HDPE as a New Alternative Material for Small Vessel Boat Strength

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Abstract: In the last decade, the use of HDPE as an alternative material for boat is increasingly. At least there are several reasons for using HDPE as substitute for FRP material, from zero corrosion, marine growth resistance, and the most important is the issues of environmentally friendly (recyclable). However, the use of HDPE as boat structures must meet shipbuilding standards, which are regulated in Classification rules, and Biro Klasifikasi Indonesia (BKI) as the only national class does not yet have detailed rules regarding of HDPE. The study was conducted to see the feasibility of HDPE as boat structures, starting from rules gap analysis (ISO 12215-5, IRS polyethylene rules, BKI rules small vessel), verification of the strength of boat construction and the effect of thermal on HDPE sheet using Finite Element Method by commercial software. The results showed that HDPE as an alternative material can be used as a boat/small vessel with the global stress results in test model at 15 MPa in transverse structures and 8 MPa in longitudinal structures (allowable stress 0.8Fy) both sagging and hogging conditions. As for thermal effects, HDPE panels are tested up to 70°C and produce elastic deformation up to 50mm for 1m frame spacing.

1 INTRODUCTION

Polyethylene is one of the simplest and most preferred polymers, and also most widely used polymeric raw material for plastics around the world. Polyethylene is generally divided into three categories based on density: Low density polyethylene (LDPE), Medium density polyethylene (MDPE), and High density polyethylene (HDPE). High density polyethylene (HDPE), as well as the grades of polyethylene processed from it, are used in places where more mechanical, physical or thermal properties are required (Mikko, 2015).

Compared to other types of plastic, HDPE has mechanical properties that allow it, to further utilized in the field of Engineering (Prihatmoyo P.E. et.al, 2018). By increasing the density, the yield strength, toughness, modulus of elasticity, hardness and heat resistance of polyethylene can be increased. Increasing the density also reduces solubility and swelling, gas permeability, and impact strength (Nuryosuwito N. et.al., 2019)

In the last decade, the use of HDPE as an alternative material for boat/small vessel is increasingly, especially for professional use. At least there are several reasons for using HDPE as substitute for FRP or wood material, from durable against material aging, zero corrosion, marine growth resistance (Wahyudin et.al., 2021), lighter vessel weight (up to 30% compared to wood (Wilma A., 2019)), easier to assemble, UV and fire resistance, and the very most important is the issues of environmentally friendly (100% recyclable) (Jamal, 2015). There are two main types of materials that can be used as a boat or small vessels, HDPE plastic in the form of plate-shaped and powder or pellets (Siswandi, 2016), HDPE with base material shaped like grains as shown in Figure 1 and in the form of plate-shaped as shown in Figure 2.

Figure 1: Grain of plastic HDPE (Siswandi,2016).

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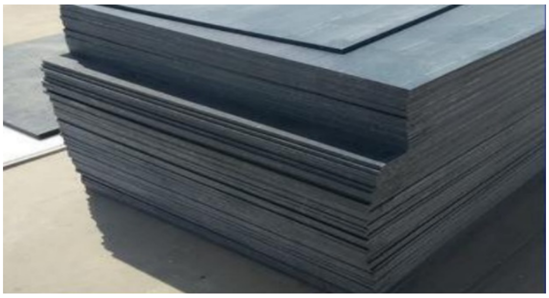


Figure 2: Plate-shape of plastic HDPE (Wahyuddin et.al., 2021).

However, the use of HDPE as boat structures should meet shipbuilding standards which are usually regulated in the Classification rules, therefore the government oblige classification for several type of vessels sailing in Indonesia waterways (Perhubungan P.M., 2019), and Biro Klasifikasi Indonesia (BKI) as the only national class in Indonesia does not yet have detailed regulation regarding of HDPE, BKI rules only regulates vessels with metal, wood, FRP and composite materials (Indonesia, B.K, 2021).

The study was conducted to see the feasibility of HDPE material as boat/small vessel hull, and will focus on the strength aspect of vessel construction made of HDPE plate-shape / HDPE sheet, and not discuss the stability, seakeeping or material quality aspects..

2 METHODOLOGY

The study methodology to see the feasibility of HDPE as boat/small vessel structures, starting from rules gap analysis and perform manual calculations according to the respective reference rules, followed by verification of the strength of boat/small vessel construction and also thermal effect on HDPE sheet using Finite Element Method by commercial software.

2.1 Rules Gap Analysis

Rules gap analysis is carried out to see the different requirement given by each rule, then reconciled with some adjustments. HDPE vessel models with lengths of 14m and 17m (Class Approved) as structural geometry assumptions and verification of manual calculations supplied by one of the HDPE shipyards. The standard/rules that will be used as a manual calculate comparison and gap analysis are:

- BKI rules for small vessels up to 24m (BKI, 2021)
- ISO 12215-5 Small craft - Hull construction and scantlings (ISO, 2008)
- Class Partner Indian Register Shipping Guidelines on Hull Structure of Thermoplastic Vessels (IRS, 2021)
- Other Class Partner rules like Turk Lloyd Tentative Rules for Polyethylene Crafts (TL, 2014) and Det Norske Veritas Standard for certification no.2.21 (Veritas, D.N., 2010) are exactly same as IRS guidance mentioned before.

2.2 Numerical Verification

Numerical verification is needed as an additional analysis after the rules gap, because the existing rules do not consider the global strength or longitudinal strength of small vessels, furthermore the facts regarding the effect of solar heat will also be simulated numerically using the commercial software Poseidon and ANSYS.

3 RESULTS AND DISSCUSION

IRS Thermoplastic vessels guidelines provide only the requirements for hull bottom and side thickness as following:

$$t = k \cdot s\,[P_F/(6.7L)]^{0.5} \cdot (14+3.6L) \quad (mm) \qquad (1)$$

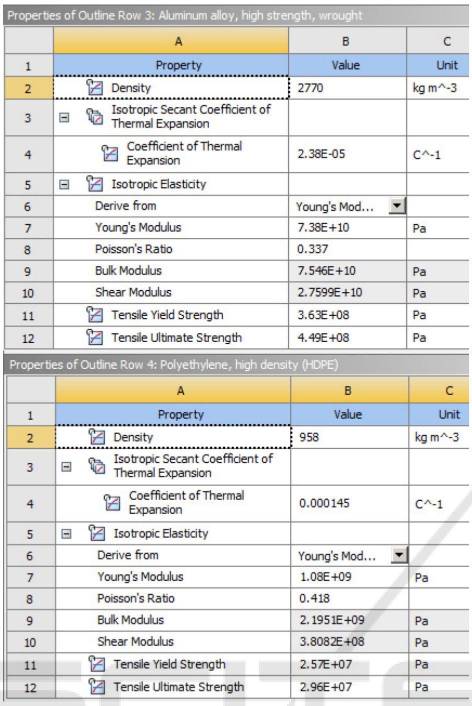
where:
k = 0.72 for HDPE; s = stiffener spacing (m); PF = Pressure factor and L = vessels length (m)

And the requirement of thickness for inner hull shall not be less than 0.8t from eq.(1). However, vessel constructions are complex structures, many part have not been covered in those guidance therefore the other rules will be used to cover this shortfall.

Assumption to calculate the strength of HDPE small vessels structure is with Aluminium material approach, because although they are different in terms of metallic types, but in terms of mechanical properties both of these materials have same patterns, even in ANSYS software these two materials belong to one family of linear elastic isotropic materials as shown in Figure 3.

3.1 Rules Manual Calculation

Before calculating the local structural strength, design stress adjustments are made for each rule based on aluminium material, in general the basic design stress used in several standards / rules follows the mechanical properties of HDPE stated in IRS Guidelines, finally the adjustments of rules as shown in Table 1 below.



Properties of Outline Row 3: Aluminum alloy, high strength, wrought

	A	B	C
1	Property	Value	Unit
2	Density	2770	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	2.38E-05	C^-1
5	Isotropic Elasticity		
6	Derive from	Young's Mod...	
7	Young's Modulus	7.38E+10	Pa
8	Poisson's Ratio	0.337	
9	Bulk Modulus	7.546E+10	Pa
10	Shear Modulus	2.7599E+10	Pa
11	Tensile Yield Strength	3.63E+08	Pa
12	Tensile Ultimate Strength	4.49E+08	Pa

Properties of Outline Row 4: Polyethylene, high density (HDPE)

	A	B	C
1	Property	Value	Unit
2	Density	958	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	0.000145	C^-1
5	Isotropic Elasticity		
6	Derive from	Young's Mod...	
7	Young's Modulus	1.08E+09	Pa
8	Poisson's Ratio	0.418	
9	Bulk Modulus	2.1951E+09	Pa
10	Shear Modulus	3.8082E+08	Pa
11	Tensile Yield Strength	2.57E+07	Pa
12	Tensile Ultimate Strength	2.96E+07	Pa

Figure 3: Material Properties Comparison of HDPE and Aluminium.

Table 1: Design stress adjustment for several rules.

BKI	ISO	IRS*
$Rp_{0.2}$ 17 MPa Rm 24 MPa k 15,5	SF_{plate} 17 MPa SF_{stiff} 15,4 MPa	Yield 17 MPa Break 14 MPa Ultimate 24MPa *All in Tensile

Table 2: Manual calculation vs actual.

Item	BKI	ISO	IRS	Actual
Bottom plate	18.74	14.6	19.50	15
Side Plate	13.47	9.22	16.03	10
Deck Plate	10.8	-	-	10
Bulkhead P.	4.04	9.22	15.6	12
Bar Keel	52x340	-	-	40x250
Rect. Stem	42x302	-	-	40x250
Floor	393	-	-	360
Centre Girder	393*	-	-	360
Side Transv.	150	-	-	360
Deck Transv.	67.3	-	-	73.5
* BKI requires the fitted a centre girder for vessels above 15 m with aluminium material, with a beam deflection approach (ML/(8EI)) then a new criterion is obtained, "*All HDPE craft shall have a centreline girder* "				

Manual calculation is carried out for each standard/rules. Regulations that cover almost all parts of the ship are BKI rules, but some results exceed actual conditions, while the ISO standard provides requirements of hull plate thickness that are very close to actual, while IRS Guidance provides the greatest requirement. Therefore, combining several standards/rules is the aim of this study. The results of local strength calculations can be seen in Table 2 below.

3.2 Numerical Calculation

3.2.1 Global Strength of Midship

When the vessels sails, it will receive loads due to waves (sagging and hogging) in addition to the loads due to hydrostatic pressure and cargo. This wave load has not been considered in the previous rules/ standards, and is used to calculate the longitudinal strength of vessels, especially the influence of centre girder on global strength. The midship section model can be seen in Figure 4 below:

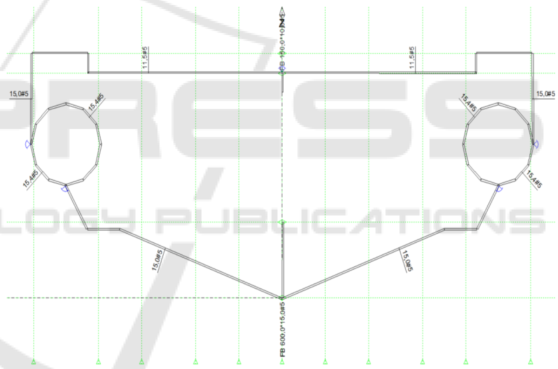


Figure 4: Midship cross section.

The assessment of the longitudinal strength of this HDPE vessel uses Poseidon commercial software, with the following input parameters:

- Length of model 3.2 m (fr.15~fr.23)
- E 1.08E+6 kN/m^2 dan F_y 25 MPa
- Bending load 391 kNm (BKI, 2022)

The results of numerical analysis as shown in Figure 5, and show that the total stress (vonmiss) in the longitudinal structure is 8 MPa and in the transverse structure is 15 MPa, while the allowable stress is 19MPa (0.8Fy) given by Standard For Certification Craft (Veritas D.N., 2010). This analysis proves that the centre girder installation reduces stress of the transverse structure significantly by dividing the floor in two equal length, however the assessment of global strength of the longitudinal structure is not required for vessels under 24m due to the stress in the longitudinal structure is less than half the allowable stress.

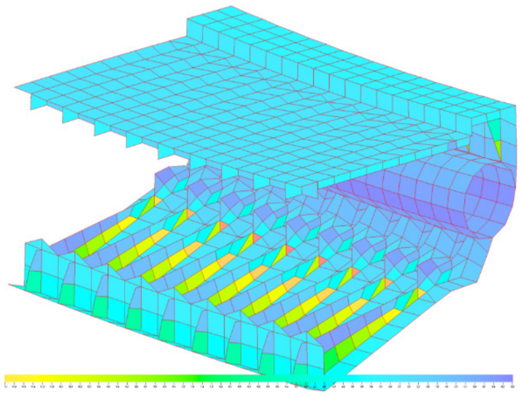


Figure 5: Vonmiss stresses in Sagging condition.

3.2.2 Thermal Effect on HDPE

Thermal analyses were carried out to relate the behaviour of HDPE sheets in areas of the ship's structure that are frequently exposed to the sunlight (eg. decks and superstructures), and also based on information from builders who stated that HDPE vessels decks which exposed to sunlight often deformed, but returned to normal at night.

This analysis uses ANSYS commercial software, with the following input parameters:

- Model consist of 9 panel (3x3)
- Variation of plate thickness 5 ~ 15mm
- Variation of frame space 0.1 ~ 1 m
- Variation of thermal load 22~70 °C
- Film coefficient 5E-6 W/mm^2 °C

The results of the analysis can be seen in Figure 6. The greater frame space as the thermal load increases, will increase the total deformation, and maximum deformation of 50 mm is obtained with a combination of 70°C thermal load and 1 m frame space of stiffener.

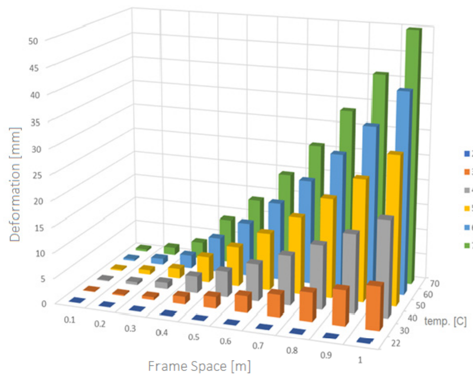


Figure 6: Deformation of HDPE sheet.

IACS provides a deformation tolerance limit, for stiffener with 1 m of frame space will give maximum allowable deformation limit of 3 mm (IACS rec.47, 2013), so by this standard, assuming an average temperature at sea level is 30°C, then only 0.3 m of frame space or less can meets the criteria.

However this deformation not only related to material safety, but also related to passenger/crew safety. For material safety, the analysis will be continued until the material stress limit is obtained. The analysis results are shown in Figure 7, and show that the deformation that occurs is entirely elastic deformation, which is indicated by the stresses that never exceeds the yield of HDPE material.

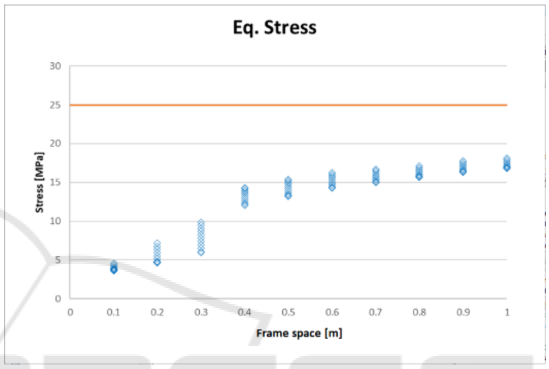


Figure 7: Thermal stress versus yield material.

4 CONCLUSIONS

Recommendations for the development of BKI HDPE regulation regarding vessels strength are to combine several standard/rules and some methods with the following details:

- Calculation of shell (bottom and side) and transverse bulkhead thickness according to IRS Guidelines
- Other structural calculations using BKI Rules for small vessels using aluminium formulations with adjustment of design stress $Rp_{0.2}$ 17 MPa, Rm 24 MPa and k 15.5
- Additional requirement as follows "All HDPE craft shall have a centreline girders"
- Other part that are not regulated by the two references above can be solved numerically with an acceptance criterion limit of $0.8F_y$
- It is recommended to take the smallest elastic deformation (see Figure 6) for passages way area and also for the area of equipment whose performance will be impaired due to such deformation.

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