# MODELLING OF GAS METAL ARC WELDING PROCESS ON ANGULAR DISTORTION OF T JOINT

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**ABSTRACT:** Gas Metal Arc Welding (GMAW) is one of the widely used joining technologies in metal fabrication. The quality of a joint is greatly influenced by the selection of GMAW process parameter settings. One of the quality issues faced in welding is angular distortion. This research focused on angular distortion issues due to welding that happened in a local car chassis manufacturing company. The distortion resulted in high reject and rework rate. Conventional approach to optimize the welding process parameter in solving this issue has yet to result in significant improvement. The aims of this work is to study the influence of welding speed, welding angle, welding current and the resultant angular distortion using Response Surface Methodology (RSM) approach. The experiment was carried out using robotic welding manipulator AVII V6, OTC DAIHEN. Deposition of fillet weld on T joint arrangement was performed on test piece made of low carbon steel SAPH S45C. The angular distortion was measured using Olympus STM stereo measuring microscope and the data analysis was carried out using Design Expert version 8.0.7. The result indicated that interaction between welding angle and speed is the most significant factors that influence the angular distortion and the relationship between the evaluated input parameters and the angular distortion can be modeled using 2Factor Interaction model.

**KEYWORDS**: *GMAW, Distortion, Welding Speed, Welding Angle, Welding Current.*

## 1.0 INTRODUCTION

Gas Metal Arc Welding (GMAW) was first used in the mid 1940s [1]. Since then, the process has been used extensively in a wide range of industries due to its benefits such as high production rate, high weld quality, ease of automation, and the ability to weld many metals make it attractive to manufacturer. However, welding involves complex interactions between thermal, metallurgical and mechanical phenomena and therefore, leads to residual stresses and distortions which must be controlled. Localized heating during welding, followed by rapid cooling generates residual stress and distortion in the weld and base metal. In the last few decades, various research efforts have been directed towards the control of welding process parameters aiming at reducing the residual stress and distortion [2]. This study is an industrial application based research to address distortion phenomena due to welding process in car chassis manufacturing company which caused high reject and rework rate.

The conventional approach to optimize process parameters to address this problem has yet to result in significant improvement. Holistic study looking into angular distortion minimization by optimization of process parameter is lacking. In this study, the influence of welding process parameters on the distortion of work-piece was investigated and the related empirical mathematical model was developed using Response Surface Methodology (RSM) approach.

## 2.0 EXPERIMENTAL SETUP

The three input process parameters evaluated in this study were welding current (Ampere, A), Welding speed (mm/sec) and welding torch angle (°). The ranges of those parameters are as shown in Table 1. The welding equipment used was OTC Inverter type GMAW couple with OTC Alamega six-axis robot. The flow of CO2 was set at 5 liter/min to ensure the shielding effectiveness was constant for all experimental runs. The experimental matrix was developed based on RSM centre cubic design, using Design Expert version 8.0.7 software. It consists of 8 factorial points, 4 axial points and 6 central points to enable an estimation of process variability.

The test piece used for all experimental runs was carbon steel SAPH S45C plates which are commonly used in automotive chassis manufacturing operation. The plates were tact welded and held in a fixture prior to the experiment, as shown in Figure 1, to ensure 90° T joint setup prior to welding experiment. Fillet weld was then deposited on one side of the test piece. The angular distortion of the welded test piece was measured by cross sectioning the middle of each test piece and polishing it to expose the HAZ surface.

Table 1: Welding input process parameters and their ranges

| Parameters | Range |
|---|---|
| Current (A) | 160 – 170 A |
| Welding speed (mm/s) | 40 – 60 (mm/s) |
| Welding angle (°) | 40°- 50° |

Olympus STM stereo measuring microscope was used to capture the HAZ image and the distortion angle was determined by calculating the deviation of the T joint after welding process with assistance of built-in PRS system. Data analysis to determine the influence of the welding parameters on the distortion angle and to develop related mathematical model was done using of the Design Expert version 8.07 software.

Figure 1: Test piece position

## 3.0 RESULT AND DISCUSSIONS

The summary of distortion angles for respective experimental runs is tabulated in Table 2. Sample of HAZ cross-sectioned image to enable angular distortion measurement is shown in Figure 2. Fit analysis, ANOVA analysis, and main effect analysis was carried out on the experimental run result to achieve the objective of this study.

Table 2: Angular distortion data for respective experimental runs

| Run | A:Angle (°) | B:Speed (mm/s) | C:Current (Amp) | Distortion (°) | Run | A:Angle (°) | B:Speed (mm/s) | C:Current (Amp) | Distortion (°) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 45 | 50 | 165 | 1.96 | 11 | 50 | 60 | 170 | 1.79 |
| 2 | 40 | 60 | 160 | 1.52 | 12 | 50 | 40 | 160 | 10 |
| 3 | 40 | 40 | 170 | 1.2 | 13 | 50 | 40 | 170 | 2.3 |
| 4 | 45 | 50 | 156.6 | 0.8 | 14 | 50 | 60 | 160 | 0 |
| 5 | 45 | 50 | 165 | 2.06 | 15 | 45 | 50 | 165 | 1.1 |
| 6 | 40 | 40 | 160 | 1.4 | 16 | 45 | 33.2 | 165 | 0.07 |
| 7 | 45 | 50 | 173.4 | 0 | 17 | 45 | 66.8 | 165 | 0 |
| 8 | 45 | 50 | 165 | 0.72 | 18 | 53.4 | 50 | 165 | 0.99 |
| 9 | 40 | 60 | 170 | 1.19 | 19 | 45 | 50 | 165 | 2.12 |
| 10 | 45 | 50 | 165 | 1.48 | 20 | 36.6 | 50 | 165 | 0.82 |

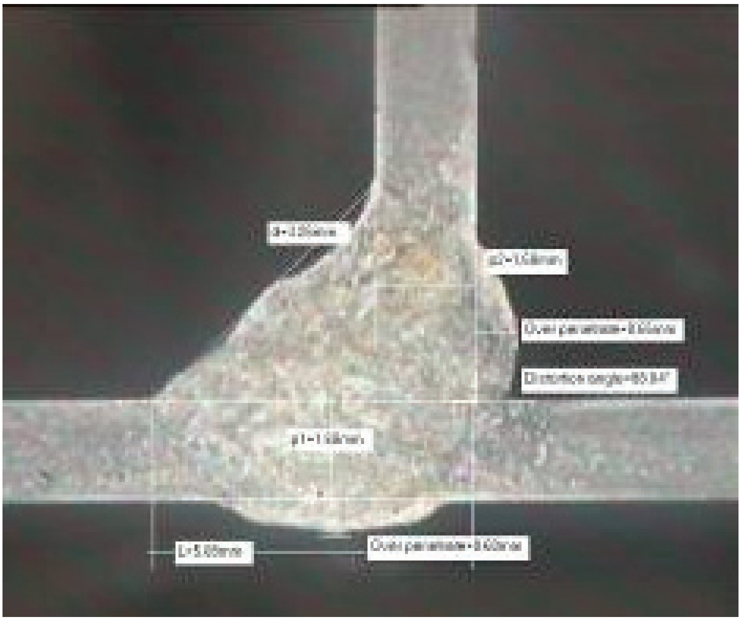

Figure 2: HAZ cross section to enable angular distortion calculations

## 3.1 Fit Analysis

The objective of fit summary analysis is to determine the most suitable model that represent the relationship between input variables (welding speed, current, and angle) and the output response being studied (angular distortion). The summary of this analysis is shown in Table 3. The analysis indicates that the 2 FI (2 Factorial Interaction) has a lowest "P value" (0.054) indicating that the there is only 5.4% probability that the F value for 2FI model is due chance. Due to this 2 FI model was selected to represent the relationship between the evaluated input parameters and angular distortion.

Table 3: Fit analysis

| Source | Sum of square | Df | Mean of square | F values | p-value |
|---|---|---|---|---|---|
| | | | | | Prob > F |
| Mean vs Total | 49.68 | 1 | 49.68 | | |
| Linear vs Mean | 18.56 | 3 | 6.19 | 1.50 | 0.2537 |
| 2FI vs Linear | 28.67 | 3 | 9.56 | 3.31 | 0.0540 |
| Quadratic vs 2FI | 0.80 | 3 | 0.27 | 0.07 | 0.9731 |
| Cubic vs Quadratic | 21.69 | 4 | 5.42 | 2.17 | 0.1900 |
| Residual | 15.02 | 6 | 2.50 | | |
| Total | 134.42 | 20 | 6.72 | | |

## 3.2 ANOVA Analysis

Using acceptance level of "p-value" of 0.1, ANOVA analysis shown in Table 4 indicates that interaction between angle and speed is most significant factor with "p-value"of 0.0456. The second most important factor is interaction between speed and current with "p-value" of 0.0733. As for the individual input process parameters, none of them are significant because their"p-values" are greater than

0.1. However, since interactions among them are significant, they have to be included in the model.

Table 4: ANOVA analysis

| **Source** | **Sum of square** | **df** | **Mean of square** | **F value** | **P-value Prob > F** |
|---|---|---|---|---|---|
| Model | 47.22 | 6.00 | 7.87 | 2.73 | 0.0611 |
| A-Angle | 6.02 | 1 | 6.02 | 2.09 | 0.1724 |
| B-Speed | 8.10 | 1 | 8.10 | 2.81 | 0.1177 |
| C-Current | 4.44 | 1 | 4.44 | 1.54 | 0.2368 |
| AB | 14.10 | 1 | 14.10 | 4.89 | 0.0456 |
| AC | 3.62 | 1 | 3.62 | 1.25 | 0.2831 |
| BC | 10.95 | 1 | 10.95 | 3.79 | 0.0733 |
| Residual | 37.52 | 13 | 2.89 | | |
| Lack of Fit | 35.87 | 8 | 4.48 | 13.62 | 0.0053 |
| Pure Error | 1.65 | 5 | 0.33 | | |
| Cor Total | 84.74 | 19 | | | |

## 3.3 Main effect analysis

The main factor analysis indicates the magnitude and trend of distortion angle as the input parameter changes. Figure 3 is the main effect graph for welding angle, it indicates that as welding angle increases, distortion value also increases. The increase in welding angle resulted in increase of the width of weld bead which resulted in higher contraction the top surface of the weld pool and hence an increase in angular distortion [3].

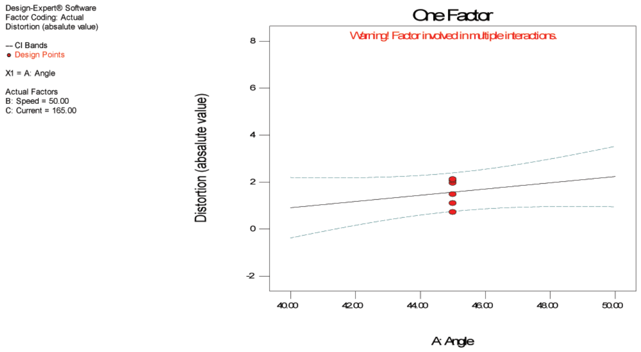

Figure 3: Main effect of welding angle on angular distortion

Figure 4 shows the relation between speed and distortion angle. It indicates that as speed increases the distortion angle decreases. This relationship can be explained in terms of the magnitude of residual stress in the weld join as welding speed varies.

The heat flux into the weld joint increases as the welding speed decreases [4-5]. Due to that, the residual stress at lower welding speed is higher than welding at higher speed which resulted in greater angular distortion at lower welding speed.

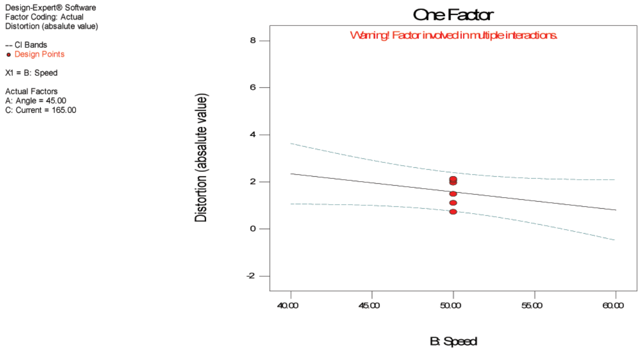

Figure 4: Main effect of welding speed on angular distortion

Figure 5 shows the relation between current and the angular distortion. It indicates that as current increases, the distortion decreases or in other word current in is inversely proportional to distortion. This finding is aligned with that of [6]. The higher current setting forms deeper penetration and bead width due to higher heat input along welding line [7]. This resulted in greater contraction as the weld bead cools down causing greater angular distortion.

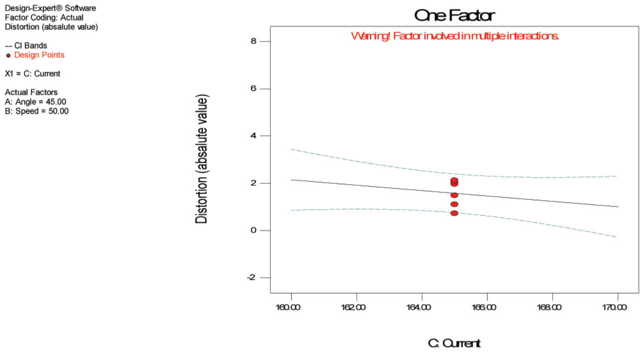

Figure 5: Main effect curve of current on angular distortion

### 3.4 Modeling of angular distortion behavior

Based on the ANOVA analysis, the model that best represent the relationship between the angular distortion and the evaluated welding parameters was the 2 Factor Interaction Model. This model, generated using the Design Expert software, can be represented by polynomial equation shown in Equation 1.

$$\text{Angular Distortion} = \begin{aligned}&-48.15532+5.89877(\text{Angle})-2.74326(\text{Speed})\\&-0.073515(\text{Current})-0.026550(\text{Angle})\\&(\text{Speed})-0.02690(\text{Angle})(\text{Current})\\&+0.023400(\text{Speed})\\&(\text{Current})\end{aligned} \qquad (1)$$

The model accuracy was validated using three sets of welding parameter settings. The predicted angular distortion values were compared with that of the validation runs. The comparison is tabulated in Table 5. The residual errors between predicted and actual angular distortion value range from 2% to 19%. In average, the residual error is 9% which it is acceptable.

Table 5: Validation run data

| Data set no. | Angle (°) | Speed (mm/s) | Current (A) | Predicted Angular distortion | Actual Angular Distortion | Residual Error % |
|---|---|---|---|---|---|---|
| 1 | 40 | 60 | 160 | 1.43° | 1.40° | 2 |
| 2 | 45 | 50 | 165 | 1.58° | 1.48° | 6 |
| 3 | 50 | 40 | 170 | 1.92° | 2.30° | 19 |

## 4.0 CONCLUSION

The relationship between welding process parameter (welding current, welding angle and welding speed) and angular distortion can modelled 2 Factor Interaction model and represented by polynomial equation (1). This model was validated with average residual error of 9%. The ANOVA analysis indicates that the significant factors that influenced the angular distortion are interaction between welding angle and welding speed and the interaction between welding speed and current.

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