Study of Utilization Plastic Waste as Basic Material for Boat Manufacturing Using Eco-green Design Concept

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Abstract. The plastic waste problem has become a global problem and the effect on the environment is horrible. Almost all countries make an effort to reduce their daily utilization. Environmental organizations and researchers are also performing research to find ways to recycle plastic waste. In this paper introduces the “Eco-green Design Concept” to utilize plastic waste (type 2) as fishing boat material. This concept will recycle 3 tonnes of plastic waste into the material of a fishing boat. In addition, the implementation element of eco-green design concept (design quality (D), Environmental Friendly (E), Eco-green Material (G)) into the design of fishing vessels has been successful. The concept does not only utilize type 2 plastic waste into the hull of the ship, but the design of the ship is made to have small resistance, good stability and has a large cargo area. And also has a machine that is environmentally friendly and does not cause pollution.

Keyword : Eco-green Design Concept, Utilization Plastic Waste, Alternative Boat Material

Nomenclature

| D  | Design Quality |
| E  | Environmental Friendly |
| G  | Eco-green Material |
| D  | Design Quality not Intersect |
| E  | Environmental Friendly not Intersect |
| G  | Eco-green Material Doesn’t Intersect |
| P  | Probability |
| x  | Sub element Design Quality |
| y  | Sub element Environmental Friendly |
| z  | Sub element Eco-green Material |
| Ee  | The extensional module of elasticity |
| νe  | Poisson Rations |
| σe  | Normal Stress |
| τe  | Shear Stress |
| e  | Normal Strain |
| γ  | Shear Strain |

1. Introduction

Indonesia is the second most plastic waste polluter in the world. According to Jenna R. Jambeck [1] Indonesia is polluting the ocean with maximum 1.29 tonnes per year. From the daily plastic waste production point of view, Indonesia is in the 16th position in the world, however from the...
mismanagement point of view, Indonesia is in the runner up. Apart from the big population of Indonesia as a multiplying factor of plastic waste, mismanagement becomes the main factor. For example, the USA with 112.9 million population and waste produced per person is 2.58 kg/day hence the daily waste production is 0.291 million tonnes. However, the error rate of waste mismanagement is only 0.9% thus the USA pollutes 0.11 million tonnes/year plastic waste into the ocean. Unlike Indonesia, with the 187.2 million population and 0.5 kg/day waste produced per person, total waste produced is 0.097 million tonnes/day. Less than the USA but with the waste mismanagement about 10.1% thus the plastic waste into the ocean is 1.29 million tonnes/year. This is becoming a red note for the government to improve the waste management system hence will not pollute the ocean anymore.

This article will review the concept of plastic waste utilization in product design namely, “Eco-green Design Concept”. Plastic waste will be selected and processed to become fishing boat material, in which plastic Type 2 (HDPE) is chosen to substitute fiberglass in the composite hull boat.

2. Methode

2.1. Utilization of Plastic Waste

Plastic waste processing has been conducted by researchers [2-6], this is done to reduce the increasing plastic waste that harms the environment ecosystem. According to the Plastic Waste Management Institute [3] plastic waste processing is categorized into 3 methods, viz. mechanical recycling, chemical recycling, and thermal recycling (energy recovery). The difference between these methods is focused on the process which in the mechanical recycling the plastic material is cleaned, chopped and melted by extrusion without changing the plastic component. In chemical recycling, plastic waste is transformed into a small particle (ion) and revolutionized into monomers or partially mutated into oligomer (complex structure) or mixed with hydrocarbon compound. There are some ways to process, the most common one in Indonesia is Pyrolysis (transform plastic waste into BBM). In thermal recycling, plastic is processed by burning it in a furnace and utilized to generate energy or other products. However, this process often causes air pollution from toxin as a by-product of the burning process. According to M.Elina Grigore [4], the product of plastic waste recycling can be used for the food industry and household needs, which will return to plastic waste if it is not utilized and will be processed from the beginning. This is a chain process that always repeats, the plastic waste problem will never end until the end of time. According to Yosi et.al [7], waste management in Indonesia is not effective, therefore a new strategy to overcome this problem is needed starting from waste processing to utilization of the recycled product by industry.

2.2. Eco-green Design Concept

Based on the explanation above, in addition to the reduction of plastic utilization, plastic waste management should also be focused thus the error chain process will not be repeated. In this study attempt to cut off this chain by creating “Eco-green Design Concept” which in creating product design utilizes plastic waste, prevents environmental pollution, and has a long lifetime. This concept guarantees product quality. Eco-green material and environment conservation at the same time hence can make the product more competitive in the global market.

By this approach as a goal, each step of the design process, three main equal criteria are categorized by design quality (D), environmentally friendly (E) and Eco-green material (G).
3. **Mathematical Model**

According to Attaf et. al [8], ecodesign can be achieved when interaction between three main aspects and produces area the intersection within these aspects and achieve maximum value if intersected maximally. Hence Eco-green Design Concept can be illustrated as follow:

![Figure 1. Eco-green Design Concept](image)

Universally, Eco-green Design Concept can be shown in the sample space below:

![Figure 2. Eco-green Design Concept Classification](image)

![Figure 3. Eco-green Design Concept Formulation](image)
Based on the figure above, each element of Eco-green Design Concept can be formulated as follow:

\[ I = D \cap E \cap G \]  
(1)

\[ II = D \cap E \cap G \]  
(2)

\[ III = D \cap E \cap G \]  
(3)

\[ IV = D \cap E \cap G \]  
(4)

\[ V = D \cap E \cap G \]  
(5)

\[ VI = D \cap E \cap G \]  
(6)

\[ \eta = D \cap E \cap G \]  
(7)

And if the equation (7) is substituted into probability, hence the possibility of Eco-green Design Concept can be written as follow:

\[ \eta = P(D \cap E \cap G) \]  
(8)

Each element has various sub-elements hence they can be written as follow:

\[ D = (x_1, x_2, x_3, \ldots, x_n) \]  
(9)

\[ E = (y_1, y_2, y_3, \ldots, y_n) \]  
(10)

\[ G = (z_1, z_2, z_3, \ldots, z_n) \]  
(11)

By substituting equation (9), (10), (11) into equation (8) the equation will be as follow:

\[ P_\eta = P( (D = (x_1, x_2, x_3, \ldots, x_n)) \cap (E = (y_1, y_2, y_3, \ldots, y_n)) \cap (G = (z_1, z_2, z_3, \ldots, z_n)) ) \]  
(11)

And if each sub element is created with a clear variable hence it can be illustrated in the table below.

| Rating       | D=(x_1,x_2,...,x_n) | E=(y_1,y_2,...,y_n) | G=(z_1,z_2,...,z_n) |
|--------------|---------------------|---------------------|---------------------|
| Excellent    | 1                   | 1                   | 1                   |
| Very Good    | 0.8                 | 0.8                 | 0.8                 |
| Good         | 0.6                 | 0.6                 | 0.6                 |
| Average      | 0.4                 | 0.4                 | 0.4                 |
| Bad          | 0.2                 | 0.2                 | 0.2                 |
| Very Bad     | 0                   | 0                   | 0                   |

The number of sub-element variables affects the accuracy of the results obtained.

4. Implementation Eco-green Design Concept

To achieve maximum value in Eco-green Design Concept, each element will be optimized to reach the best limit in the fishing boat. The optimization procedure can be seen in below figure.
4.1. *Fishing Boat Design Quality*
To obtain a good design quality, a boat should comply with international standards [9]. The common requirement of a fishing boat is to have a large storage space, good stability, and small resistance. In accordance to Table 1, to ease the assessment process the sub-element should be defined clearly so a design with good quality can be determined.

**Table 2. Sub-Element Variable of Fishing Boat Design Quality.**

| Assessment                                      | D=(x1,x2,x3,...,xn) |
|------------------------------------------------|--------------------|
| Good Stability, Small Resistance and Big Capacity | 1                  |
| Good Stability, Small Resistance and Medium Capacity | 0.9                |
| Good Stability, Small Resistance and Small Capacity | 0.8                |
| Good Stability, Medium Resistance and Big Capacity | 0.7                |
| Good Stability, Medium Resistance and Medium Capacity | 0.6                |
| Good Stability, Big Resistance and Big Capacity   | 0.5                |
| Bad Stability, Big Resistance and Big Capacity     | 0.4                |
| Bad Stability, Big Resistance and Medium Capacity  | 0.3                |
| Bad Stability, Big Resistance and Small Capacity   | 0                |

This article will be employing a 5GT fishing boat (Type V) of 1000 fishing boat program of the Ministry of Marine Affairs and Fisheries [10] with the following dimension:
Table 3. Preliminary Dimension Fishing Boat 5GT.

| Dimension                  | Size  |
|----------------------------|-------|
| Length Overall (LOA)       | 11 m  |
| Length of Water Line (LWL) | 9.15 m|
| Breadth (B)                | 2.6 m |
| Height (H)                 | 0.95 m|
| Draught (T)                | 0.6 m |
| Gross Tonnage (GT)         | 5 GT  |
| Speed (v)                  | 7-8 knot|
| Operating                  | 5 Day |

To obtain optimum design, hull variation will be simulated (utilizing Maxsurf software: design stability, resistance) to obtain ideal design based on the required criteria in table 2. According to Shahroz [11], single hull divided into 3 categories: planing hull, semi-displacement hull, and displacement hull however, each hull has many variations. This article will only use 3 main hulls as a research object and will be searched the most suitable one for 5 GT fishing boat in the Ministry of Marine Affairs and Fisheries.
Table 4. Results of Optimization Hull

| Hull Type | Displacement (T) | Volume (displaced) (m³) | Draft Amidships (M) | Immersed depth (M) | WL Length (M) | Prismatic coeff. (Cₚ) | Block coeff. (Cₜ) | LCB length | LCF length | LCB % | LCF % | Hp (m³) | Stability |
|-----------|-----------------|------------------------|--------------------|-------------------|--------------|----------------------|------------------|-------------|------------|--------|--------|---------|-----------|
| DISPLACEMENT HULL | 13.72 | 13.385 | - | - | 9.15 | 0.862 | 0.828 | -5.301 | -5.567 | -51.152 | -53.723 | 30.345 | Good |
| SEMI-DISPLACEMENT HULL | 7.448 | 7.267 | - | - | 9.15 | 0.728 | 0.485 | -6.116 | -5.917 | -60.572 | -58.594 | 15.82 | Good |
| PLANNING HULL | 6.051 | 5.903 | - | - | 9.15 | 0.758 | 0.388 | 4.859 | 4.548 | 47.059 | 44.042 | 11.539 | Good |
From the result of above simulation, can be seen the significant difference between these three hulls, after inserted into table 2 so each hull has the following values:

| Type oh Hull          | Assessment                                      | D=(x1,x2,x3,...,xn) |
|-----------------------|-------------------------------------------------|--------------------|
| Displacement Hull     | Good Stability, Big Resistance and Big Capacity | 0.5                |
| Semi-Displacement Hull| Good Stability, Light Resistance and Medium Capacity | 0.9                |
| Planing Hull          | Good Stability, Light Resistance and Medium Capacity | 0.9                |

From above table, it can be seen that Semi-Displacement Hull and Planing Hull have score 0.9 close to perfect score from all elements of design quality. However a Planing Hull is widely used for fast boat, hence Semi-Displacement Hull is chosen for fishing boat design.

4.2. *Fishing boat Eco-green Material*

Basic concept of Eco-green material is the utilization of environmentally friendly material, the utilization of effective and efficient energy, as well as the utilization of waste recycling into products with a higher value and help to reduce harmful waste. The waste that has been selected and cleaned is processed into small pieces by chopper. In this study the plastic type 2 is chosen, and then the plastic flakes are extruded with a special tool to become a string / HDPE filament with various sizes. The string then is used to substitute glass fibre in the boat hull composite. The illustration is shown below:

![Figure 7. Fiber Glass substitution with HDPE Filaments](image)

The composite coordinate system is illustrated as follow:

![Figure 8. Coordinate System of Composite](image)
By implementing Hook’s Law in the stress strain relationship of orthotropic material so strain stress correlation of HDPE composite can be expressed by the following equation:

\[
\begin{bmatrix}
\frac{1}{E_1} & -v_{12}/E_2 & -v_{13}/E_3 \\
-v_{12}/E_2 & \frac{1}{E_2} & -v_{23}/E_3 \\
-v_{13}/E_3 & -v_{23}/E_3 & \frac{1}{E_3}
\end{bmatrix}
\begin{bmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\lambda_{12} \\
\lambda_{23} \\
\lambda_{31}
\end{bmatrix}
= \begin{bmatrix}
\sigma_1 \\
\sigma_2 \\
\tau_{23} \\
\tau_{31} \\
\tau_{12}
\end{bmatrix}
\]

...(13)

To ease the assessment of the Eco-green Material element, the sub-element variables are defined as follow:

**Table 6. Eco-green Material Sub Element Variables of Fishing Boat.**

| Assessment | G=(x1,x2,x3,...,xn) |
|------------|---------------------|
| Good strength, recyclable, and cheap manufacturing cost | 1 |
| Good strength, recyclable, and medium manufacturing cost | 0.9 |
| Good strength, recyclable, and expensive manufacturing cost | 0.8 |
| Good strength, non-recyclable, and medium manufacturing cost | 0.7 |
| Good strength, non-recyclable, and expensive manufacturing cost | 0.6 |
| Moderate strength, recyclable, and cheap manufacturing cost | 0.5 |
| Moderate strength, recyclable, and medium manufacturing cost | 0.4 |
| Moderate strength, recyclable, and expensive manufacturing cost | 0.3 |
| Low strength, non-recyclable, and cheap manufacturing cost | 0.2 |
| Low strength, non-recyclable, and medium manufacturing cost | 0.1 |
| Low strength, non-recyclable, and expensive manufacturing cost | 0 |

For comparison, 3 types of material composition will be employed, Carbon Fiber Reinforce, Glass Fiber Reinforce, HDPE Filament Reinforce with the same composition. After the numerical simulation, the result as follows:

**Table 7. Fishing Boat Design Quality Assessment.**

| Material | Assessment | G=(x1,x2,...,xn) |
|----------|------------|-----------------|
| Carbon Fiber Reinforce | Good strength, recyclable and expensive manufacturing cost | 0.6 |
| Glass Fiber Reinforce | Good strength, non-recyclable and medium manufacturing cost | 0.7 |
| HDPE Filament Reinforce | Kekuatan Baik, Bisa didaur Ulang dan Biaya Pembuatan Murah | 1 |
From above table it can be seen, HDPE Filament Reinforce has the maximum value, so it can be utilized as the boat hull material. Base on simulation, required 3 ton of Plastic waste type 2 (HDPE) to manufacture 1 Fishing boat (5 GT)

4.3. Environmentally Friendly Fishing Boat
The boat we design will not disturb and pollute the environment either from design and the selected material, the energy source utilized will also not pollute. Same with the above process so the assessment of environmentally friendly can be seen as follow:

| Machine       | Assessment                              | E=(x1,x2,x3,...,xn) |
|---------------|-----------------------------------------|--------------------|
| Diesel Engine | Cause pollution, economical price, easy maintenance | 0.6                |
| Electric Motor| Doesn’t cause pollution, moderate price, easy maintenance | 0.9                |
| Water Jet     | Doesn’t cause pollution, expensive price, difficult maintenance | 0.7                |

The electric motor is chosen as the prime mover of the fishing boat because it doesn’t cause pollution, moderate price, and easy maintenance

5. Discussion and Conclusion
From the above analysis, the fishing boat design with using plastic waste recycle type 2 (HDPE) and using the electric motor as prime mover and selecting Semi-Displacement Hull have achieved for Eco-green Design Concept criteria very well (with score = 0.9 x 1 x 0.9 = 0.81). Hence it can be used as a design proposal in producing fishing boat 5 GT of The Ministry of Marine Affair and Fisheries program. To manufacture a boat, it requires 3 tonnes of HDPE filament; this is a good solution to reduce plastic waste in Indonesia. In the future, it is expected Eco-green Design Concept can be implemented into the other featured products and has a high competitive value.

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