The Effect Of The Submerged Arc Welding Parameters To Distortion On The Steel Joints

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Abstract. The ST 37 Steel ordinarily has good tensile strength, hence, the purpose is generally used for the building frame. An electric arc welding is one of the welding methods of joining the metal by means of an electric arc flame which is directed to the metal surface to be joined. The research conducted using factorial Completely Randomized Design (CRD) in the Design Of Experimental method. The aim of this observation is to investigate the influence of independent variables on the dependent variable, whether the types of cooling (X1), types of groove welding (X2) and welding currents (X3) affect to distortion of welding (Y) on the st 37 steel joints. The significant data are indicated by the normal plot distribution in which the significant factors (A, C, AC, BC, and ABC) influenced the response. The A factor is the type of cooling, C factor is welding currents, AC factor is a combination of cooling types and welding currents, BC factor is combination factor between types of groove welding and welding currents, and ABC factor is combination factor of cooling types, groove welding types and welding currents. Based on the regression model reached the value of RSquare is 75.99%, which means the A, C, AC, BC, and ABC factor represent the influence on the distortion of welding at that value. While the rest of 24.01 % is described by other factors

Keywords— Arc welding, Design of experiment, Factorial design, Completely Randomized Design (CRD);

1. Introduction
The development of the industrial world today bringing a change to economy matters of countries and to the prosperity of workers. The use of modern equipment, on the one hand, will provide a convenience to the process of production and productivity of workers [1]. On the other hand, it has the possibility to increase health of workers and safety risks arising from the employment relationship [2].

Technological development in the construction sector is more advanced which cannot be separated from the welding because it has an important role in the engineering and metal reparation [3]. The construction with metal at the present time involves a lot of welding, especially the construction design sector for welding joints is one of making connections that technically requires high skill of the welding in order to obtain a welding connection with good quality [4].

The scope of the use of welding techniques in the construction is very broad including shipbuilding, bridges, steel structures, pressure vessels, transportation, rail, pipelines etc [5]. Factors affecting the welding is the welding procedure that is a plan for the implementation of the research which includes how to manufacture welding construction in accordance with plans and specifications specify all the necessary things in the implementation [6].
Demands for improved productivity, efficiency, and quality pose challenges to the welding requests for upgraded productivity, efficiency, and quality model dares to the welding industry[7]. As materials grow ever more complex in their chemical composition to produce ever-better functionally special properties, a more comprehensive and accurate perception of how such materials can be connected for optimal effectiveness and efficiency will become crucial[8].

Nowadays, arc welding was conducted manually so that the weld quality could be measured by the welder skill [9]. A great attractiveness of welding techniques results from several technical and economic benefits, such as high performance and durability of the method or better circumstances of industrial safety and health in the case of conventional welding technologies[10].

The welder, when welding, can directly monitor flow model in the rut and make quick modifications in welding parameters to achieve great weldability[11]. In research areas and industries frequently applied welding program is submerged arc welding, because of its various advantages such as greater deposition time, high strength joint, and high surface features, high efficiency, low operator ability provision and ease of automation[12]. The effective purpose of any welding process depends on the perception of associated process parameters influence the weld quality[13]. selecting appropriate values for process variables is crucial to control bead size and quality. Welding is the most vital and general work use for bounding of two similar and dissimilar components[14].

Based on the background that has presented, the research is conducted in the laboratory using factorial Completely Random Design (CRD), Design Of Experiment. The researchers want to see the influence of independent variables on the dependent variable whether the types of cooling (X1), types of groove welding (X2) and welding currents (X3) effect to distortion of welding (Y).

1.1 Welding Parameters

Definition of welding according to Deutsche Industrie Norman (DIN) is a metallurgical bond at the junction of the metal or metal alloy which is carried out in a molten or liquid state[15]. In other words, welding is a local connection of several metal rods by using heat energy. Definition according to AWS (American Welding Society) is the process of connecting material by heating until it reaches a temperature welding, with or without the use of pressure or by using a filler metal[16].

The parameters of welding as follow:

a) The electric currents

The use of currents that is too high will cause fusion penetration, sometimes lead to the breakdown of the welding and the heat affected area will be greater as well. If the currents use is too small will cause shallow penetration[17].

b) The welding current

Welding current will determine the form of fusion and reinforcement. The added voltage will make the average welding width increases, the width and the use of flux grew too. The voltage that is too high will damage the closure of the welding metal by a liquid flux that can provide opportunities outside air touching and causing the porosity[18].

c) Types of cooling

Types of cooling is a very important variable in the SAW (Submerged Arc Welding) process because it determines the amount of welding and metallurgy products of welding[19]. The addition of the connection fillet types of cooling is to shorten the time, but at the welding connections are grooved only small blunt short the time[20]. Due to the amount of the deposit is grooved connection variables to the welding time. The types of cooling will reduce heat input to the welding process.

d) The diameter of the wire electrode

Reduction in the diameter of the wire electrode without changing other parameters will increase the pressure arc, which means the penetration will be deeper and wider deposit wane[21].

e) The thickness of the layer of Flux

Flux coating thickness used in the welding process of SAW, it also influence the shape and depth of welding penetration. When the coating is too thin, the currents flux will not be covered and the results will be cracked. When the flux coating is too thick it will generate too high reinforcement[22].

1.2 Design of Experiment

The experiment is a test specifically created to investigate the influence whether or not a given treatment of the research object. The objectives of Experimental design:
a) Effectively, the ability to achieve the goals, objectives, and usability outlined.
b) Managed, namely with regard to the reality of the limitations or constraints contained in the execution of experiments and data analysis.
c) Efficient, namely with regard to the funding, resources, and time. It can be monitored, controlled and evaluated.

2. Objectives
There are two objectives in this study.
a. To know the combination between factors which are significant that conducted in the experiment.
b. To know which among the independent variables are related to the dependent variable.

3. Research Methodology
3.1 The experimental procedure
1. Set up the Check Sheet and the object of the experiment in the form of steel ST 37.
2. Preparation of equipment used for the welding process.
3. Perform the welding process in accordance with the rules of research that will be done is about the effect of the type of cooling, welding groove types, and welding currents are used. The following is the size of the specimens from the specifications to be welded.
4. Collecting data in accordance with a variable combination of data on the Check Sheet.
5. Measurement uses a vernier caliper, with an accuracy of 0.02 mm.
6. Researchers determine the significance level of \( \alpha = 0.05 \).
7. Determination of hypotheses on the results of the experiment will be conducted, in this case, there are three things to be noted:
   a. Must be proven through trial implementation.
   b. Proving to be the right method.
   c. Results of proof can be said to be accepted or rejected.
   The basic model used to this research is using factorial design 23
\[
Y_{ijk} = \mu + \alpha_i + \beta_j + C_k + (\alpha \beta)_{ij} + (\alpha C)_{ik} + (\beta C)_{jk} + (\alpha \beta C)_{ijk} + \varepsilon_{ijk}
\]
\( i = 1,2, \ldots, a; \)
\( j = 1,2, \ldots, b; \)
\( k = 1,2, \ldots, c; \)
Description :
\( Y_{ij} = \) Observation on the experimental unit that receives the treatment combination of the level (i) for A factor, the level (j) for B factor, and the level (k) for C factor.
\( \mu = \) Mean of population.
\( \alpha_i = \) Effect of the level (i) for A factor.
\( \beta_j = \) Effect of the level (j) for B factor.
\( C_k = \) Effect of the level (k) for C factor.
\( (\alpha \beta C)_{ijk} = \) Effect of the level (i) for A factor and the level (j) for B factor and the level (k) for C factor.
\( \varepsilon_{ijk} = \) Influence random from the k-th experimental unit that received the combination treatment \( \varepsilon_{ijk} \sim N(0, \sigma^2) \).

4. Analysis And Discussion
The research carried out in accordance with the treatment combination that is as much as 8 combinations and for each combination which is performed by a total of 4 replications, data necessary means as many as 32 data. Measurement of the specimen is done on two different sides, namely the right and left side. Further processing data which is an average of data collection for each specimen.
Table 2. The collecting data for all combination

| Types of cooling | Circular groove | Welding current | Zig-zag |
|------------------|-----------------|-----------------|---------|
|                  | 90              | 90              | 120     |
|                  | 120             | 90              | 120     |
|                  | 120             | 120             |         |
| Part of specimen | Right side     | Left side       | Right side | Left side | Right side | Left side |
| 1.78             | 1.78            | 2.62            | 2.64     | 2.12      | 2.1        | 2.08      | 2.12     |
| 1.16             | 1.18            | 2.9             | 2.92     | 2.24      | 2.24       | 2.4        | 2.4      |
| 1.64             | 1.56            | 2.14            | 2.14     | 2.98      | 3.06       | 2.78       | 2.74     |
| 1.54             | 1.54            | 2.82            | 2.84     | 1.94      | 1.94       | 1.28       | 1.28     |
| 1.12             | 1.12            | 2.68            | 2.68     | 1.62      | 1.66       | 2.44       | 2.5      |
| 0.74             | 0.72            | 1.98            | 1.98     | 1.02      | 1.02       | 2.24       | 2.28     |
| 1.2              | 1.2             | 2.04            | 1.98     | 0.94      | 0.94       | 2.68       | 2.64     |
| 0.96             | 0.98            | 2.62            | 2.66     | 1.18      | 1.22       | 2.46       | 2.42     |

4.1 Test of Half Normal
The test of half normal for factorial 2^3.

Figure 2. Test of the half-normal plot of standardized effects

The figure 2 shows the absolute values of all effects factor, indicated by the normal plot in which the significant factor affecting the response (A, C, AC, BC, and ABC factor). The A factor is a type of cooling, C factor is welding currents, AC factor is combination of cooling factor and welding currents, BC factor is combination of groove welding factor and welding currents, and ABC factor is combination of cooling factor, types of groove welding and welding currents. It means that there is an influence of distortion factor in the welding process.

4.2 Experimental Data Tabulation
The tabulation of experimental factorial 2^3.

Table 3. Tabulation of experimental factorial 2^3

| Run | CODED FACTOR | Each Rate | TOTAL | Factor level |
|-----|--------------|-----------|-------|--------------|
|     | A            | B         | C     | Replicate 2 | Replicate 3 | Replicate 4 | Low (-1) | High (+1) |
| 1   | -1           | -1        | 1.78  | 1.17        | 1.6         | 1.54        | 6.09 A    | Free air  |
| 2   | 1            | -1        | 2.63  | 2.91        | 2.14        | 2.83        | 10.51 B   | Oil       |
| 3   | -1           | 1         | 2.11  | 2.24        | 3.02        | 1.94        | 9.31 C    | Circular  |
| 4   | 1            | 1         | 2.1   | 2.4         | 2.76        | 1.28        | ab = 8.54 | zig-zag   |
| 5   | -1           | -1        | 1.12  | 0.73        | 1.2         | 0.97        | c = 4.02  | Welling current  |
| 6   | 1            | -1        | 2.68  | 1.98        | 2.01        | 2.64        | ac = 9.31 | 90 120    |
| 7   | -1           | 1         | 1.64  | 1.02        | 0.94        | 1.2         | bc = 4.8  |             |
| 8   | 1            | 1         | 2.47  | 2.26        | 2.66        | 2.44        | abc = 9.83 |             |
4.3 Normal Test Plot

The normal plot of the standardized experimental factorial $2^3$.

![Normal Plot of the Standardized Effects](image)

**Figure 3.** Normal plot of the standardized

The figure 3 describes the significant data, which is indicated by the normal plot of the standardized effects in which the significant factor affecting the response, they are A, C, AC, BC, and ABC. The A factor is a type of cooling factor, C factor is welding currents, AC factor is combination of cooling types and welding currents, BC factor is combination of types of groove welding factor and welding currents, and ABC factor is combination of types of cooling factor, types of groove welding and welding currents.

4.4 Cube Plot

The cube plot for distortion of the results of experimental factorial design $2^3$.

![Cube Plot (fitted means) for Distortion](image)

**Figure 4.** Cube Plot for distortion

As can be seen from the figure 4, the test used for cube plot in the distortion of 3 factors are circular groove, free air and the current at 90 Ampere which get the average distortion at 1.5225 mm. The level of factors (zig-zag, oil and current at 120 Ampere) get the average distortion at 1.0050 mm, and for other factors are similar to the analysis which have described.
4.5 **ANOVA (Analysis Of Variance)**

Analysis of variance which concern to make decision on each factors combination.

| Source                          | DF | Adj SS   | Adj MS   | P-Value | sig  |
|---------------------------------|----|----------|----------|---------|------|
| Model                           | 7  | 10,6963  | 1,52805  | 0.000   | 0.05 |
| Linear                          | 3  | 7,6182   | 2,53941  | 0.000   | 0.05 |
| Types of cooling (A)            | 1  | 1,3163   | 1,31625  | 0.005   | 0.05 |
| Types of groove welding (B)     | 1  | 0.2032   | 0.2032   | 0.241   | 0.05 |
| Welding (C)                     | 1  | 6.0988   | 6.09878  | 0.000   | 0.05 |
| 2-Way Interactions              | 3  | 2.3186   | 0.77285  | 0.005   | 0.05 |
| Types of cooling (A)*Types of groove welding (B) | 1  | 0.0001   | 0.00008  | 0.981   | 0.05 |
| Types of cooling (A)*Welding groove (C) | 1  | 1.3903   | 1.39028  | 0.004   | 0.05 |
| Types of groove welding (B)*welding current (C) | 1  | 0.9282   | 0.9282   | 0.017   | 0.05 |
| 3-Way Interactions              | 1  | 0.7595   | 0.7593   | 0.029   | 0.05 |
| Types of cooling (A)*Types of groove welding (B)*welding current (C) | 1  | 0.7595   | 0.7593   | 0.029   | 0.05 |
| Error                           | 24 | 3.3788   | 0.14078  |         |      |
| Total                           | 31 | 14.0751  |          |         |      |

Decision making:

1. **A Factor** (types of cooling)
   - The types of cooling factor influences distortion of welding, due to the value of P-Value < 0.05 (0.005 <0.05), the decision is that H0 is rejected.

2. **B Factor** (types of groove welding)
   - The types of groove welding factor does not influence distortion of welding, due to the value of P-Value > 0.05 (0.241> 0.05) the decision is that H0 is accepted.

3. **C Factor** (welding currents)
   - The welding currents factor influences distortion of welding, due to the value of P-Value < 0.05 (0.000 <0.05), the decision is that H0 is rejected.

4. **Combination of AB factor** (types of cooling and types of groove welding)
   - The types of cooling factor and types of groove welding do not influence distortion of welding, due to the value of P-Value < 0.05 (0.981> 0.05), the decision is that H0 is accepted.

5. **Combination of AC factor** (types of cooling and welding currents)
   - The types of cooling factor and welding currents influence distortion of welding, due to the value of P-Value < 0.05 (0.004 <0.05), the decision is that H0 is rejected.

6. **Combination of BC factor** (types of groove welding and welding currents)
   - The types of groove welding factor and welding currents influence distortion of welding, due to the value of P-Value < 0.05 (0.017 <0.05), the decision is that H0 is rejected.

7. **Combination of ABC factor** (types of cooling, types of groove welding and welding currents)
   - The types of cooling factor, types of groove welding and welding currents influence distortion of welding, due to the value of P-Value < 0.05 (0.029 <0.05), the decision is that H0 is rejected.

4.6 **Assumption of normality**

The assumption of normality is used to determine the residual value which has a normal distribution or not. The following is plot figure of normal probability.

![Normal probability plot](image-url)
Figure 5 illustrates the residuals follow of normal distribution lines, it can be concluded that the residuals are normally distributed.

4.7 Assumption of Homogeneity

The assumption is used to determine the residual value which has a homogenous from the value of the average variance, the variance is same as the other variance.

Figure 6. plot residual values for the assumption of homogeneity of the distortion of welding

4.8 Model of Regression

Model of regression which is the equation formed from the research that has been done.

\[
Y_{ijk} = \mu + \alpha_i + \beta_j + C_k + (\alpha\beta)_{ij} + (\alpha C)_{ik} + (\beta C)_{jk} + (\alpha\beta C)_{ijk} + \varepsilon_{ijk}
\]

\[
\hat{Y} = 1.9503 - 0.20281 X_i + 0.07968 X_j + 0.43656 X_k + 0.00156 X_{ij} + 0.20846 X_{ik} - 0.17031 X_{jk} + 0.15406 X_{ijk} + \varepsilon_{ijk}
\]

4.9 Analysis of R²

Analysis of R² from the research that has been done

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|------|-----------|------------|
| 0.37521 | 75.99% | 68.99% | 57.32% |

Table 5 shows the regression model obtained the value of R² is 75.99%, which means A, C, AC, BC, and ABC factors describe the Y variable, the distortion of welding at 75.99%. the rest of 24.01% is explained by other factors, from the factors that explain the Y variable for 75.99%.

5. Conclusion

Some conclusions can be taken from this research:

1. The union of factors which are important that carried out in the research are A (types of cooling), C (Welding currents), AB (types of cooling and types of groove welding), AC (types of cooling and welding currents), BC (types of groove welding and welding currents), ABC (types of cooling, types of groove welding and welding currents).
2. According to the model of regression, the value of R² is 75.99%, it means that the factor of A, C, AC, BC, and ABC demonstrates the Y variable, the distortion of welding (75.99%). The rest of 24.01% is described by other factors, from the factors that represent the Y variable for 75.99%. Hence, there is a correlation between independent variables to the dependent variable.

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