Material Effectiveness Model for the Construction of Aluminum Hull

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Abstract

Construction of a hull generally requires several plates and profile material. Early indications for shipbuilding indicate that in manner, the linear function approach for installed material was 75% to 90%, and waste material was 10% to 25%. This study found that an assessment of the area of installed material and waste material on small vessels made of aluminum with variations in ship length and the method of approach trend lines both linear and nonlinear. Secondary data retrieval in the form of an aluminum cutting plan for profile material and profile from the AutoCAD application, which is then reprocessed through the FastCAM application to obtain results in the form of identification of installed material and waste material area. Based on variations in length and material area results, a scatter plot process was carried out through the Excel application to obtain results in the form of trend line functions with an R-squared determination coefficient of more than 0.9 and the results of the calculation of the intersection between the function of installed material and waste material, and the waste material function with the x-axis uses the balance method. The final result showed that the linear function gives an indication of the effectiveness of the material located in the range of 6 to 23 meters in length of the boat and polynomial function of order 2 in the range of 6 to 18 meters in length, while the waste material area in the two functions maximum 22%.

1. Introduction

Shipbuilding was characterized by heavy fluctuations of demand over the short-term and high material supply, leading to short periods of prosperity and long periods of depression [1]. On the other hand, the steel material contributes 50% to 70% of the total cost of building a ship, wherein the fabrication stage in the cutting process, there was waste material that is still difficult to measure systematically [2]. It follows that the effectiveness of the use of materials in the construction of a hull consisting of installed and waste materials has not been fully controlled. The tendency on the part of the shipbuilding industry wants to keep the volume of waste material as minimal as possible. According to Bossink and Brouwers [3] that sources of waste material, such as: lack of attention paid to the sizes of the used products, lack of influence of contractors, and lack of knowledge during design activities.

There are several previous studies in Indonesian shipyard. E. Setiawan and A. Azhar compared the value of the installed material area in the form of plates larger than the waste material and the installed material area in the form of a smaller profile than the waste material in 5 tanker blocks [4]. M. F. Kusuma compared the value of the wasted material based on planning calculations and nesting drawings for 100 TEUS container vessels in DB4 block [5] and A. N. Ramadhan compared the weight of the waste material between the manual cutting method and the NC cutting method on four blocks of a steel vessel [6]. E. Setiawan and A. Azhar compared the value of the installed material area in the form of plates larger than the waste material and the installed material area in the form of a smaller profile than the waste material in 5 tanker blocks [4]. M. F. Kusuma compared the value of the wasted material based on planning calculations and nesting drawings for 100 TEUS container vessels in DB4 block [5] and A. N. Ramadhan compared the weight of the waste material between the manual cutting method and the NC cutting method on four blocks of a steel vessel [6].

There are several previous studies too from the outside of Indonesian shipyard. The profile and plate in order cutting process by CNC machine showed that 360 cut steel tons work performed by the Shipyard, only about 75% of the steel plate was used for parts generation, the remaining 25% of waste material can be reused for small parts cutting or sold as scrap [7]. The shortcomings of conventional approach and traditional mathematical modeling with the analytic solution for complex production processes design have been perceived [8]. Furthermore, the suitability of discrete event simulation modeling method application for designing shipyard processes, in particular, has been determined through the case study of designing the shipbuilding production process of fabrication line. Therefore the process quality was of critical importance in the
shipbuilding industry, and there are three main factors affecting process quality, such as: the flow of information between engineering phase and production phase, the amount of rework, and the delays[9].

Based on previous research studies, it showed that a simple linear approach to the waste material on steel vessels would increase linearly to reach 25%, while this study assessing the area of installed material and waste material on small vessels made of aluminum with variations in ship length and the method of approach trend lines both linear and non-linear. This study aims to find the limit of the length of the ship that is able to be built and the extent of the waste material produced, while for the research benefits obtained is the flexibility of linear and non-linear functions through the length of the ship in finding a balance of the use of installed and waste materials.

2. Methods

2.1. Aluminum Material Data

The aluminum material used in the shipbuilding process has marine use standards of type 5052 and 5083, which have been approved by the classification. On the other hand, aluminum material has a very good level of strength and weight ratio when compared to steel ship construction materials in general [10].

Secondary data retrieval in the form of a cutting plan of 5 (five) aluminum boats obtained from CV. Javanese Boat is one of the aluminum ship industries with the main workshop located in the Safe N Lock Industrial Zone in the East Ring city of Sidoarjo, as shown in Table 1 [11].

| No | Length (m) | Breadth (m) | Height (m) | Draught (m) | Production Code |
|----|------------|-------------|------------|-------------|-----------------|
| 1  | 5          | 2.0         | 1.0        | 0.25        | JAL 5620        |
| 2  | 6          | 2.2         | 1.0        | 0.30        | JAL 6525        |
| 3  | 10         | 2.7         | 1.2        | 0.45        | JAL 1028        |
| 4  | 10.5       | 2.8         | 1.3        | 0.45        | JAL 1029        |
| 5  | 12         | 3.0         | 1.6        | 0.60        | JAL 1234        |

2.2. Material Cutting

Cutting aluminum material activities in CV. Javanese Boat uses NC Cutting engine with the support of FastCam-FastNet and AutoCAD software. The FastCAM system has been designed to draw, nest, and cut metal as simply and efficiently as possible. Ease of use was as important as the high levels of materials utilization and optimization the software provides. FastCAM’s long experience in heavy plate fabrication makes the system ideal for even the largest construction projects. The FastCAM system was used successfully in Service Centers, Shipbuilding, Mining, Steel Fabrication, Metal Fabrication, and Sign Cutting.

Where drawing information exists electronically, FastCAM has an extremely Powerful CAD interface that cleans and compresses code ready for quality cutting. FastCAM Reads and/or Nest DXF, DWG, DSTV/NC1, StruCAD, IGES, and PDF file formats. Cut plan drawings were done through AutoCAD software and image output with the file extension in the form of DXF or DWG. Furthermore, the cut plan image was entered into the FastCam software as software for the nesting plan in an effort to maximize the use of installed materials and minimize waste material.

2.3. Scatter Plots and Trend Lines

Scatter plots use points that represent values for two different numerical variables and use to observe relationships between variables. The position of each point on the horizontal and vertical axis shows values for individual data points [12, 13, 14]. Trend lines were created by connecting between peaks or valleys along with the trend. There were three types of trend lines, and there were: internal, external, and curved. Reliable trend lines through time, points on trend lines, and slope angles of 24 degrees to 30 degrees [15, 16].

Approaching logarithmic function models with the help of Minitab software can be used to calculate used tanker prices [17]. In comparison, another approach in the form of multiple regression functions with the help of SPSS devices can be used for general cargo loading calculations [18].

For scatter plot and trend line analysis in this study using Ms. Excel Software to produce 5 (five) types of functions, such as linear, exponential, logarithmic, polynomial, and power functions. The selection criteria for the various functions are through the trend line movement, the coefficient of determination with R-squared notation, the point of intersection between the function of attached material and the waste material, and the point of intersection between the function of waste material with the x-axis as an indicator of the length of the aluminum ship. If the value of R-square was getting closer to the value of 1, then the regression model can be said to meet [19].

Trend line analysis was a linear least squares regression tool that can be employed to provide some correlation to data points that are seemingly not linked at all. The Trend line analysis package was a built-in analysis tool in Excel. There were several types of trend lines correlation functions, which are Linear Fit (Eq. 1), Exponential Fit (Eq. 2), Logarithmic Fit(Eq. 3), Polynomial Fit/oro 2(Eq. 4), and Power Fit (Eq. 5) [20]:

\[ y = ax \pm b \]

\[ y = ae^{bx} \]
\[ y = a \ln(x) \pm b \]  
\[ y = ax^b \pm bx \pm c \]
\[ y = ax^b \]

where \( y \) = dependent variable or respond variable as the material area, \( x \) = independent variable or predictor variable as length over all of ship, \( a, b, c \) = regression coefficient.

The accuracy of the fit can be interpreted using the R-squared value (the coefficient of determination): 1) \( 0.0 < \text{R-squared value} \leq 0.5 \) interpreted poor, 2) \( 0.5 < \text{R-squared value} \leq 0.8 \) interpreted moderate, 3) \( 0.8 < \text{R-squared value} \leq 1.0 \) interpreted good fit. According to Frost [21] a physical process which have very good measurements, it expects R-squared values over 0.9 or 90%.

3. Results and Discussion

3.1. Calculation of the Material Area

Cutting plan drawing with AutoCAD software for the design of construction plate shape patterns from JAL 5620, JAL 6525, JAL 1028, JAL 1029, and JAL 1234 in 2 Dimensions, as shown in Figure 1. The results of the work plan were converted into FastCam to determine the location (marking) of the construction parts to the plate sheet. The final result of the nesting process was in the form of the display area of installed material and waste material, as shown in Table 2a-2e, Table 3, and Figure 2.

It can be seen that the waste material was formed because lack of optimizing design from the cutting plan and natural process from plate cutting activities. The source of waste material, according to Bossnik [3] was a lack of knowledge during design activities. Meanwhile, the compilation of material identification shown in Table 3 and Figure 2.

Based on Table 3 and Figure 2 can be seen that the length of boats required a greater area of installed material and vice versa for the smaller waste material. Meanwhile, across the line between installed and waste material occurs in length of the boat less than 6.5 meters and cutting plan from the used material less than 50% so that the waste material can be used to next boat.

![Figure 1. No. 2 of Cutting Plan JAL 1028 in FastCam](image1)

![Figure 2. Area Description of Installed and Waste Material](image2)
Table 2a. Identification of Material from JAL 5620 Boat Length = 5 m

| Plate Position                  | Nesting Code | n - Plate |
|--------------------------------|--------------|-----------|
| Bottom Plate (P&S)              | A0           | 6.5546    |
| Side Girder (P&S)               | A1           | 4.4444    |
| Face Side Girder (P&S)          | A2           | 1.8843    |
| Centre Girder (C)               | A2.1         | 0.2624    |
| Centre Floor (P&S)              | A3           |           |
| Face Centre Floor (P&S)         | A3.1         | 0.0389    |
| Side Floor Fr.01-05 (P&S)       | A4.1.1       | 1.0754    |
| Side Floor Fr.06 (P&S)          | A4.1.2       | 0.8608    |
| Side Floor Fr.07 (P&S)          | A4.1.3       | 0.3977    |
| Side Floor Fr.08 (P&S)          | A4.1.4       | 0.2298    |
| Face Side Floor Fr.01-05 (P&S)  | A4.2.1       | 0.5015    |
| Face Side Floor Fr.06 (P&S)     | A4.2.2       |           |
| Face Side Floor Fr.07 (P&S)     | A4.2.3       |           |
| Face Side Floor Fr.08 (P&S)     | A4.2.4       |           |
| Bottom Transverse Fr.01,02,03,05 (P&S) | A5.1.1 | 0.2633 |
| Bottom Transverse Fr.07 (P&S)   | A5.1.2       | 0.0649    |
| Bottom Transverse Fr.08 (P&S)   | A5.1.3       | 0.0681    |
| Bottom Transverse Fr.09 (P&S)   | A5.1.4       | 0.0751    |
| Tank Top (P&S)                  | A6           | 3.2352    |
| Bulkhead                        | A7           | 0.3281    |
| Transom                         | A8           | 0.9907    |
| Total Area (m²)                 | 5.8670       | 4.1863    |
| Total Installed Material (m²)    | 19.1716      |           |
| Total Waste Material (m²)       | 25.8284      |           |
Side Floor Fr.01-02 (P&S) | C4.1.1 | 0.5452 | - | - | - | - | -
Side Floor Fr. 04, 07, 08, 10, 11 (P&S) | C4.1.2 | 1.3195 | - | - | - | - | -
Side Floor Fr.05 (P&S) | C4.1.3 | 0.3953 | - | - | - | - | -
Side Floor Fr.13 (P&S) | C4.1.4 | 0.2566 | - | - | - | - | -
Side Floor Fr.14 (P&S) | C4.1.5 | 0.2523 | - | - | - | - | -
Side Floor Fr.16 (P&S) | C4.1.6 | 0.2417 | - | - | - | - | -
Side Floor Fr.17 (P&S) | C4.1.7 | 0.1378 | - | - | - | - | -
Face Floor (P&S) | C4.2 | - | - | - | 2.1099 | - | -
Bottom Transverse Fr.01-11 (no Fr.03&09) (P&S) | C5.1.1 | 0.9800 | - | - | - | - | -
Bottom Transverse Fr.12-17 (no Fr.15) (P&S) | C5.1.2 | 0.5474 | - | - | - | - | -
Frame 01-15 (P&S) | C6.1 | - | - | - | 1.7679 | - | -
Frame 16-17 (P&S) | C6.2 | - | - | 0.2473 | - | - | -
Frame 18 (P&S) | C6.3 | - | - | - | 0.1435 | - | -
Bulkhead 03 (P&S) | C7.1 | - | - | - | 0.6566 | - | -
Bulkhead 06 (P&S) | C7.2 | 0.1977 | - | - | - | - | -
Bulkhead 09 (P&S) | C7.3 | - | - | - | - | - | 0.6535
Bulkhead 12 (P&S) | C7.4 | 0.1950 | - | - | - | - | -
Bulkhead 15 (P&S) | C7.5 | - | - | - | - | 0.5739 | -
Bulkhead 17 (P&S) | C7.6 | - | - | - | 1.6443 | - | -
Bulkhead 18 (P&S) | C7.7 | - | - | 0.1877 | - | - | -
Transom | C8 | - | - | - | - | - | 1.4638
Vender | C9 | - | - | - | 1.5648 | - | 1.5648
Stiffener | C10 | 0.2747 | - | - | - | - | -
Bracket | C11 | - | - | 0.2616 | - | - | -
Chine Hull | C12 | - | - | - | 0.5711 | - | 0.5285
Fin Stabilizer | C13 | - | - | - | - | - | - | 0.8758

**Total Area (m²)** | 5.6328 | 2.2141 | 5.5736 | 8.3449 | 8.9645 | 6.1924 | 5.8102
**Total Installed Material (m²)** | 42,7324 | - | - | - | - | - | -
**Total Waste Material (m²)** | 20,2676 | - | - | - | - | - | -

| Position | Nesting Code | n - Plate |
|----------|--------------|-----------|
| Bottom Plate (P&S) | D0 | | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Side Girder (P&S) | D1 | - | - | 2.4991 | 2.4991 | - | - | - | - |
| Face Side Girder (P&S) | D1.1 | - | - | - | - | - | - | 0.9000 | - | - |
| Centre Girder | D2 | - | - | - | - | - | - | - | - | - |
| Face Centre Girder | D2.1 | - | - | - | - | - | - | - | - | - |
| Tank Top (P&S) | D3 | - | - | - | - | - | - | - | - | - |
| Side Floor Fr.01-02 (P&S) | D4.1.1 | 0.8196 | - | - | - | - | - | - | - | - |
| Side Floor Fr. 03-08 (P&S) | D4.1.2 | 1.9054 | - | - | - | - | - | - | - | - |
| Side Floor Fr.09 (P&S) | D4.1.3 | 0.4217 | - | - | - | - | - | - | - | - |
| Side Floor Fr.10 (P&S) | D4.1.4 | 0.2704 | - | - | - | - | - | - | - | - |
| Side Floor Fr.11 (P&S) | D4.1.5 | 0.2523 | - | - | - | - | - | - | - | - |
| Side Floor Fr.12 (P&S) | D4.1.6 | 0.3663 | - | - | - | - | - | - | - | - |
| Side Floor Fr.13 (P&S) | D4.1.7 | 0.3238 | - | - | - | - | - | - | - | - |
| Side Floor Fr.14 (P&S) | D4.1.8 | 1.2959 | - | - | - | - | - | - | - | - |
| Side Floor Fr.15 (P&S) | D4.1.9 | 0.1694 | - | - | - | - | - | - | - | - |
| Side Floor Fr.16 (P&S) | D4.1.10 | 0.1008 | - | - | - | - | - | - | - | - |
| Side Floor Fr.17 (P&S) | D4.1.11 | 0.0590 | - | - | - | - | - | - | - | - |
| Side Floor Fr.18 (P&S) | D4.1.12 | 0.0839 | - | - | - | - | - | - | - | - |
| Side Floor Fr.19 (P&S) | D4.1.13 | 0.0231 | - | - | - | - | - | - | - | - |
| Face Floor (P&S) | D4.2 | - | - | - | 0.3098 | 0.9215 | - | - | - | - |
| Bottom Transverse Fr.01 (P&S) | D5.1.1 | - | - | - | - | - | - | - | - | - |
| Bottom Transverse Fr.02-08 (P&S) | D5.1.2 | - | - | - | 1.2533 | - | - | - | - | - |
| Bottom Transverse Fr.09 (P&S) | D5.1.3 | - | - | - | 0.1567 | - | - | - | - | - |
| Bottom Transverse Fr.10 (P&S) | D5.1.4 | - | - | - | 0.1570 | - | - | - | - | - |
| Bottom Transverse Fr.11 (P&S) | D5.1.5 | - | - | - | 0.1529 | - | - | - | - | - |

Table 2d. Identification of Material from of JAL 1029 Boat Length = 10.5 m
| Position                        | Nesting Code | n - Plate |
|--------------------------------|--------------|-----------|
| Bottom Transverse Fr.12 (P&S)  | D5.1.6       | 0.7365    |
| Bottom Transverse Fr.13 (P&S)  | D5.1.7       | 0.1636    |
| Bottom Transverse Fr.14 (P&S)  | D5.1.8       | 0.1990    |
| Bottom Transverse Fr.15 (P&S)  | D5.1.9       | 0.2076    |
| Bottom Transverse Fr.16 (P&S)  | D5.1.10      | 0.5155    |
| Bottom Transverse Fr.17 (P&S)  | D5.1.11      | 0.3048    |
| Keel                           | D6           | 0.9600    |
| Face Keel                      | D6.1         | 0.4000    |
| Bulkhead 01 (P&S)              | D7.1         | 0.3787    |
| Bulkhead 12 (P&S)              | D7.2         | 0.3683    |
| Bulkhead 16 (P&S)              | D7.3         | 0.2577    |
| Bulkhead 17 (P&S)              | D7.4         | 0.1524    |
| Transom                        | D8           | 1.4719    |
| Vender                         | D9           | 1.6730    |
| Stiffener                      | D10          |            |
| Bracket                        | D11          |            |
| Chine Hull                     | D12          | 0.8744    |
| Fin Stabilizer                 | D13          | 2.1082    |

Total Area (m²) = 6.0917 + 6.1077 + 8.5468 + 7.9626 + 4.4970 + 7.9411 + 4.2959 = 7.4090

Total Installed Material (m²) = 52.8518

Total Waste Material (m²) = 17.1482

Table 2e. Identification of Material from JAL 1234 Boat Length = 12 m
Table 3. Area of Aluminum Materials

| No | Length (m) | Installed Material (m²) | Waste Material (m²) |
|----|------------|-------------------------|---------------------|
| 1  | 5          | 19.1716                 | 25.8284             |
| 2  | 6          | 20.6548                 | 25.3452             |
| 3  | 10         | 42.7324                 | 20.2676             |
| 4  | 10.5       | 52.8518                 | 17.1482             |
| 5  | 12         | 56.1855                 | 15.8145             |

3.2. Scatter Plots and Trend Lines

Based on Figure 2, the scatter plots and trend lines using Ms. Excel software shown in Figure 3. There are 10 trend lines function that can be obtained with various functions and R-squared, as shown in Table 4.

**Figure 3. Scatter Plots and Trend Lines from Material Effectiveness of Aluminum Boats**

Table 4. Aluminium Material Trend Lines Function

| Trend Line   | Function                        | R²     |
|--------------|---------------------------------|--------|
| Linear       | Yd = 5.6901x − 11.184           | 0.9698 |
|              | Yt = −1.4835x + 33.788          | 0.9598 |
| Exponential  | Yd = 7.9832e0.183x              | 0.9773 |
|              | Yt = 38.04e−0.071x              | 0.9435 |
| Logarithmic  | Yd = 4.684ln(x) − 55.875        | 0.9552 |
|              | Yt = −11.6ln(x) + 45.327        | 0.9367 |
| Polynomial   | Yd = 0.0997x² + 4.0269x − 4.9941| 0.9705 |
|              | Yt = −0.0863x² − 0.0433x + 28.427| 0.9671 |
| Power        | Yd = 2.0813x1.3347              | 0.9750 |
|              | Yt = 65.865x0.554               | 0.9132 |

Based on Figure 3, Table 4 and the criteria for selecting the trend line through the degree of slope of the function, R-squared [20, 21], the intersection point between functions, and the intersection point between the function with the x-axis, the selected trend lines function are as shown in Eq. 6 – Eq. 9:

1. Linear Function

   \[ Y_d = 5.6901x - 11.184 \]  
   \[ Y_t = -1.4835x + 33.788 \]

2. Polynomial Function Ordo-2

   \[ Y_d = 0.0997x^2 + 4.0269x - 4.9941 \]  
   \[ Y_t = -0.0863x^2 - 0.0433x + 28.427 \]
3.3. Intersection Of The Order-2 Polynomial Function

The calculation for the intersection of two linear functions and the linear function of the waste material with the x-axis is as follows:

\[ Y_{Lt\text{installed}} = Y_{Lt\text{waste}} \]
\[ 5.6901x - 11.184 = -1.4835x + 33.788 \]
\[ (5.6901 + 1.4835)x = 33.788 + 11.184 \]
\[ Y_{Lt\text{installed}} = Y_{Lt\text{waste}} \]
\[ Xd = Xt = X\text{Linear1} = 6.2691 \text{ m} \]
\[ Yd = 5.6901x - 11.184 \]
\[ Yd = (5.6901 \times 6.2691) - 11.184 \]
\[ Yd = Yt = Y\text{Linear} = 24.4878 \text{ m}^2 \]

\[ Y_{Lt\text{waste}} = f(x\text{-axis}) \]
\[-1.4835x + 33.788 = 0 \]
\[ 1.4835x = 33.788 \]
\[ X\text{Linear2} = 22.7759 \text{ m} \]

Interpretation of Figure 4 and the results in the calculation of the intersection of linear functions in Eq. 10 and Eq. 11 are shown in Table 5.

| LoA (m) | Installed Material (m²) | Waste Material (m²) | Total Material (m²) | % Waste |
|--------|------------------------|---------------------|---------------------|---------|
| 6      | 22.9566                | 24.8870             | 47.8436             | 52.02   |
| 6.2691 | 24.4878                | 24.4878             | 48.9756             | 50.00   |
| 7      | 28.6467                | 23.4035             | 52.0502             | 44.96   |
| 8      | 34.3368                | 21.9200             | 56.2568             | 38.96   |
| 9      | 40.0269                | 20.4365             | 60.4634             | 33.80   |
| 10     | 45.7170                | 18.9530             | 64.7000             | 29.31   |
| 11     | 51.4071                | 17.4695             | 68.8766             | 25.36   |
| 12     | 57.0972                | 15.9860             | 73.0832             | 21.87   |
| 13     | 62.7873                | 14.5025             | 77.2898             | 18.76   |
| 14     | 68.4774                | 13.0190             | 81.4964             | 15.97   |
| 15     | 74.1675                | 11.5355             | 85.7030             | 13.46   |
| 16     | 79.8576                | 10.0520             | 89.9096             | 11.18   |
| 17     | 85.5477                | 8.5685              | 94.1162             | 9.10    |
| 18     | 91.2378                | 7.0850              | 98.3228             | 7.21    |
| 19     | 96.9279                | 5.6015              | 102.5294            | 5.46    |
| 20     | 102.6180               | 4.1180              | 106.7360            | 3.86    |
| 21     | 108.3081               | 2.6345              | 110.9426            | 2.37    |
| 22.7759| 118.4131               | 0.0000              | 118.4131            | 0.00    |
| 23     | 119.6883               | -0.3325             | 119.3558            | -0.28   |

Based on Table 5 the following results are obtained that the effectiveness span of aluminium shipbuilding has a length which was located at 6.2691 < LoA ≤ 22.7759 meters. There were similarities with Leal and Gordo [7] show that the effectiveness of waste material in range of 2.37 to 21.87% and the length of boat in range 12 to 21 meters.
3.4. Intersection of The Order-2 Polynomial Function

The calculation of finding the intersection points for the two polynomial functions and the polynomial functions of the waste material with the x-axis are as follows:

\[ Y_{Pd(\text{installed})} = Y_{P(t\text{waste})} \]
\[ 0.0997x^2 + 4.0269x - 4.9941 = -0.0863x^2 - 0.0433x + 28.427 \]
\[ Y_P = Y_{Pd} + Y_{Pt} = (0.0997 + 0.0863)x^2 + (4.0269 + 0.0433)x - (4.9941 + 28.427) \]
\[ Y_P = 0.186x^2 + 4.0702x - 33.4211 \]

\[ x_p = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

where \( a = 0.186; b = 4.0702; c = 33.4211; \) then

\[ X_{P1} = 6.3617 \text{ and } X_{P2} = -28.2445 \]
\[ Y_{P1} = 0.0997x^2 + 4.0269x - 4.9941 \]
\[ Y_{P2} = [0.0997(6.3617)] + (4.0269*6.3617) - 4.9941 \]
\[ Y_{P1} = 24.6589 \]
\[ Y_{P(t\text{waste})} = f(x-axis) \]
\[ -0.0863x^2 - 0.0433x + 28.427 = 0 \]

\[ x_{Pt} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

where \( a = -0.0863; b = -0.0433; c = 28.427; \) then

\[ X_{P2} = -18.4019 \text{ and } X_{Pt} = 17.9002 \]

Interpretation of Figure 3 and the results of the intersection of the second order polynomial function in Eq. 12 to Eq. 15 are shown in Table 6.

| LoA (m) | Installed Material (m²) | Waste Material (m²) | Total Material (m²) | % Waste |
|---|---|---|---|---|
| 6 | 22.7565 | 25.004 | 47.8169 | 52.41 |
| 6.3617 | 24.6588 | 24.6589 | 49.3177 | 50.00 |
| 7 | 28.0795 | 23.8952 | 51.9747 | 45.97 |
| 8 | 33.6019 | 22.5574 | 56.1593 | 40.17 |
| 9 | 39.3237 | 21.0470 | 60.3707 | 34.86 |
| 10 | 45.4429 | 19.364 | 64.6089 | 29.97 |
| 11 | 51.3655 | 17.5084 | 68.8739 | 25.42 |
| 12 | 57.6875 | 15.4802 | 73.1657 | 21.16 |
| 13 | 64.2049 | 13.2794 | 77.4843 | 17.14 |
| 14 | 70.9237 | 10.906 | 81.8297 | 13.33 |
| 15 | 77.8419 | 8.3600 | 86.2019 | 9.70 |
| 16 | 84.9595 | 5.6414 | 90.6009 | 6.23 |
| 17.9002 | 99.0338 | -7.9572 | 99.0337 | 0.00 |
| 18 | 99.7929 | -0.3136 | 99.4793 | -0.32 |

Based on Table 6, the following results are obtained that the effectiveness span of aluminium shipbuilding has a length which was located at 6.3617 < LoA ≤ 17.9002 meters. There were similarities with Leal and Gordo [7] show that the effectiveness of waste material in the range of 6.23 to 21.16% and the length of boat in range 12 to 16 meters.

3.5. Intersection Of The Order-2 Polynomial Function

The percentage of the waste material from the construction of aluminium ships with the linear trend line approach reached 21.87%, while the polynomial trend line approach of order 2 reached 21.16%. Therefore, from the results of several studies on the waste material in the process of building steel vessels and aluminium vessels in a maximum range of 25% [7].

Aluminium shipbuilding production activities in CV. Javanesse Boat, Sidoarjo with a length of 6 meters to 21 meters was closer to the linear trend line approach, namely Yld(\text{installed}) = 5.6901x - 11.184 with a magnitude of R-squared 0.9698, and Ylt(waste) = -1.4835x + 33.788 with a magnitude of R-squared 0.9598. These results indicate the company’s ability to build an aluminium boat reaching a maximum length of 21 meters, with the waste material reaching 21.87%.
4. Conclusion

Aluminium boatbuilding using the linear trend line approach have two functions. The installed material function \( f_{\text{ld}}(x) = 5.6901x - 1.096 \) with \( R^2 = 0.9698 \), and the waste material function \( f_{\text{wl}}(x) = -1.4835x + 33.778 \) with \( R^2 = 0.9598 \). The results of the cut point calculation show that the effective length stretch was located at \( 6.691 \leq \text{LOA} \leq 22.7759 \) meters and the waste material lie at 2.37 to 21.87% for the length of the boat reaching 12 to 21 meters.

Whereas the construction of aluminum ships using the second order polynomial trend line approach have two functions. The installed material function \( f_{\text{2d}}(x) = 0.0997x^2 + 4.0269x - 4.9941 \) with \( R^2 = 0.9705 \), and the waste material function \( f_{\text{2w}}(x) = -0.0863x^2 - 0.0433x + 28.427 \) with \( R^2 = 0.9671 \). The results of the cut point calculation show that the effective length stretch was located at \( 6.3617 \leq \text{LOA} \leq 17.9002 \) meters and the waste material lie at 6.23 to 21.16% for the length of the boat reaching 12 to 16 meters.

The percentage of the waste material from the cutting plan of aluminium boatbuilding with the approach of linear trend lines and the second order polynomial trend lines have similarities with the maximum waste materials of steel shipbuilding reached 25%.

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