# Technical Study of Ship Plate Firing Process Time with Variation of Deformation Values

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**Abstract**

In the process of shipbuilding production and repair, deformation is sometimes encountered due to several factors, starting from load pressure, pulling, lifting, and welding processes. A fairing process is carried out to overcome the plate deformation, in which the plate is heated and cooled simultaneously. The method used in this research is direct time measurement during the fairing process on test plate specimens with variations in the depth of deformation curvature. The data obtained, processed, and analyzed to obtain an estimate of the fairing processing time the longer the fairing process takes, following the equation Y = 41.285X + 530.94, where X is the deformation angle, and Y is the estimation fairing processing time area per half square meter.

*Keywords:* Deformation; Firing; Time estimation

## 1. Introduction

Indonesia is highly competitive in various fields, especially in shipping. The process of building new ships at the shipyard experienced several problems even though the concept and workmanship were by SOP (standard operating procedures). Hot or cold working processes cause inaccurate sizes and ship components' shape deviations [1], [2], [3], [4], [5]. The working process needs to be standardized so the repairs can be carried out quickly, precisely, and of good quality. In the production and repair of shipbuilding, deformations occur due to several factors, starting from load pressure, pulling, lifting, and welding processes [6], [7], [8], [9], [10], [11]. Deformation is a change in the position and dimensions of an object due to stresses in the metal, namely longitudinal and transverse stresses [12], [13], [14], [15]. The deformation of the plate joints is of great concern [16]. This is shown in various standards, giving a deformation tolerance limit of 5x the plate thickness. To overcome this problem, a heating process is used, and then extreme cooling of the plate is often referred to as the fairing process. The fairing process is a method used to improve the ductility and toughness of a plate after it is cold bent [17].

In this study, the method used is line heating. Line Heating is a heating technique that uses a brander flame to make curved shapes or eliminate deformation on steel plates. The heating method refers to IACS no. 47 of the 1996 Shipbuilding Repair Quality Standard with water cooling variations. This method obtains the standard time for the fairing process on the shipbuilding plate deformation.

## 2. Method

### *2.1. Problem Identifications*

Identifying the problem is done by surveying the parameters used in the study. The survey included the place to conduct the testing and the materials for this research. In preparing the specimen for the test object, the first thing to do is to determine the dimensions: half a square meter with a thickness of 6 mm. Then the specimens are divided into three variables, 1xt, 3xt, and 5xt. This process applies pressure from above the material to form the desired angle.

### *2.2. Observation and Measurement*

At this stage, Line Heating treatment is discussed. The process is explained by cutting the plates, bending the test specimens, and heating the line. The heating process has variations in cooling using water cooling. For plate cutting, use a predetermined automatic cutting machine. Before carrying out the line heating process, the material must be subjected to a bending process [18]. The stages of giving deformation to the test plate are as follows: The process begins by preparing the specimen slated for deformation, ensuring meticulous attention to detail. Once prepared, the specimen is carefully affixed to the rolling machine, and the appropriate diameter on the fulcrum is selected to achieve the desired deformation. Next, a measuring tool is readied to serve as a reference for the desired bent plate. Load is then applied to the bending machine until deformation occurs, with measurements taken using a ruler to assess alignment with desired specifications. If necessary, adjustments are made, and the load is reapplied until the desired outcome is achieved. The material is primed and ready for the subsequent line heating process with the deformation completed. The plate that has been deformed to the size that is made will then be carried out by the heating process. Figure 1 shows the result of plate cutting after deformation.

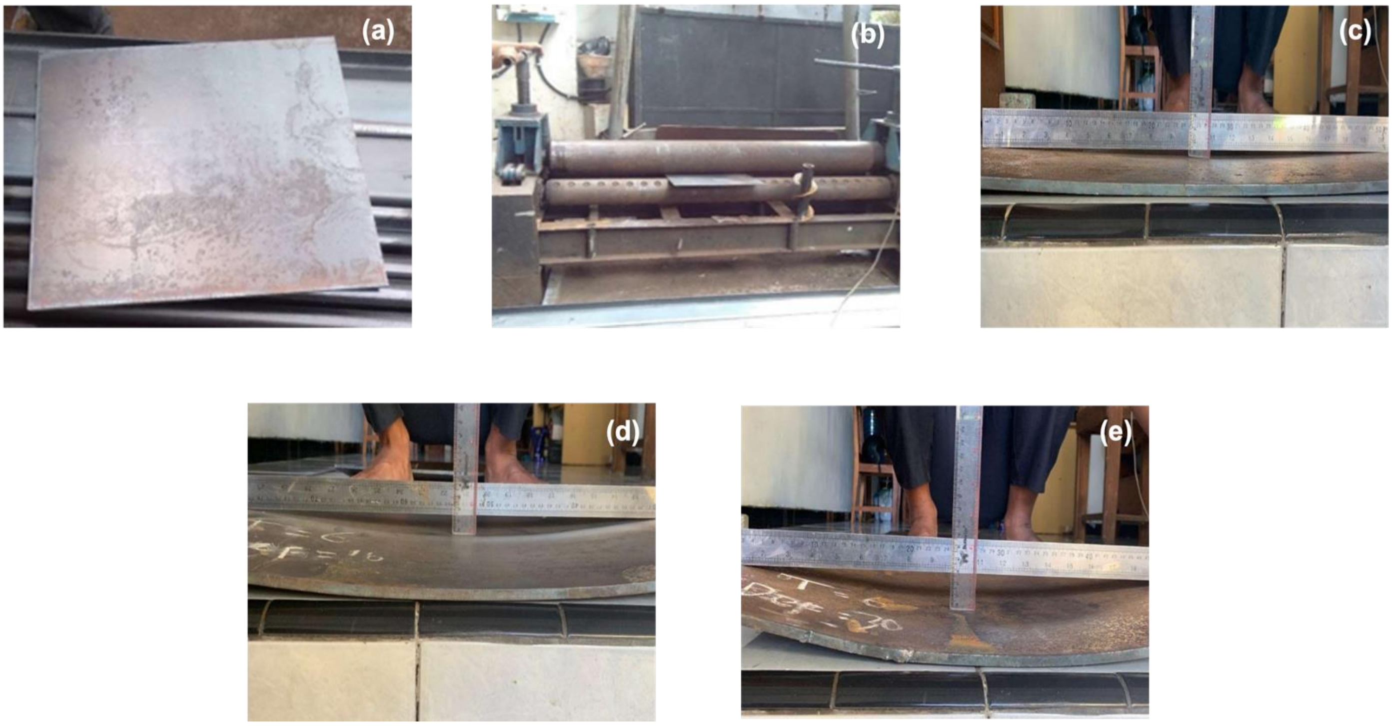


Figure 1. Results of 50 cm x 50 cm plate cutting (a), process specimen deformation (b), plate thickness after one time deformation (c), two times deformation (d), three times deformation (e)

As tools were readied for line heating, scatter tools, oxy-acetylene welding equipment, and water hoses were gathered. Each piece was meticulously installed between the heater and oxy-acetylene gas. The specimen was carefully attached to the rolling machine, ensuring the appropriate diameter on the fulcrum for the desired deformation. Heat adjustments were made to prevent cuts during heating, ensuring smooth operation. Then, water discharge was finely tuned, neither too heavy nor too slow, with a precise rate of 36.67 ml/s determined through meticulous measurement. Test specimens were positioned on the backing plate, ensuring they were perfectly straight to monitor any changes resulting from the heat treatment. The heating process commenced on the test specimens placed on the backing plate, utilizing the provided heat treatment grooves for precision. Heating was initiated once the allowable limit was reached, with variations in cooling achieved through water. The heating results were summarized upon reaching temperatures of 500-600°C, with recorded time indicating the duration of the line heating process, from initial movement to restoration to its original position. Strict temperature control is imperative to ensure compliance with specified requirements throughout the heating process. Should the temperature surpass allowable conditions, the heating speed escalates accordingly.

Conversely, if the temperature falls short, the heating pace is decelerated. Moreover, once heating has been conducted twice, subsequent specimens are substituted with fresh ones, continuing this cycle until all specimens have completed the line heating process [19]. Figure 2 shows the heating flow process and firing process of the specimens.

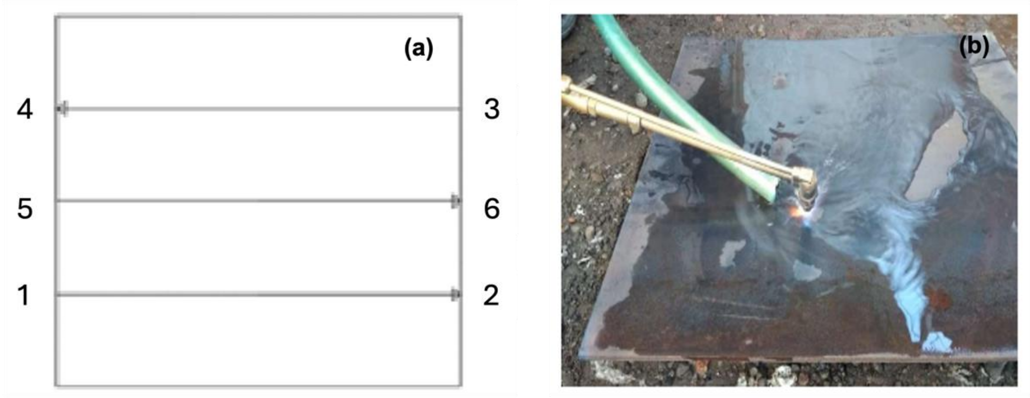

Figure 2. Heating Flow (a) and Firing Process (b)

### *2.3. Analysis*

To obtain an estimate of the fairing processing time, the deformed specimens were faired using a 1.1 mm nozzle diameter brander at 5000C and water-cooling media. The use of temperature in the fairing process varies greatly. This temperature determination does not significantly affect the mechanical properties of the material [20].

The data analysis process uses SPSS software. Before the data is analyzed, data testing will be carried out. The data tests include hypothesis testing and classic assumption testing. The classic assumption test consists of a heteroscedasticity test, a multicollinearity test, a linearity test, and a data normality test. The hypothesis test consists of a linear regression test, a test of the coefficient of determination, and a t-test.

1) Multicollinearity Test
   This classical assumption test analyses multiple regression consisting of two or three independent variables. The multicollinearity test tests whether the regression model found a correlation between the independent variables. In a good regression model, there should be no correlation between the independent variables. The method for testing the presence of multicollinearity can be seen from the Tolerance Value Variance Inflation Factor (VIF). If VIF > 10 or tolerance value < 0.1, multicollinearity occurs.
2) Linearity Test
   The classical assumption test of linearity is used to select the regression. The linearity test is intended to determine whether there is a linear relationship between the dependent variable on the model to be tested. Rules for linearity decisions can be made by comparing the significance value of the deviation from linearity resulting from the linearity test (using SPSS assistance) with the value of α (alpha) used. If the significance value of Deviation from Linearity > α (alpha) is 0.05, then the value is linear.
3) Data Normality Test.
   The normality test is based on research models before the data is processed. It aims to determine the data distribution in the variables used in the research. Data with a normal distribution is excellent and suitable for use in research. Data normality can be seen using the P-P Plots of Regression chart.
4) Simple Regression Test
   Simple regression is used to test one independent variable and the dependent variable. Regression is a causal or causal relationship, namely estimating the magnitude of the increase or decrease in the response (dependent) variable based on the increase or decrease in the independent (independent) variable. In simple regression, the relationship between variables is linear, where variable X changes will be permanently followed by changes in variable Y. Mathematically, a simple regression analysis can be described as follows:

$$Y = A + BX + e \tag{1}$$

Where:
Y: Dependent Variable
A: Intercept or Constanta
B: Regression Coefficient
e: error

5) Coefficient Determination Test
The coefficient determination test (R Square), commonly symbolized by R2, is used to predict how much the influence of variable X contributes to variable Y, provided that the results of the F test in the regression analysis are significant. Conversely, suppose the results in the F test are not significant. In that case, the value of the coefficient of determination cannot be used to predict the contribution of the influence of variable X to variable Y.
The magnitude of the value of the coefficient of determination or R square is only between 0-1. Meanwhile, if the R square is found to be minus (-), then it can be said that X does not affect Y. The smaller the coefficient of determination (R square), the weaker the effect of variable X on variable Y. Conversely, if the R square value gets closer to 1, the impact of variable X on variable Y will be more substantial.
6) T Test
The t-test shows how far the influence of one independent variable individually explains the variation of the dependent variable. Partial regression testing is intended to determine whether the independent variables individually influence the dependent variable, assuming the other variables are constant. To perform the t-test, it can be used with the following formula. The t-test shows how far the influence of one independent variable individually explains the variation of the dependent variable. Partial regression testing is intended to determine whether the independent variables individually influence the dependent variable, assuming the other variables are constant. To perform the t-test, it can be used with the following formula:

$$t = \frac{\beta n}{S\beta n} \tag{2}$$

Whare:
t : Following the t function with degrees of freedom (df)
βn : Regression coefficient of each variable
Sβn : Standard error for each variable.

If the probability (significance) > 0.05 (α) or T count < T table means the hypothesis is not proven, then H0 is accepted, and H1 is rejected if a partial test is carried out. If the probability (significance) < 0.05 (α) or T count > T table means the hypothesis is not proven, then H0 is rejected, and H1 is accepted if a partial test is carried out.

Before collecting research data, researchers made observations regarding deformations that often occur in the field. To overcome this deformation, fairing line heating is carried out, which refers to the Shipbuilding and Repair Quality Standard No. 47 in 1996 with variations of water cooling. To determine the estimated time for the fairing process on shipbuilding plate deformation, a problem limitation is needed, including:
1. The material used is KI grade A
2. The material is half a square meter thick, 6 mm.
3. The deformation curvature angle is 1 x plate thickness, 3 x plate thickness and 5 x plate thickness.
4. The heating method (fairing) used is the line heating method.
5. The equipment used uses a brander with a nozzle diameter of 1.1 mm and a temperature of 500-600°C.
6. Down-hand welding position.
7. The cooling medium is freshwater cooling.

## 3. Results and Discussion

The data used was obtained from direct time measurements. Variations in the deformation angle used are one time, three times and five times the plate thickness because, in the field, deformation can be tolerated if it is still within the provisions/standards used. The tolerance limit is up to 5 times the thickness of the plate used. Each variation of the deformation is carried out in as many as three ways so that the data obtained is 9. The following is a recap of the fairing process data on plate deformation.

Table 1. Data Firing Process

| No | Curvature Deformation | Plate Thickness (mm) | Area (mm) | Firing Time (s) | AVG |
|---|---|---|---|---|---|
| 1 | 1 x Tick Sample A | 6 | 500 | 424 | |
| 2 | 1 x Tick Sample B | 6 | 500 | 466 | 446 |
| 3 | 1 x Tick Sample C | 6 | 500 | 448 | |
| 4 | 1 x Tick Sample A | 6 | 500 | 771 | |
| 5 | 1 x Tick Sample B | 6 | 500 | 806 | 803 |
| 6 | 1 x Tick Sample C | 6 | 500 | 833 | |
| 7 | 1 x Tick Sample A | 6 | 500 | 1052 | |
| 8 | 1 x Tick Sample B | 6 | 500 | 1042 | 1040 |
| 9 | 1 x Tick Sample C | 6 | 500 | 1026 | |

*3.1. Multicollinearity Test*

The multicollinearity test is used to determine whether there are independent variables in a model that are similar. A similarity between the independent variables will result in a robust correlation.

Table 2. Multicollinearity Test Data

| Coefficients [a] | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Unstandardized Coefficients | | Standardized Coefficients | | | Collinearity Statistics | |
| | B | Std. Error | Beta | t | Sig | Tolerance | VIF |
| Constant | 169.111 | 34.067 | | 4.964 | 0.002 | | |
| Curve deformation | 297.000 | 15.770 | 0 .990 | 18.833 | 0.000 | 1.000 | 1.000 |
| a. Dependent Variable: Time Estimation | | | | | | | |

The VIF value in the table above is 1, meaning no multicollinearity exists. Because of the existing provisions, if the resulting VIF is between 1 and 10, then multicollinearity does not occur.

*3.2. Linearity Test*

The linearity test determines whether two variables have a linear relationship. This can be seen from the results of significance; if the sig obtained is <0.05, then the two variables have a linear relationship.

Table 3. Linearity Data Test

| ANOVA | | | | | |
|---|---|---|---|---|---|
| Time Estimation | Sum Of Squares | df | Mean Square | F | Sig. |
| Between Groups | 536534.222 | 2 | 268267.111 | 508.617 | 0.000 |
| Within Groups | 3164.667 | 6 | 527.4445 | | |
| Total | 539698.889 | 8 | | | |

From the table above, a significance value of 0.000 is obtained. That means <0.05, which means that the relationship between the variable deformation curvature (X) and the estimated time (Y) has a linear relationship.

### *3.3. Data Normality Test*

The normality test determines whether the residual values from the regression are normally distributed. A good regression model has normally distributed residual values. The normality test method uses the normal P-P plot of the regression graph.

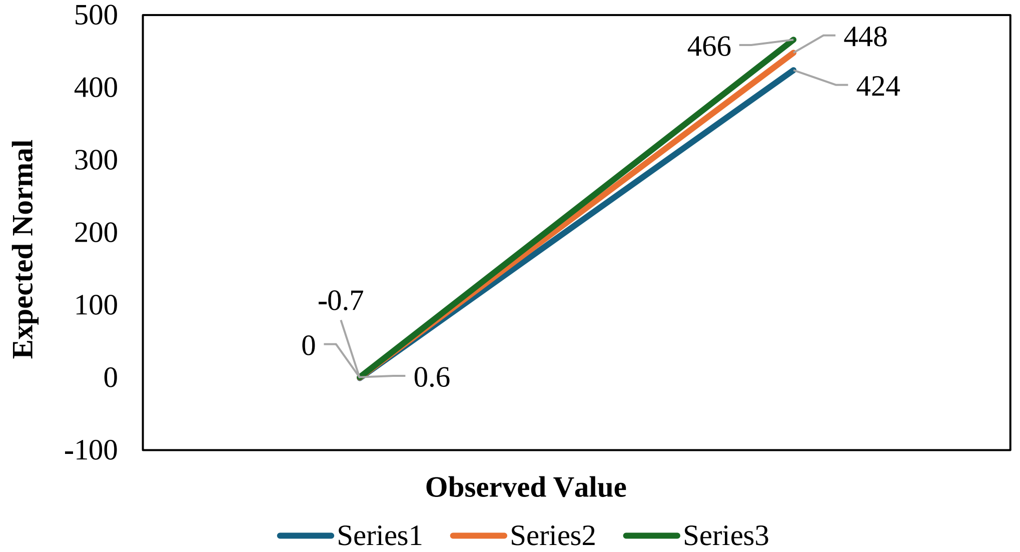


Figure 3. Normality-Distributed Residual Values

If the residuals come from a normal distribution, then the value of the data distribution lies around a straight line. In the picture above, the distribution of the chart data is spread around the line and follows the diagonal line, fulfilling normality.

### *3.4. Simple Regression Test*

Regression aims to examine the effect of one variable on another variable. Linear regression has one dependent variable (time estimate) and one independent variable (deformation curvature).

Table 4. Regression Data Test

| | **Unstandardized Coefficients** | | **Standardized Coefficients** | | |
|---|---|---|---|---|---|
| | **B** | **Std. Error** | **Beta** | **t** | **Sig** |
| Constant | 31.611 | 26.932 | | 11.793 | 0.00 |
| Curve Deformation | 24.750 | 1.314 | 0.990 | 18.833 | 0.00 |

The significance value obtained is 0.000 <0.05, which means that H0 is rejected, so it can be concluded that the deformation curvature variable (X) affects the estimated time (Y). The regression equation obtained is Y = 24.750x + 317.611.

### *3.5. Coefficient Determination Test*

Table 5. Coefficient Determination Test

| **Model Summary** | | | | |
|---|---|---|---|---|
| **Model** | **R** | **R Square** | **Adjusted R Square** | **Std. Error of the Estimate** |
| 1 | 0.990[a] | 0,981 | 0.978 | 38.628 |
| a. Predictors: Constant, Curve deformation | | | | |

From the table above, the coefficient of determination, or R square, is 0.981. The magnitude of R square 0.981 equals 98.1%. This figure means that technological developments affect consumptive behaviour by 98.1%, while other variables outside this regression model influence the rest. The R square value obtained is close to 1, which means that the effect of deformation curvature on the estimated time is very strong.

### *3.6. T Test*

The t-test tests how each independent variable influences the dependent variable individually.

Table 6. T-Test Data

| Coefficients | | | | | |
|---|---|---|---|---|---|
| | **Unstandardized Coefficients** | | **Standardized Coefficients** | | |
| | **B** | **Std. Error** | **Beta** | **t** | **Sig** |
| Constant | 317.611 | 29.932 | | 11.793 | 0.000 |
| Curve deformation | 24.750 | 1.314 | 0.990 | 18.833 | 0.000 |
| a. Dependent Variable : Time Estimation | | | | | |

As seen in the table above, it is known that the t value is 18.833 > t table 12.708. So, it can be concluded that the deformation curvature variable (X) affects the time estimation variable (Y).

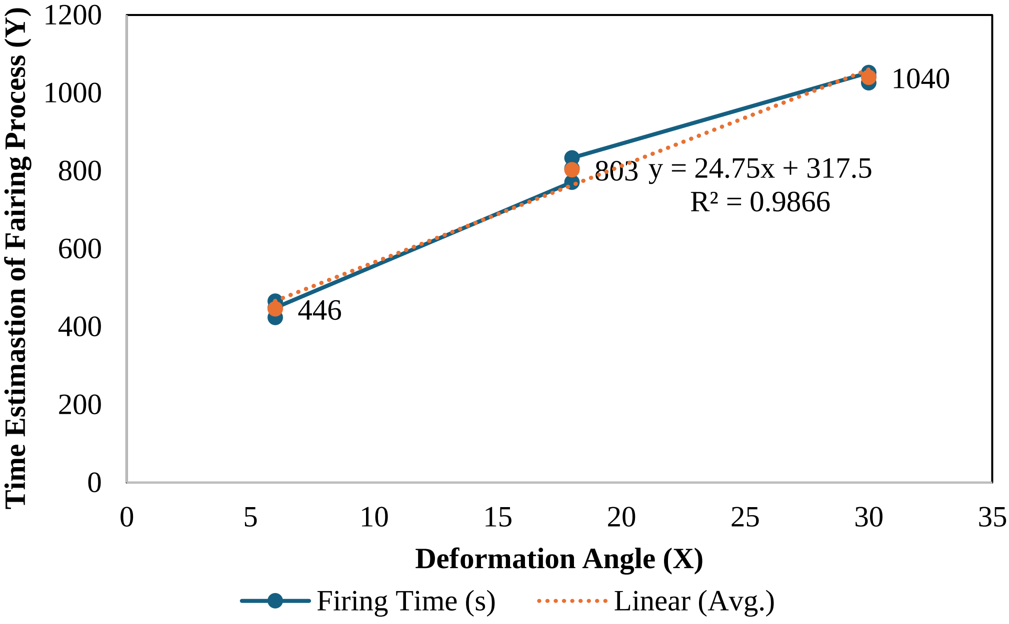


Figure 4. Graphic of Linear Regression Transform

The graph above explains the magnitude of the correlation/relationship value (R) between the deformation angle and the heating process time required for the fairing process; the ship-building deformation is 0.986, which is included in the excellent category. A positive regression coefficient indicates that the direction of influence is positive, meaning that the greater the deformation angle, the longer the standard time used. The regression linier transform Y= 24.75x + 317.5. An example of applying the equation to variations in deformation depth of 2 x plate thickness is as follows:

$$Y = 24.75x+317.5 =24.75 \times 12+317.5 = 614.5 \text{ second} \quad (3)$$

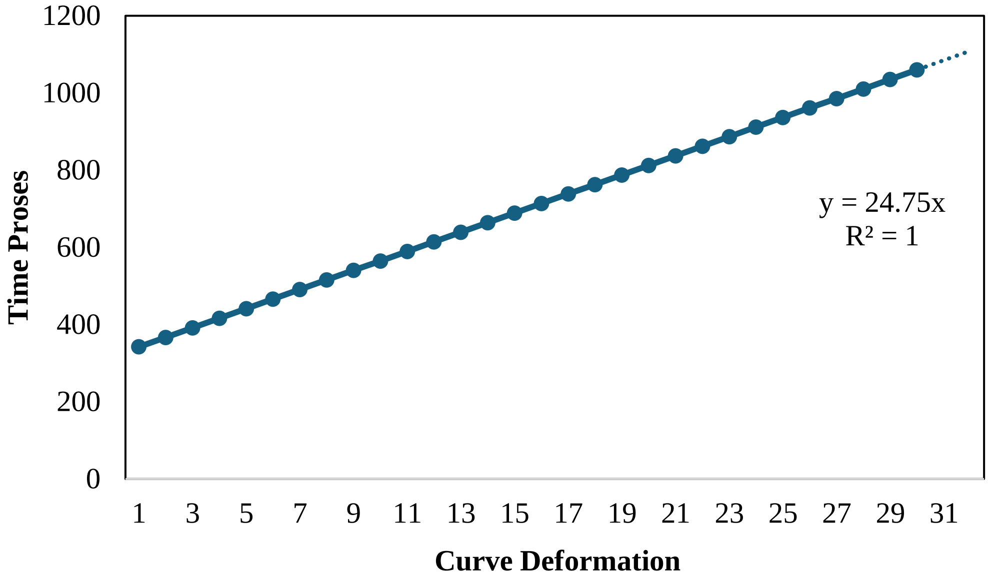


Figure 5. Graphic of Time Deformation Transform

The graph above explains the magnitude of the correlation value (R) between the deformation angle and the heating process time required for the fairing process in shipbuilding deformation, namely one or constant. A positive regression coefficient indicates that the direction of the influence is positive, meaning that the greater the deformation, the longer the time used. From the graph above, the linear regression equation Y= 24.75x is obtained. This means the time used increases by 24.75 seconds for every additional deformation per mm. To determine the effect of the independent variable (curvature deformation) on the dependent variable (Time Estimate), data processing was carried out using the SPSS 25 for Windows program. The results of data processing have gone through hypothesis testing.

Hypothesis testing can be seen in the t-test, which shows that the influence of the curvature angle on time estimation is significant; this can be seen from the sig value of 0.000, which is less than 0.05. This is also supported by the calculated t value, which is more significant than the table t value. The calculated t value obtained is 18.833, more significant than the t table of 12.708. Thus, the hypothesis H0 is rejected and H1 is accepted, which means that the curvature of the deformation can influence the estimated time of the fairing process.

The one-way F test produces a calculated F of 508.617 with a significance of 0.000, which is smaller than 0.05, which means that the curvature of the deformation affects the estimated fairing work process time. The research variable can be seen in R square to determine how significant the coefficient of determination (R) is. The R square obtained is 0.986 or 98.6%, which means that the estimated time can be explained by the curvature deformation variable of 98.6%, while other factors explain the remaining 1.4%. The angle of curvature of the deformation influences the estimated time of the fairing process, which is classified as vital because the resulting value is close to 1.

The beta value for the constant in Unstandardized Coefficients is 317.611. This shows that the influence of curvature deformation on time estimation is high. The beta value for the technology development variable is 24.750 or 24.75%. This means that when the deformation curvature increases by 1 point, the estimated time behavior rises by 24.75%. A positive regression coefficient indicates that the direction of influence is positive, meaning that the greater the deformation angle, the longer the standard time used. So, the regression equation is Y= 24.75x + 317.5.

## 4. Conclusions

Based on the data analysis obtained, it is concluded that the estimated time required for the fairing process adheres to the equation Y = 41.285X + 530.94, where X represents the deformation angle, and Y signifies the estimated time for the fairing process per half-square meter. Moreover, with each additional 1 mm of deformation, the time required escalates by 24.75 seconds. Navigating the research process inevitably encounters obstacles and shortcomings. To facilitate refinement in future research endeavors, the following recommendations are proposed: Experiment with various material thickness variations in upcoming fairing processes is advised to ascertain the estimated time required for the heating process. Introducing plate deformation variations of 2x and 4x plate thickness can provide valuable insights. In addition, it is advisable to incorporate variations of cooling with air in addition to those conducted with water. Given field conditions, the water temperature may surpass the designated threshold, rendering the heated material excessively brittle for further fabrication. Hence, periodic temperature monitoring during the heat treatment process is indispensable.

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