - |

Table.12 ANOVA table for hardness for TIG welding

Table 12 shows the ANOVA table for hardness for TIG welding process. From the values from table 6, DOF, sum of squares, mean squares, F calculated and tabulated values had been found.

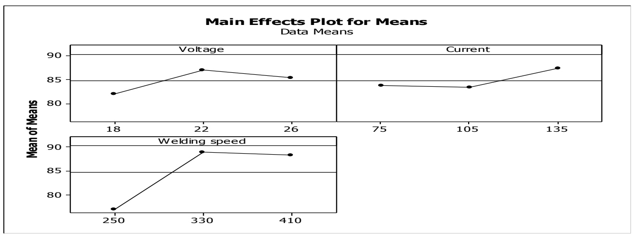


Fig.12. Effect of process parameters on hardness

The figure 12 shows the plots for the data means along X-axis and the mean of means along Y axis. From the figure 12 and the ANOVA table 11 and 12 the optimum values of hardness has been predicted for the welding process.

## XII. OPTIMUM CONDITION FOR HARDNESS

1. From Table 11 and 12, percentage contribution value shows that welding speed influences the hardness a lot compared to other factors.
2. From figure 12 it is clear that 22 volts, 135 amps and 330mm/min are best. Therefore the optimum condition is $A_2B_3C_2$
3. It is clear that 190 amps, 70 amps and 150mm/min are best. Therefore the optimum condition is $A_2B_2C_3$ for TIG welding.

| S. No. | Response | Regression equation |
|---|---|---|
| 1 | Notch tensile strength (MPa) | X = - 143 + 13.9 A + 1.59 B - 0.0458 C |
| 2 | Impact toughness (J) | X = 29.4 + 0.125 A + 0.0444 B + 0.0115 C |
| 3 | Hardness (HRB) | X = 45.8 + 0.417 A + 0.0611 B + 0.0708 C |

Table.13. Regression equations for the mechanical properties for MIG welding

Where, A = Voltage, B = Current, C = Welding speed, and X = Response

From the table 13, Regression equations were developed using MINITAB software. Regression equations are used to predicting the notch tensile strength, impact toughness and hardness within the factorial space exploited for MIG welding process.

| S. No. | Response | Regression equation |
|---|---|---|
| 1 | Notch tensile strength (MPa) | X = - 281 + 24.5 A + 4.23 B - 0.4287 C |
| 2 | Impact toughness (J) | X = 43.5 + 0.358 A + 0.1576 B + 0.3574 C |
| 3 | Hardness (HRB) | X = 68.4 + 0.543 A + 0.2865 B + 0.1573 C |

Table.14. Regression equations for the mechanical properties for TIG welding

Where, A = Voltage, B = Current, C = Welding speed, and X = Response

From the table 14, Regression equations were developed using MINITAB software. Regression equations are used to predicting the notch tensile strength, impact toughness and hardness within the factorial space exploited for TIG welding process. The optimum conditions were found by main effect plot for means which is shown in Figure 10, 11 and 12. This plot for means was verified by manual means calculation [16]. For optimum conditions, the optimal results were predicted by simple calculations by using MINITAB software.

## XIII. CONFIRMATION EXPERIMENT

The purpose of the confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental conclusions. Conformation experiment is performed by conducting a test using a specific combination of factors and levels evaluated in analysis phase. The sample size of the confirmation experiment is large than the experiment trails. The key task is the determination of the preferred combination of the levels of the factors indicated to be significant by the analytical methods. The insignificant factors may set at any desired levels. The conclusions drawn during the analysis phase. The confirmation experiment also serves the purpose of testing that specific combination of factors and levels.

Table 13 and 14 provides S/N ratio of measured responses. The main objective of this work maximizing the notch tensile strength, impact toughness and hardness of the weldment, so it is recommended to use means plot. Plot for S/N ratio was not used for finding optimum conditions, because plot for S/N ratio will give optimum condition for minimizing the variations of the process not for maximizing the weld quality characteristics.

| S.No | Response | Optimum condition | Predicted value | Experimental Value |
|---|---|---|---|---|
| 1 | Notch tensile strength (MPa) | $A_3B_3C_1$ | 420.58 | 418 |
| 2 | Impact toughness (J) | $A_2B_3C_3$ | 43.22 | 42 |
| 3 | Hardness (HRB) | $A_2B_3C_2$ | 93.77 | 91 |

Table.15. Validation of the optimum results for MIG welding

A1=18 Volts, A2=22 Volts, A3=26Volts.
B1= 75 Amps, B2= 105 Amps, B3= 135 Amps.
C1=250 mm/min, C2=330 mm/min, C3=410 mm/min.

Table 15 shows the purpose of the confirmation experiment to validate any specific trail on factorial experiment welding process parameters recommended by the investigation. The optimum conditions had been selected from the predicted and the experimental values for MIG welding process.

| S. No | Response | Optimum condition | Predicted value | Experimental Value |
|---|---|---|---|---|
| 1 | Notch tensile strength (MPa) | $A_1B_3C_3$ | 486.42 | 458 |
| 2 | Impact toughness (J) | $A_3B_2C_1$ | 48.32 | 47 |
| 3 | Hardness (HRB) | $A_2B_2C_3$ | 108.48 | 93 |

Table.16. Validation of the optimum results for TIG welding

A1=185 Amps, A2=190 Amps, A3=195 Amps.
B1= 65 Amps, B2= 70 Amps, B3= 72 Amps.
C1=120 mm/min, C2=140 mm/min, C3=150 mm/min.

Table 16 shows the purpose of the confirmation experiment to validate any specific trail on factorial experiment welding process parameters recommended by the investigation. The optimum conditions had been selected from the predicted and the experimental values for TIG welding process.

| S. No | Voltage (Volts) | Current (Amps) | Welding speed (mm/min) | S/N values for notch tensile strength | S/N values for impact toughness | S/N values for hardness |
|---|---|---|---|---|---|---|
| S1 | 18 | 75 | 250 | -46.56 | -31.58 | -36.89 |
| S2 | 18 | 105 | 330 | -48.23 | -31.93 | -38.48 |
| S3 | 18 | 135 | 410 | -49.59 | -32.45 | -39.27 |
| S4 | 22 | 75 | 330 | -48.53 | -31.81 | -39.46 |
| S5 | 22 | 105 | 410 | -50.08 | -32.66 | -38.69 |
| S6 | 22 | 135 | 250 | -48.38 | -32.25 | -38.16 |
| S7 | 26 | 75 | 410 | -50.04 | -32.03 | -38.78 |
| S8 | 26 | 105 | 250 | -51.52 | -32.15 | -38.06 |
| S9 | 26 | 135 | 330 | -52.30 | -32.46 | -38.99 |

Table.17. S/N ratio for MIG welding

The table 17 shows existing condition specimen with joint spacing of 0.5 mm, has partial penetration, so that it has less notch tensile strength whereas optimized condition specimen with 1.58 mm joint spacing has higher notch tensile strength due to its correct joint spacing and optimal parameter settings. The S/N ratio for MIG welding had been calculated using

  

MINITAB software.

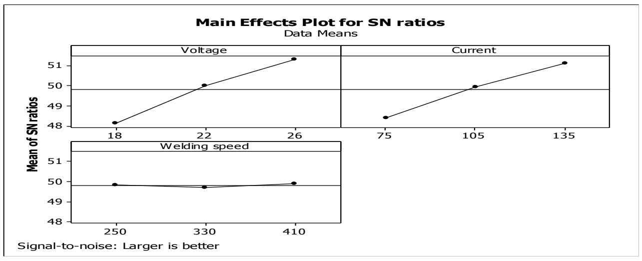


Fig.13. Effect of process parameters on notch tensile strength (S/N ratio)

| S. No | Peak current (Amps) | Base Current (Amps) | Welding speed (mm/ min) | S/N values for notch tensile strength | S/N values for impact toughness | S/N values for hardness |
|---|---|---|---|---|---|---|
| S1 | 185 | 62 | 120 | -66.64 | -42.43 | -53.92 |
| S2 | 185 | 70 | 140 | -58.53 | -42.72 | -45.84 |
| S3 | 185 | 72 | 150 | -59.92 | -30.42 | -54.72 |
| S4 | 190 | 62 | 140 | -39.35 | -48.56 | -38.68 |
| S5 | 190 | 70 | 150 | -49.28 | -43.88 | -57.96 |
| S6 | 190 | 72 | 120 | -53.43 | -46.85 | -43.64 |
| S7 | 198 | 62 | 150 | -53.53 | -48.72 | -51.87 |
| S8 | 198 | 70 | 120 | -58.25 | -54.40 | -50.63 |
| S9 | 198 | 72 | 140 | -57.20 | -43.46 | -52.95 |

Table.18. S/N ratio for TIG welding

Table 18 shows existing condition specimen with joint spacing of 0.45 mm, has partial penetration, so that it has less notch tensile strength whereas optimized condition specimen with 1.65 mm joint spacing has higher notch tensile strength due to its correct joint spacing and optimal parameter settings. The S/N ratio for TIG welding had been calculated using MINITAB software.

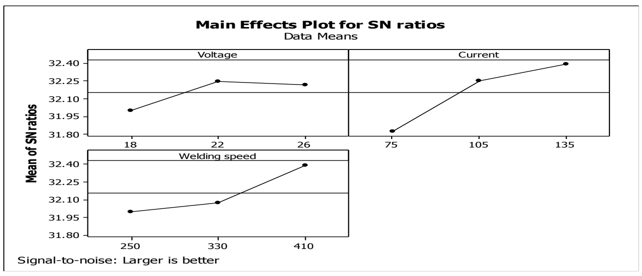


Fig.14. Effect of process parameters on impact toughness (S/N ratio)

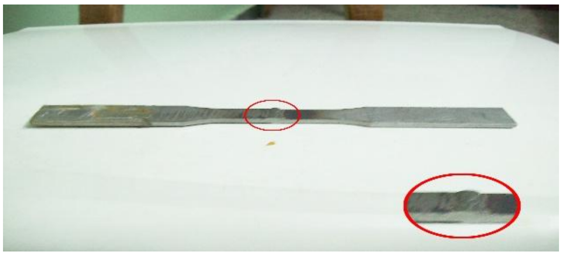

Fig.15. Optimized condition specimen

Fig.16. Optimized condition Specimen – Back side view

Figure 15 and 16 shows the specimen which had been welded the optimized predicted values by DOE process. The notch tensile strength, impact toughness and hardness of the welded specimen had been improved when compared to the existing specimen properties.

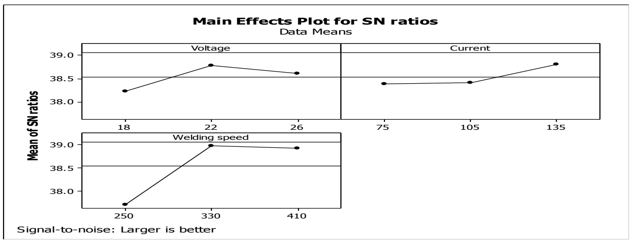


Fig.17. Effect of process parameters on hardness (S/N ratio)

Figure 13, 14 and 17 shows the effect of various process parameters on the notch tensile strength, impact toughness and hardness for the welding process.

## XIV. CONCLUSION AND FUTURE SCOPE

The optimal welding parameters for MIG welding process was selected by using Taguchi method. An $L_9$ orthogonal array was adopted to select welding parameter combinations. ANOVA was performed to find the impact of process parameters on the individual quality parameters. For the considered optimization problem, it is found that the voltage and current are the most influential factors on the notch tensile strength. High current and high voltage increases heat input, it causes slow rate of cooling thereby increases notch tensile strength. Current is most important factor on the impact toughness. And welding speed is most significant factor on hardness.

Welding joints produced by optimized welding parameter improved the mechanical properties of the weldment compared to existing welding parameter settings.

  

a. Notch tensile strength increased to 14.05%,
b. Impact toughness increased to 3.7% and
c. Hardness increased to 10.97%.
d. For selected application, notch tensile strength is important, therefore optimum condition is $A_3B_3C_1$. (i.e.) 26 volts, 135 amps and 250 mm/min are best combinations in **MIG welding**.
e. Notch tensile strength increased to 21.54%,
f. Impact toughness increased to 8.5% and
g. Hardness increased to 14.69%.
h. For selected application, notch tensile strength is important, therefore optimum condition is $A_1B_3C_3$. (i.e.) 185 amps, 72 amps and 150 mm/min are best combinations in **TIG welding**.

Of the two welded joints, the joints fabricated by GTAW process exhibited higher strength value and enhancement in strength value is approximately 21% compared to GMAW joints. The strength and hardness value has been increased due to precipitation of chromium carbide and tungsten carbide.

The project can also be extended for plasma arc welding and can compare the results using analysis software.

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