Optimization of parameters involved in robotic MIG welding process based on quality responses

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Abstract. Automation in the welding process are preferred for the enhancement of quality and time reduction. Robots are widely used for welding process in sheet metal fabrication industries. In this study, the parameters of robotic (ABB IRB 1520) Metal Inert Gas (MIG) welding process (reference voltage, wire feed rate and gas flow rate) is optimized based on the quality responses such as depth of penetration, bead width and reinforcement at welded joints in IS2062 (GRADE A) material. In order to locate optimum conditions with a relatively small number of experiments in parameter optimization, Response Surface Methodology is used. RSM is an empirical approach which uses the polynomials as local approximation to relate the true relationship between input and output. The process improvement in industrial setting is achieved by this empirical approach. The mathematical model has been deduced based on experimental data and model selection techniques. And the approach reveals the condition which favour the good balance between maximum penetration, minimum bead reinforcement and minimum bead width.

1. Introduction

Initially Robots were introduced in the year 1960’s in the industries of US and since1980, robots were being used for spot welding process. In recent times, the robots are developing very fast for arc welding process.

Weld bead geometry is major factor that has to be considered when it comes to the quality of the weld [1-2]. The Weld bead geometry is affected by the input process parameters which has to be optimized for better weld bead quality [3,4]. Weld bead width, reinforcement and depth of penetration are three main factors that affect the quality of weld bead as show in figure 1.
Response Surface Methodology is the method has to be used to find the optimized value [5] using the Minitab tool. In automated MIG Welding process, besides the chemical composition, the weld bead shape [6] is considered as an important factor for better quality [7].

To optimize the input parameters (reference voltage, wire feed rate [8] and gas flow rate) [9] that affect the weld bead geometry in IS2062 material using ABB 1520ID welding robot is the main aim of the project. The graphs are to be plotted showing the best result obtained by the experimental values.

2. Methodology of work

In order to get a better weld bead quality, the input parameters and output parameters of MIG welding process which has to be considered for optimization has be selected initially. Then the optimization method required for getting optimum condition has to be selected.

The next step is to simulate the robotic welding process using Robot Studio software and teach it to the robot. Then the set of input parameters has to be generated using optimization method in Minitab software.

After the input values for performing the robotic welding is generated, the input values are fed to welding machine and several experiments are done.

Then the experimental values are tabulated and fed into Minitab software. Then the set of values are optimized using Minitab software.

In the next step, the graphs are plotted with experimental values for finding the optimum value. This methodology is shown in the figure 2.

Figure 1. Weld Bead Geometry
Selection of I/P and O/P parameters

Selection of material and method for optimization

Robotic welding simulation in Robot Studio software

Input parametric values are generated using Minitab software

Experiments are conducted by feeding generated input values

Optimization is done using Response Surface Methodology

Experimented values are plotted in graph and optimum values are found

**Figure 2.** Flow chart of methodology
2.1 Response Surface Methodology

Response Surface Methodology has a set of mathematical and statistic technique to develop a functional relationship between input variables \((x_1, x_2, \ldots, x_k)\) and response, \(y\). In this method the design of experiments is used for finding the input parameters which have the influence on response. Then RSM is done to quantify the relationship between input variables and response \([10,11]\). With the help of this method the input variables affecting the response are controlled for getting a better response value.

In MIG welding process, when RSM is applied, the relationship of welding with the bead geometry is found and individual variable is controlled for improving the bead geometry \([12,13]\). In this project, the individual variables are current \((x_1)\), voltage \((x_2)\) and gas flow rate \((x_3)\) which has to maximize the depth of penetration \((y_1)\) and have to minimize the width of the bead \((y_2)\) and the reinforcement \((y_3)\). The dependency of response \((y)\) on the individual variables \((x_i)\) is illustrated in the equation (1) with the experimental error, \(\varepsilon\)

\[
y = f(x_1, x_2, x_3) + \varepsilon
\]

It is proved that the equation (2) can be used for many engineering process without doing over parameterization. The similar functional relationship is used in the field of the welding process. The model represented in equation (2) has the regression parameters \((\beta_0\) to \(\beta_k)\) which is estimated from the experimental values \([14]\).

\[
y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_{i=2}^{k} \sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon
\]

2.2 Selection of material and optimization method

The most commonly used sheet metal in fabrication industries is IS2062 (Grade A) material and shielding gas used for welding is corgon gas mixture (CO\(_2\) + Argon). The thickness of the material used for testing is 5 mm. IS2062 Grade A material is selected for doing optimization. The method selected for optimizing process is Response Surface Methodology. This method is selected since it is easier and most effective method which involves less no. of experiments and less cost.

| Grade | C%   | Mn%  | S%   | P%   | C.E% |
|-------|------|------|------|------|------|
| A     | 0.23(max) | 1.5(max) | 0.05(max) | 0.05(max) | 0.42(max) |
Table 2. Corgon Gas Mixture.

| GAS    | PERCENTAGE |
|--------|------------|
| CO₂    | 12%        |
| ARGON  | 88%        |

2.3 ABB IRB 1520ID specification

ABB IRB 1520ID the lean arc welder is widely used in industrial welding application. In this work, this robot is used for the welding process. The specification of this robot is as follows.

Table 3. Specifications of ABB IRB1520ID Robot.

|                  |          |
|------------------|----------|
| Payload          | 4 kg     |
| Armload          | 10 kg    |
| Reach            | 1.50 m   |
| Number of axes   | 6        |
| Dimensions Robot base | 300 x 300 mm |
| Robot weight     | 170 kg   |

3. Input Parametric value Generation

In Response Surface Methodology, the values of input parameters for conducting experiments can be generated using Minitab software. Initially the minimum and maximum range of input parameters is fed into the Minitab software and the input values for experiments are generated.

Table 4. Process Variables and Experimental Design level.

| I/P Variables | -1.414 | -1 | 0  | +1  | +1.414 |
|---------------|--------|----|----|-----|--------|
| Voltage(V)    | 16.6364| 18 | 20 | 22  | 23.3636|
| Wirefeed rate (m/min) | 2.63641| 4  | 6  | 8   | 9.36359|
| Gasflow Rate(lpm) | 8.2955 | 10 | 12.5 | 15 | 16.7045|
| RunOrder | Voltage V | Gas flow rate m/min | Gas flow rate lpm |
|----------|-----------|---------------------|------------------|
| 1        | 18.0000   | 8.00000             | 15.0000          |
| 2        | 22.0000   | 4.00000             | 10.0000          |
| 3        | 20.0000   | 6.00000             | 12.5000          |
| 4        | 23.3636   | 6.00000             | 12.5000          |
| 5        | 20.0000   | 6.00000             | 12.5000          |
| 6        | 20.0000   | 2.63641             | 12.5000          |
| 7        | 22.0000   | 8.00000             | 15.0000          |
| 8        | 18.0000   | 4.00000             | 10.0000          |
| 9        | 20.0000   | 6.00000             | 12.5000          |
| 10       | 20.0000   | 6.00000             | 16.7045          |
| 11       | 18.0000   | 4.00000             | 10.0000          |
| 12       | 20.0000   | 6.00000             | 12.5000          |
| 13       | 20.0000   | 9.36359             | 12.5000          |
| 14       | 20.0000   | 6.00000             | 12.5000          |
| 15       | 22.0000   | 8.00000             | 10.0000          |
| 16       | 22.0000   | 4.00000             | 15.0000          |
| 17       | 20.0000   | 6.00000             | 8.2955           |
| 18       | 18.0000   | 8.00000             | 10.0000          |
| 19       | 20.0000   | 6.00000             | 12.5000          |
| 20       | 16.6364   | 6.00000             | 12.5000          |

4. Experimental results

The experiments were done with above input parametric values and the welded parts are sheared for viewing cross sectional view of it. The welded part is etched with Nital and the values of depth of penetration, reinforcement and bead width is measured as shown in figure 3 and tabulated as shown in figure 4.
Figure 3. Cross sectional view of the welded part

Figure 4. Output values entered in minitab software for analysis

The output values are updated in minitab software and then the values are analysed and optimized using response surface methodology in minitab software.

The graph clearly states that the lower feed rate and lower voltage gives minimum bead width, minimum reinforcement and higher depth of penetration as shown in figure 5,6
and 7. In this optimization process, the depth of penetration is given double the weightage when compared to other two outputs.

![Contour Plot for Reinforcement](image)

**Figure 5.** Contour plot for reinforcement.
Figure 6. Contour plot for bead width
Figure 7. Contour plot for depth of penetration
Figure 8. Optimized response graph

The optimized input parametric value is 17.9275v, 2.6364 m/min and 8.2955 lpm which gives 2.0505 mm depth of penetration, 1.1219 mm reinforcement and 4.1619 mm bead width as shown in figure 6.

5. Conclusion

In this study, it is found that Response Surface Methodology is the method which creates a quantitative relation between the response and the parameters which has to be controlled for finding an optimum condition. The simulation of robotic welding is done in Robot Studio software. The design levels and values of the input parameters for conducting experiments is generated and experiments were done and optimized using Response Surface Methodology in Minitab software. In future, the optimized value have to be experimented and has to be tested practically.
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