Performance Analysis of Welded Joint Made by MIG Welding Process on EN-24 Steel Work Pieces for Micro Hardness

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Abstract: In industry welded joints are most significant part for making engineering items. Welded joints are made by different procedure like TIG, MIG, and spot opposition welding, bend welding process and so on. For present research analysis about MIG welding process is chosen for examination the welded joints. Three procedure parameters are chosen for this examination which is feed rate, gas stream rate and gap among test pieces. The structure of test technique is chosen for making the trial table. The strategy is BB reaction surface technique. In this strategy low focus and abnormal states are chosen. All out 30 tests are created utilizing this DOE approach. A reaction parameter micro hardness is estimated for this examination think about. Model condition age utilizing sufficiency check is additionally direct in this examination contemplate.

Keywords: MIG, process parameters, welding time box-bhenken design, ANOVA analysis.

I. INTRODUCTION

Welding is a process of joining at least two pieces of the equivalent or different materials which are liquefied together by the utilization of warmth or pressure or both and with or without adding filler material to get solid structures.

A. Welding Process

Welding process is divided into two sections which are following
1) Plastic Welding
2) Fusion Welding

B. Plastic Welding Process-Theory

Plastic Welding Process is generally called Pressure Welding Process. The process in which two metal pieces are braced together by the utilization of external forces making a temperature underneath the conditioning motivation behind the base material without the extension of filler material is known as Pressure Welding Process. In this process, the metal pieces experience a plastic state as a result of warming besides, by the utilization of an outside pressure. Thusly, the joining of metal pieces is conveyed as a result of the utilization of temperature, time and pressure blend without dissolving the base material. The metals joined using this process can keep up their original properties as base metals, in light of the way that no dissolving happens in the base metals in the midst of Pressure Welding Process.

C. Fusion Welding Process

Combination Welding Process is otherwise called Non-Pressure Welding Process. In this process, the metals are joined by warming the material to the liquid state and after that cooling it to harden. In Fusion Welding Process, no outer pressure is connected. The combination happens just by the use of different sources. The protecting gases, for example, argon, helium, nitrogen and so on shield the liquid metal from the encompassing environment by giving legitimate protecting. Essentially, filler material is likewise added to accomplish completely filled joints. The fundamental target of present research paper is to perform practicable research examination on process parameters of MIG welding on EN-08 object material which isn’t in the warmth treated condition. The impact of process parameters of MIG on reaction parameters are additionally explored in present research work. The individual examination of present research work is following:
A. Perform investigation on MIG for shifting the feed rate of filler material for various dimensions to check the attainability of MIG reactions like hardness, joint structure, quality and so on.
B. Perform examination on MIG for various dimensions of inactive gas stream conditions to check the distinctive reactions. 
Play out the investigation for changing the hole among two diverse test pieces, which have same article material to discover the quality of joined item. This investigation is significantly more progressed and new for this exploration result.

II. EXPERIMENTAL SETUP

In present research study the MIG machine used for field experiments are present in figure 1. The machine is installed at college foundry shop at RIET, Jaipur.

![Experimental Setup of MIG welding machine](image)

As seen in figure, the machine setup show the feeder system as well as the torch used for welding process. Pilot experiments are conduct to verify the machine process parameters and the outcome of pilot experiments are show in figure 2. The pilot experiment is conduct to find the effect of changing the process parameters like feed rate, gas flow rate and effect of gap for welded joints.

![Pilot experiments analysis for MIG process](image)

III. MATERIAL SPECIFICATION

In present work one material is chosen for welding tests, the determination of material is rely upon writing audit and neighborhood accessibility of material and machine working conditions. The material is mechanical evaluation of steel (EN-24). EN-24 is utilized as a rule applications like house hold items made of sheets, car body making, farming items, development equipment's and so forth. Concoction and mechanical properties of EN-24 is available in table 1 and table 2 separately.

| Material | C   | Mn  | Si  | Cr  | Ni  | P    | Fe   |
|----------|-----|-----|-----|-----|-----|------|------|
| EN-24    | 0.35| 0.60| 0.25| 0.85| 1.8 | 0.035| Balance |
Table-2: Mechanical Properties Of En-24 (Ansi-4340)

| Material | Tensile Strength (N/mm²) | Yield Strength (N/mm²) | % Elongation | Impact (Izod J) | Hardness HB |
|----------|--------------------------|------------------------|--------------|----------------|-------------|
| EN-24    | 900                      | 700                    | 13           | 55             | 250         |

IV. FACTOR AND LEVELS

Three factors are selected for current research study and present in this section, the factors are selected on the basis of pilot experiments which is preformed and present in this chapter. These parameters are present in table 3 with levels.

| Factor | Unit | Min (-1) | Center (0) | Max (+1) |
|--------|------|----------|------------|----------|
| Feed rate | Inch/sec | 4 | 5 | 6 |
| Gas Flow | Psi | 3 | 3.5 | 4 |
| Gap | Mm | 0 | 1 | 2 |

The experiment table is generated using Box-bhenken design method and the experiment table generated using MINITAB software is present in table 1 for this research study.

V. RESULT AND DISCUSSION

The present research work is focused to improve process parameters effect, on welding quality made with MIG welding machine. In present research work design of experiment method is used for experiment table generation and the factor and levels are present in table 3 for this research work. The adequacy check for micro hardness is present in table 4. As discussed in following section the various test are conduct to analysis the regression modeling of equation through adequacy check is performed for micro hardness and the results are present in table 4.

| Source | SS | df | MS | F-Value | P-value |
|--------|----|----|----|---------|---------|
| Linear | 144.87 | 3 | 48.29 | 2.66 | 0.069 |
| Linear + Square | 372.29 | 6 | 62.04 | 5.85 | 0.001 |
| Linear +2-way | 320.62 | 6 | 53.43 | 4.16 | 0.006 |
| Full Quad | 548.04 | 9 | 60.89 | 17.88 | 0.000 |
| Lack of Fit Test | | | | | |
| Linear | 422.79 | 9 | 46.97 | 16.47 | 0.000 |
| Linear + Square | 195.37 | 6 | 32.56 | 11.41 | 0.000 |
| Linear +2-way | 247.04 | 6 | 41.17 | 14.43 | 0.000 |
| Full Quad | 19.62 | 3 | 6.54 | 2.29 | 0.115 |
| Error Test | | | | | |
| Linear | 471.29 | 26 | 18.27 | 76.49 |
| Linear + Square | 243.87 | 23 | 10.60 | 39.58 |
| Linear +2-way | 295.54 | 23 | 12.85 | 47.96 |
| Full Quad | 68.12 | 20 | 3.40 | 10.06 | | Selected |
| Model Summary Test | | | | | |
| Linear | 4.25 | 23.51 | 14.69 | 637 | 0.00 |
| Linear + Square | 3.25 | 60.42 | 50.10 | 428 | 30.38 |
| Linear +2-way | 3.58 | 52.04 | 39.52 | 505 | 18.02 |
| Full Quad | 1.84 | 88.94 | 83.97 | 159 | 74.15 | | Selected |

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As seen in table 4, the full quad mode equation is selected for further analysis means optimization of response analysis. As seen in SS test, P value is in range of 0.05 for all options but in lack of fit test only one equation show p value more than 0.05 which is full quad model equation, in Error test Full quad show lower contribution when compare with other model equation options.

A. Analysis of Variance table for all Modeling Options for MH

In previous section the adequacy check is performed for micro hardness (MH) for all possible modeling equations option available in MINITAB software, in this section the ANOVA tables with model summary is present for all these modeling options. The ANOVA table for all these model equations are present in table 5 to table 8 for linear, square, interaction and full quad model options. In each table model summary is also present for selective model equation.

Table- 5: Anova Analysis For Linear Model For Mh

| Source        | DF | Seq SS  | Contribution | Adj SS  | Adj MS | F-Value | P-Value |
|---------------|----|---------|--------------|---------|--------|---------|---------|
| Model         | 3  | 144.875 | 23.51%       | 144.875 | 48.292 | 2.66    | 0.069   |
| Linear        | 3  | 144.875 | 23.51%       | 144.875 | 48.292 | 2.66    | 0.069   |
| Feed Rate     | 1  | 0.25    | 0.04%        | 0.25    | 0.25   | 0.01    | 0.907   |
| Gass Flow Rate| 1  | 126.563 | 20.54%       | 126.563 | 126.563| 6.98    | 0.014   |
| Gap           | 1  | 18.062  | 2.93%        | 18.062  | 18.062 | 1       | 0.327   |
| Error         | 26 | 471.292 | 76.49%       | 471.292 | 18.127 |         |         |
| Lack-of-Fit   | 9  | 422.792 | 68.62%       | 422.792 | 46.977 | 16.47   | 0       |
| Pure Error    | 17 | 48.5    | 7.87%        | 48.5    | 2.853  |         |         |
| Total         | 29 | 616.167 | 100          |         |        |         |         |

| S         | R-sq | R-sq(adj) | PRESS | R-sq(pred) |
|-----------|------|-----------|-------|------------|
| 4.25      | 23.51| 14.69     | 637   | 0.00       |

As seen in table 5, very few factors has significant levels (If any factor is treated as significant otherwise its P value is lower or equal to 0.05) major factors of linear model are non-significant for this analysis.

Table -6: Anova Analysis For Linear And Square Model For Mh

| Source        | DF | Seq SS  | Contribution | Adj SS  | Adj MS | F-Value | P-Value |
|---------------|----|---------|--------------|---------|--------|---------|---------|
| Model         | 6  | 372.292 | 60.42%       | 372.292 | 62.049 | 5.85    | 0.001   |
| Linear        | 3  | 144.875 | 23.51%       | 144.875 | 48.292 | 4.55    | 0.012   |
| Feed Rate     | 1  | 0.25    | 0.04%        | 0.25    | 0.25   | 0.02    | 0.879   |
| Gass Flow Rate| 1  | 126.563 | 20.54%       | 126.563 | 126.563| 11.94   | 0.002   |
| Gap           | 1  | 18.062  | 2.93%        | 18.062  | 18.063 | 1.7     | 0.205   |
| Square        | 3  | 227.417 | 36.91%       | 227.417 | 75.806 | 7.15    | 0.001   |
| Feed Rate     | 1  | 21.488  | 3.49%        | 29.538  | 29.538 | 2.79    | 0.109   |
| Gass Flow Rate| 1  | 11.967  | 1.94%        | 5.654   | 5.654  | 0.53    | 0.473   |
| Gap*Gap       | 1  | 193.962 | 31.48%       | 193.962 | 193.962| 18.29   | 0.000   |
| Error         | 23 | 243.875 | 39.58%       | 243.875 | 10.603 |         |         |
| Lack-of-Fit   | 6  | 195.375 | 31.71%       | 195.375 | 32.563 | 11.41   | 0.000   |
| Pure Error    | 17 | 48.5    | 7.87%        | 48.5    | 2.853  |         |         |
| Total         | 29 | 616.167 | 100.00%      |         |        |         |         |
As seen in table 6, most of the factors have significant levels (If any factor is treated as significant otherwise its P value is lower or equal to 0.05) some factors (feed rate, square of gas flow rate) like linear model are non-significant for this analysis.

| Source                   | DF | Seq SS   | Contribution | Adj SS   | Adj MS   | F-Value | P-Value |
|--------------------------|----|----------|--------------|----------|----------|---------|---------|
| Model                    | 6  | 320.625  | 52.04%       | 320.625  | 53.438   | 4.16    | 0.006   |
| Linear                   | 3  | 144.875  | 23.51%       | 144.875  | 48.292   | 3.76    | 0.025   |
| Feed Rate                | 1  | 0.25     | 0.04%        | 0.25     | 0.25     | 0.02    | 0.89    |
| Gass Flow Rate           | 1  | 126.563  | 20.54%       | 126.562  | 126.562  | 9.85    | 0.005   |
| Gap                      | 1  | 18.062   | 2.93%        | 18.063   | 18.063   | 1.41    | 0.248   |
| 2-Way Interaction        | 3  | 175.75   | 28.52%       | 175.75   | 58.583   | 4.56    | 0.012   |
| Feed Rate*Gass Flow Rate | 1  | 153.125  | 24.85%       | 153.125  | 153.125  | 11.92   | 0.002   |
| Feed Rate*Gap            | 1  | 10.125   | 1.64%        | 10.125   | 10.125   | 0.79    | 0.384   |
| Gass Flow Rate*Gap       | 1  | 12.5     | 2.03%        | 12.5     | 12.5     | 0.97    | 0.334   |
| Error                    | 23 | 295.542  | 47.96%       | 295.542  | 12.85    |         |         |
| Lack-of-Fit              | 6  | 247.042  | 40.09%       | 247.042  | 41.174   | 14.43   | 0       |
| Pure Error               | 17 | 48.5     | 7.87%        | 48.5     | 2.853    |         |         |
| Total                    | 29 | 616.167  | 100.00%      |          |          |         |         |

As seen in table 7, most of the factors have significant levels (If any factor is treated as significant otherwise its P value is lower or equal to 0.05) some factors (feed rate, 2-way of gas flow rate) like linear model are non-significant for this analysis.

| Source                    | DF | Seq SS   | Contribution | Adj SS   | Adj MS   | F-Value | P-Value |
|---------------------------|----|----------|--------------|----------|----------|---------|---------|
| Model                     | 9  | 548.042  | 88.94%       | 548.042  | 60.894   | 17.88   | 0.000   |
| Linear                    | 3  | 144.875  | 23.51%       | 144.875  | 48.292   | 14.18   | 0.000   |
| Feed Rate                 | 1  | 0.25     | 0.04%        | 0.25     | 0.25     | 0.07    | 0.789   |
| Gass Flow Rate            | 1  | 126.563  | 20.54%       | 126.563  | 126.563  | 37.16   | 0.000   |
| Gap                       | 1  | 18.062   | 2.93%        | 18.062   | 18.062   | 5.3     | 0.032   |
| Square                    | 3  | 227.417  | 36.91%       | 227.417  | 75.806   | 22.25   | 0.000   |
| Feed Rate*Feed Rate       | 1  | 21.488   | 3.49%        | 29.538   | 29.538   | 8.67    | 0.008   |
| Gass Flow Rate*Gass Flow Rate | 1 | 11.967   | 1.94%        | 5.654    | 5.654    | 1.66    | 0.212   |
| Gap*Gap                   | 1  | 193.962  | 31.48%       | 193.962  | 193.962  | 56.94   | 0.000   |
| 2-Way Interaction         | 3  | 175.75   | 28.52%       | 175.75   | 58.583   | 17.2    | 0.000   |
| Feed Rate*Gass Flow Rate  | 1  | 153.125  | 24.85%       | 153.125  | 153.125  | 44.95   | 0.000   |
| Feed Rate*Gap             | 1  | 10.125   | 1.64%        | 10.125   | 10.125   | 2.97    | 0.100   |
| Gass Flow Rate*Gap        | 1  | 12.5     | 2.03%        | 12.5     | 12.5     | 3.67    | 0.070   |
As seen in table 8, most of the factors have significant levels (If any factor is treated as significant otherwise its P value is lower or equal to 0.05) some factors are non-significant for this analysis.

B. Residual Plot Analysis for all Model Equation Options for MH (Micro Hardness)

Residual plot is generated among original response value measured during experiments and predicted value of response during regression model equation development. The results for residual plots for these response variables (micro hardness) are discussed in this section. The results of residual plots are show in figure 5.6 to figure 5.9 for linear, square, 2-way interaction and full quad model equation.

Figure 3 show the residual plots for linear model for MH (Micro Hardness), as seen in normal distribution plot, it is clear show that residual is very high when compare with theoretical best value (zero). Figure 4 show the residual plots for linear and square model for MH (Micro Hardness), as seen in normal distribution plot, it is clear show that residual is very high when compare with theoretical best value (zero).
Figure 4 Residual Plot for MH for Square model

Figure 5 Residual Plot for MH for 2-way Interaction model

Figure 5 show the residual plots for linear and square model for MH (Micro Hardness), as seen in normal distribution plot, it is clear show that residual is very high when compare with theoretical best value (zero).

Figure 6 Residual Plot for MH for Full Quad model
Model equation for Micro Hardness (MH)

\[
MH = 175.6 - 49.37 \text{ Feed Rate} - 16.1 \text{ Gass Flow Rate} - 12.31 \text{ Gap} + 2.000 \text{ Feed Rate} \times \text{ Feed Rate} - \\
3.50 \text{ Gass Flow Rate} \times \text{ Gass Flow Rate} + 5.125 \text{ Gap} \times \text{ Gap} + 8.75 \text{ Feed Rate} \times \text{ Gass Flow Rate} - 1.125 \text{ Feed Rate} \times \text{ Gap} + 2.50 \text{ Gass Flow Rate} \times \text{ Gap}
\]

VI. CONCLUSION

A. The main conclusion of this study is present in this section and the conclusions are following and present here:

Box-Behnken Design (BBD) is applied for three factors feed rate, gas flow rate and gap for three levels for MIG study. Total 30 experiments are designed using this DOE technique. One response welding time is selected as output parameters for MIG research work.

B. Adequacy check analysis is performed for welding time response variables using Analysis of Variance (ANOVA) tests. The final regression model equation for micro hardness (MH) is full quad model equation.

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