Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan
(Kapal: Journal of Marine Science and Technology)
journal homepage : http://ejournal.undip.ac.id/index.php/kapal
2301-9069 (e)
1829-8370 (p)

Material Effectiveness Model for the Construction of Aluminum Hull

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Article Info

Keywords:
Aluminum Material,
Cutting Plan,
Trend Line Function,
Waste Material

Article history:
Received: 07/05/20
Last revised: 10/10/20
Accepted: 13/11/20
Available online: 13/11/20
Published: 28/02/21

DOI:
https://doi.org/10.14710/kapal.v18i1.29974

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 is conducting 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 plate 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 ship 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 the 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. Ramadhani 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. Ramadhani 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].

Table 1. Principle Dimension of Aluminum Boats

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 jobs. 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 Nests 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/ordo 2 (Eq. 4), and Power Fit (Eq. 5) [20]:

$$y = ax \pm b \quad (1)$$

$$y = ae^{bx} \quad (2)$$

$$y = a.\ln(x) \pm b \tag{3}$$

$$y = ax^2 \pm bx \pm c \tag{4}$$

$$y = ax^b \tag{5}$$

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 < R-squared value ≤ 0.5 interpreted poor, 2) 0.5 < R-squared value ≤ 0,8 interpreted moderate, 3) 0.8 < R-squared value ≤ 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.

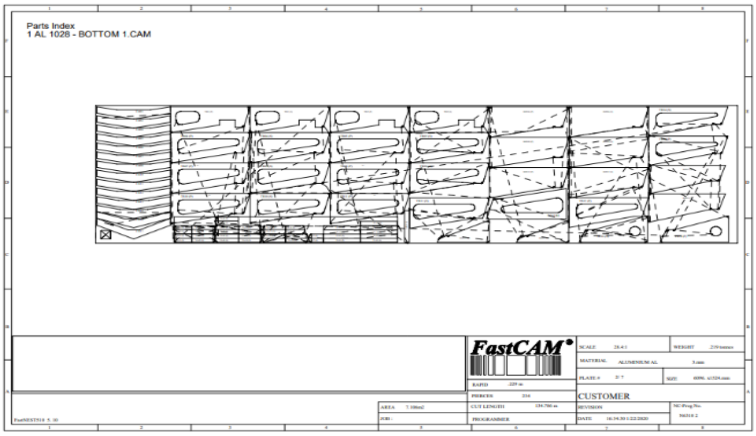

Figure 1. No. 2 of Cutting Plan JAL 1028 in FastCam

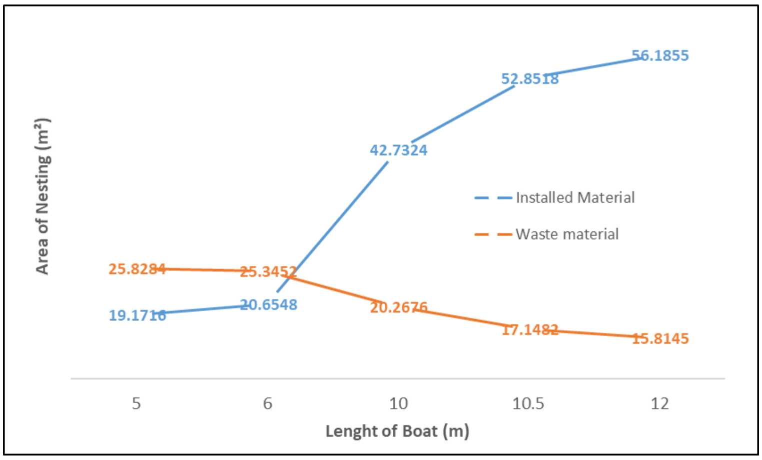

Figure 2. Area Description of Installed and Waste Material

Table 2a. Identification of Material from JAL 5620 Boat Length = 5 m

Plate Position	**Nesting Code**	**n - Plate**			
		1	**2**	**3**	**4**
Bottom Plate (P&S)	A0	-	-	6.5546	-
Side Girder (P&S)	A1	1.4783	-	-	-
Face Side Girder (P&S)	A1.1	0.4444	-	-	-
Centre Girder (C)	A2	-	1.8843	-	-
Face Centre Girder (C)	A2.1	-	0.2624	-	-
Centre Floor (P&S)	A3	0.3421	-	-	-
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	-	0.0383	-	-
Face Side Floor Fr.07 (P&S)	A4.2.3	-	0.0222	-	-
Face Side Floor Fr.08 (P&S)	A4.2.4	-	0.0156	-	-
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**	**6.5546**	**2.5637**
Total Installed Material (m²)		**19.1716**			
Total Waste Material (m²)		**25.8284**			

Table 2b. Identification of Material from JAL 6525 Boat Length = 6 m

Position	**Nesting Code**	**n - Plate**				
		5	**6**	**7**	**8**	**9**
Bottom Plate (P&S)	B0	-	4.0518	-	4.0518	-
Side Girder (P&S)	A1		-	1.9873	-	-
Face Side Girder (P&S)	B1.1		-	0.3738	-	-
Centre Girder	B2	-	-	1.9952	-	-
Face Centre Girder	B2.1	-		0.3000	-	-
Tank Top (P&S)	B3	0.2100	-	-	-	-
Side Floor Fr.01 (P&S)	B4.1.1	0.8895	-	-	-	-
Side Floor Fr. 02, 03, 05, 06 (P&S)	B4.1.2	0.9328	-	-	-	-
Side Floor Fr.04 (P&S)	B4.1.3	0.7495	-	-	-	-
Side Floor Fr.07 (P&S)	B4.1.4	0.8285	-	-	-	-
Side Floor Fr.08 (P&S)	B4.1.5	0.1548	-	-	-	-
Side Floor Fr.09 (P&S)	B4.1.6	0.1075	-	-	-	-
Side Floor Fr.10 (P&S)	B4.1.7	0.5273	-	-	-	-
Side Floor Fr.11 (P&S)	B4.1.8	0.1818	-	-	-	-
Bottom Transverse Fr.01, 02, 03, 05, 06, 08, 09 (P&S)	B5.1.1	0.5638	-	-	-	-
Bottom Transverse Fr.09 (P&S)	B5.1.2	0.1270	-	-	-	-
Tank Top (P&S)	A6	-	-	-	-	2.0352
Bulkhead	A7	-	-	-	-	-
Transom	A8	-	-	-	0.9907	-
Vender	A9	-	0.8991	1.7982	0.8991	-
Total Area (m²)		**5.2725**	**4.9509**	**6.4546**	**5.9416**	**2.0352**
Total Installed Material (m²)		**20.6548**				
Total Waste Material (m²)		**25.3452**				

Table 2c. Area of JAL 1028 Boat Length = 10 m

Position	**Nesting Code**	**n - Plate**						
		10	**11**	**12**	**13**	**14**	**15**	**16**
Bottom Plate (P&S)	C0	-	2.2141	-	4.0991		4.0991	2.2141
Side Girder (P&S)	C1	-	-	0.8452	-	4.6401	-	-
Face Side Girder (P&S)	C1.1	-	-	-	-	0.9536	-	-
Centre Girder	C2	-	-	-	-	2.3201	-	0.4226
Face Centre Girder	C2.1	-		-	-	0.4768	-	-
Tank Top (P&S)	C3	0.2898	-	-	-	-	-	-

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**						

Table 2d. Identification of Material from of JAL 1029 Boat Length = 10.5 m

Position	**Nesting Code**	**n - Plate**							
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Bottom Plate (P&S)	D0	-	-	-	7.0411	2,8240	7.0411	2.8240	-
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	-	-	-	-	-

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	-	-	7.4090
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

Position	**Nesting Code**	**n - Plate**							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Bottom Plate (P&S)	E0	-	-	-	2.6988	2.6988	5.6099	4.4099	-
Side Girder (P&S)	E1	-	4.4908	0.7116	1.2245	3.1934	-	-	-
Face Side Girder (P&S)	E1.1	-	1.0242	-	1.5374	-	-	-	-
Centre Girder	E2	-	2.6012	0.3061	-	-	-	-	-
Face Centre Girder	E2.1	-	0.5121	-	-	-	-	-	-
Tank Top (P&S)	D3	-	-	0.9289	-	-	-	-	-
Side Floor Fr.01-02 (P&S)	E4.1.1	1.5882	-	-	-	-	-	-	-
Side Floor Fr. 04,07,08,10,11 (P&S)	E4.1.2	1.9884	-	-	-	-	-	-	-
Side Floor Fr.05 (P&S)	D4.1.3	0.3961	-	-	-	-	-	-	-
Side Floor Fr.06 (P&S)	D4.1.4	0.5829	-	-	-	-	-	-	-
Side Floor Fr.13 (P&S)	D4.1.5	-	-	0.3813	-	-	-	-	-
Side Floor Fr.14 (P&S)	D4.1.6	-	-	0.3757	-	-	-	-	-
Side Floor Fr.16 (P&S)	D4.1.7	-	-	0.3899	-	-	-	-	-
Side Floor Fr.17 (P&S)	D4.1.8	-	-	0.2464	-	-	-	-	-
Side Floor Fr.18 (P&S)	D4.1.9	-	-	0.4453	-	-	-	-	-
Face Floor (P&S)	D4.2	-	-	-	-	-	-	2.4101	-
Bottom Transverse Fr.01-11 (P&S)	D5.1.1	-	-	1.5385	-	-	-	-	-
Bottom Transverse Fr.12-13 (P&S)	D5.1.2	-	-	0.3324	-	-	-	-	-
Bottom Transverse Fr.14 (P&S)	D5.1.3	-	-	0.1590	-	-	-	-	-
Bottom Transverse Fr.16 (P&S)	D5.1.4	-	-	0.1655	-	-	-	-	-
Bottom Transverse Fr.17 (P&S)	D5.1.5	-	-	0.1958	-	-	-	-	-
Keel	D6	-	-	-	-	-	-	-	-
Face Keel	D6.1	-	-	-	-	-	-	-	-
Bulkhead 03 (P&S)	D7.1	0.8040	-	-	-	-	-	-	-
Bulkhead 09 (P&S)	D7.2	0.9682	-	-	-	-	-	-	-
Bulkhead 12 (P&S)	D7.3	-	-	1.1493	-	-	-	-	-
Bulkhead 15 (P&S)	D7.4	-	-	0.8504	-	-	-	-	-
Transom	D8	-	-	-	-	-	-	-	-
Vender	D9	-	-	-	-	-	-	-	7.1929

Stiffener	D10	-	-	-	-	-	-	-	-
Bracket	D11	-	-	-	-	-	-	-	-
Chine Hull	D12	-	-	-	-	-	0.6000	-	-
Fin Stabilizer	D13	-	-	-	-	-	1.4779	-	-
Total Area (m^2)		**6.3277**	**8.6284**	**8.1759**	**5.4607**	**5.8922**	**7.6878**	**6.8199**	**7.1929**
Total Installed Material (m^2)		**56.1855**							
Total waste Material (m^2)		**15.8145**							

Table 3. Area of Aluminum Materials

No	Length (m)	Installed Material (m^2)	Waste Material (m^2)
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.

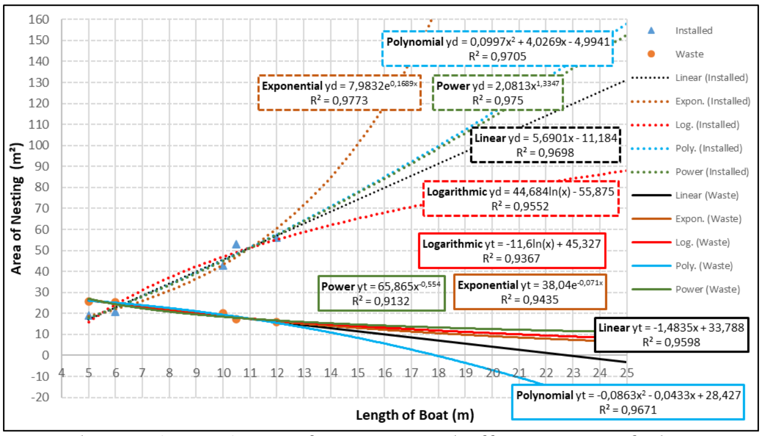

Figure 3. Scatter Plots and Trend Lines from Material Effectiveness of Aluminum Boats

Table 4. Aluminium Material Trend Lines Function

Trend Line	Function	R^2
Linear	Yd = 5.6901x – 11.184	0.9698
	Yt = -1.4835x + 33.788	0.9598
Exponential	Yd = $7.9832e^{0.1689x}$	0.9773
	Yt = $38.04e^{-0,.071x}$	0.9435
Logarithmic	Yd = 44.684ln(x) – 55.875	0.9552
	Yt = -11.6ln(x) + 45.327	0.9367
Polynomial	Yd = $0.0997x^2$ + 4.0269x – 4.9941	0.9705
	Yt = $-0.0863x^2$ – 0.0433x + 28.427	0.9671
Power	Yd = $2.0813x^{1.3347}$	0.9750
	Yt = $65.865x^{-0.554}$	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

$$Y_d = 5.6901x - 11.184 \quad (6)$$

$$Y_t = -1.4835x + 33.788 \quad (7)$$

2. Polynomial Function Ordo-2

$$Y_d = 0.0997x^2 + 4.0269x - 4.9941 \quad (8)$$

$$Y_t = -0.0863x^2 - 0.0433x + 28.427 \quad (9)$$

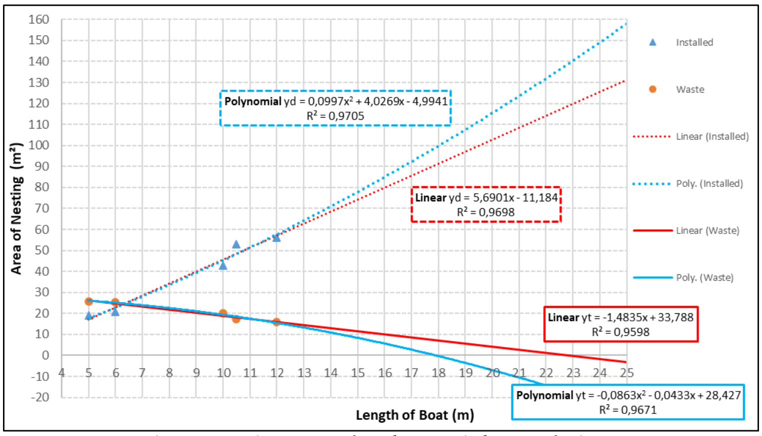

Figure 4. Linear and Polynomial Trend Lines

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:

$$Y_{Ld(installed)} = Y_{Lt(waste)} \tag{10}$$
$$5.6901x - 11.184 = -1.4835x + 33.788$$
$$(5.6901 + 1.4835)\ x = 33.788 + 11.184 Y_{Ld(installed)} = Y_{Lt(waste)}$$
$$\boldsymbol{Xd = Xt = XLinear1 = 6.2691\ m}$$

$$Yd = 5.6901x - 11.184$$
$$Yd = (5.6901 * 6.2691) - 11.184$$
$$\boldsymbol{Yd = Yt = YLinear = 24.4878\ m^2}$$

$$Y_{Lt(waste)} = f_{(x-axis)} \tag{11}$$
$$-1.4835x + 33.788 = 0$$
$$1.4835x = 33.788$$
$$\boldsymbol{XLinear2 = 22.7759\ m}$$

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.

Table 5. Interpretation of Linear Functions

LoA (m)	Installed Material (m²)	Waste Material (m²)	Total Material	% 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	64.6700	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 Oorder-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:

$$Y_{Pd(installed)} = Y_{Pt(waste)} \quad (12)$$

0.0997x2 + 4.0269x – 4.9941 = -0.0863x2 – 0.0433x + 28.427

$$YP = YPd + YPt = (0.0997 + 0.0863)x2 + (4.0269 + 0.0433)x - (4{,}9941 + 28{,}427)$$

$$YP = 0.186x2 + 4.0702x - 33.4211$$

$$x_p = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (13)$$

where a = 0.186; b = 4.0702; c = 33.4211; then

$$XP1 = 6.3617 \text{ and } XP2 = -28.2445$$

$$Y_{Pd} = 0.0997x^2 + 4.0269x - 4.9941$$

$$Y_{Pd} = [0.0997*(6.3617^2)] + (4.0269*6.3617) - 4.9941$$

$$\mathbf{Y_{Pt} = 24.6589}$$

$$Y_{Pt(waste)} = f_{(x-axis)} \quad (14)$$

$$-0.0863x^2 - 0.0433x + 28.427 = 0$$

$$x_{Pt} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (15)$$

where a = -0.0863; b = -0.0433; c = 28.427; then

$$X_{Pt2} = -18.4019 \text{ and } \mathbf{X_{Pt2} = 17.9002}$$

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.

Table 6. Interpretation of Second Order Polynomial Functions

LoA (m)	Installed Material (m^2)	Waste Material (m^2)	Total Material	% 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	45.2449	19.364	64.6089	29.97
11	51.3655	17.5084	68.8739	25.42
12	57.6855	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. Javanese Boat, Sidoarjo with a length of 6 meters to 21 meters was closer to the linear trend line approach, namely YLd(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 fLd(x) = 5.6901x - 1.096 with R^2 = 0.9698, and the waste material function fLt(x) = -1.4835x + 33.788 with R^2 = 0.9598. The results of the cut point calculation show that the effective length stretch was located at 6.691 < LoA ≤ 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 fPd(x) = $0.0997x^2 + 4.0269x - 4.9941$ with R^2 = 0.9705, and the waste material function fPt(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 < LoA ≤ 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 aluminum 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%.

Acknowledgements

Authors thank to LPPM – Universitas Hang Tuah and Modeling & Simulation Laboratory - Faculty of Engineering and Marine Sciences for their financial support and facilities.

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