HDPE as a New Alternative Material for Small Vessel Base and Joint Material Quality

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Keywords: HDPE, Destructive Test, Non Destructive Test, Ship, Weld Quality.

Abstract: The use of HDPE as an industrial material has been widely used and often encountered daily, ranging from plastic bags, bottles, to clean water pipes. However for industries with larger objects (small ship industry) HDPE has not been widely worked on. For national shipping industry, HDPE boat have not developed much, because most of the raw materials for HDPE sheets are still imported, making HDPE boat more expensive than FRP boat (even though the building of FRP ships is prohibited due to the issue of environmentally damage). HDPE as a new/alternative material for boat must meet shipbuilding standards regulated in the Classification rules, including the quality of base and welding joint of HDPE. The experiment was carried out by testing HDPE joints with an extrusion type welding with 15mm thickness by bending and tensile tests, using acceptance criteria on DVS 2203-5 and TL/IRS Rules, the results showed that in general the DT method on HDPE welded joints failed due to less of joint and full penetration of the bevel. Meanwhile, to find out defects in welds using the NDT method, a reference study was carried out which refers to the ASTM E3044:2016 standard for UT testing of polyethylene butt fusion joints.

1 INTRODUCTION

Ship class approval generally consists of design verification and supervision of the ship construction at fabricator. Design assessment can be done clearly by checking the scantling according to class rules requirement or existing standards such as (ISO-12215, 2020). Meanwhile, Challenges actually arise in the shipbuilding process. Supervision must be carried out intensively to ensure the strength of the ship. One of the most importance step is including the welding quality. Unfortunately, based on observations in the field, most HDPE welders work only based on experience and a trial / error.

Moreover, condition is getting worse since there are many HDPE raw materials on the market that are not comply with the minimum standard properties. This lead major affects to the global strength of the ship. Although the proposed design already meets the minimum standard, the risk of failure remains if the quality of the manufacturer is not guaranteed

This fact becomes an exclusive challenge for BKI considering that there is no specific guideline yet of BKI to ensure the fabrication quality of HDPE ship. For this reason, comprehensive studies are needed including welding standards and testing through the DT (Destructive Test) and NDT (Non-Destructive test) methods.

2 METHODOLOGY

This study was initiated with literature reviews and discussions with several experts so that related references regarding welding preparation and process standards, welding defect criteria, and welding quality testing have been obtained. This information can be used as a basis for establishment of welding procedures in fabrication.

2.1 Weld Joint Standard

Weld Joint for HDPE material need special treatment since it differs to metal. The specific reference below can be used as the basis of HDPE welding standard for the ship.

2.1.1 Simona Welding

Welding standards in accordance with (Simona,

Anggara, S., Firmandha, T., H., R. and Rakanda, A.
HDPE as a New Alternative Material for Small Vessel Base and Joint Material Quality.
DOI: 10.5220/0011815200003575
In *Proceedings of the 5th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2022)*, pages 478-482
ISBN: 978-989-758-619-4; ISSN: 2975-8246

20011) contain brief guidelines regarding welding methods of thermoplastic materials, weld defects, and other substantial aspect for HDPE welding. For extrusion welding method which commonly used in some fabricators, HDPE filler wire is heated. Several aspects that need to be considered according to reference (Simona, 20011) are as follows:

- Temperature range for welding HDPE (PE-HD) is 250 - 300ºC
- Filler wire material must be the same as the base material
- Cleanliness of base materials
- welding rate
- welding pressure

2.1.2 American Welding Society

(AWS-B2.4, 2012) is used as a reference for the preparation of WPS (Welding Procedure Standard). The items in the WPS include:

- Thickness of the material
- Range qualification (Thickness test pieces, and base material)
- Test preparation (Number of test pieces for each test)
- Bevel type
- Weld test specimens
- Welding filler
- Temperature factor
- Pressure factor
- Gas welding
- Electrical (current and voltage)
- Welding speed

2.1.3 DVS (DVS 2207-1, DVS 2207-4)

DVS (Die Verbindungs Spezialisten) is an international standard regarding welding procedure which is mostly used by HDPE ship builders as a reference for welding HDPE materials. The types of welding used by the builder can be either fusion welding (DVS 2207-1, 2007) for large panels (hull and deck panels joints) or extrusion welding (DVS 2207-4, 2007) for smaller and more complicated parts (e.g., stiffener and joint joints). floors)

2.2 Weld Defects

In this study, Imperfection in thermoplastic weld joints can be assess by referring to (DVS 2202-1, 2008) for acceptance criteria

In general, provisions regarding Internal quality control, for preparation before fabrication, need to be carried out to avoid welding defects. The provisions can refer to the (IRS, 2021) Guidance with several consideration as follows:

- HDPE material must be an approved type, and there is no material installed on the ship that can affect other installed materials.
- The shipyard must keep verifiable records of material certificates from supplier, and keep samples of each deliverable materials. Materials must be stored according to the manufacturer's instructions.
- Manufacturing/shipyard must comply with welding requirements in accordance with international/class standards
- WPS and NDT can refer to international standards (ISO, EN, PD CENT/TS), as well as HDPE welders must be certified according to recognize standards

2.3 Destructive Test

Destructive tests are carried out on HDPE parent base material and its welding joints. Types of the tests carried out in this study is covering bending and tensile test (i.e., base material, weld joint material to longitudinal and transversal direction). There are 6 specimens for bending test. 2 specimens for tensile base material, 5 specimens for tensile with transverse weld joint and 1 specimen for tensile with longitudinal weld joint. The dimension and shaped of the specimens are determined in accordance with (DVS 2203-5, 1999) for bending test and (ASTM D638, 2014) for tensile test. Meanwhile, the circumstance condition as per Table 1 has been set in laboratory.

Table 1: Condition of testing.

Parameter	Value
Humidity	60% RH
Temperature	26.5 ºC
Preparation (Bending Test)	DVS 2203-5: 1999
Preparation (Tensile Test)	DVS 2203-2: 2010

2.4 Non-Destructive Test

Referring to the (ASTM E3044, 2016) standard for UT of polyethylene butt fusion joints, it is explained that ultrasonic testing for thermoplastic materials in general can be done by 2 methods, namely PAUT (Phased Array Ultrasonic Testing) and TOFD (Time of Flight Diffraction). The two methods are illustrated in Figure 1 and 2 below.

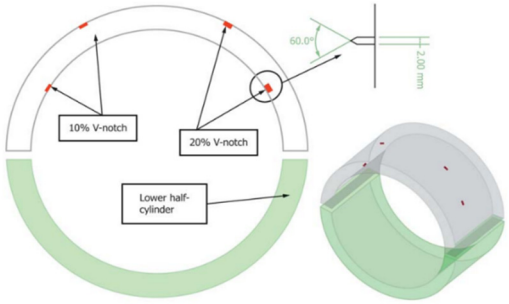

Figure 1: TOFD Examination.

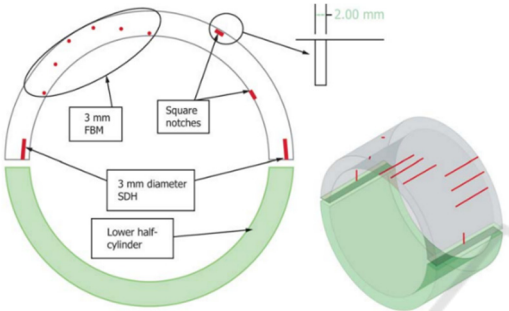

Figure 2: PAUT Examination.

2.5 Material Sampling

Based on the manufacturing certificate, material samples are produced in 1 batch (20 sheets) with the following properties:

Table 2: Material Properties Material HDPE.

Test	Value	Unit
Specific gravity	0.955	g/cm3
Tensile Strength	25.84	N/mm2
Elongation at yield	9.7	%
Modulus of Elasticity	1160	N/mm2
Elongation at break	>300	%
Notched impact strength	10.39	mJ/mm2

3 RESULT AND DISCUSSION

3.1 Bending Test (Transverse Joint)

According to the test standards on (DVS 2203-5, 1999), the weld joint will be approved if comply with acceptance criteria which there is no crack in the material that has been subjected to a bending test at 160º angle.

The test was carried out on 6 specimens with the result that all specimens cracked at a bend angle of 160º. This means that the specimen being tested does not meet the minimum requirements of (DVS 2203-5, 1999) or fails. The initial hypothesis is that the quality of the weld on HDPE material does not meet the requirements of the weld strength, the welding process does not fully penetrate into entire bevel so that there is a bevel that is not filled by the filler material. Thus, it will lead an impact on the strength of the weld itself. There result of bending test can be seen in Table 3.

Table 3: Bending test result.

ID	Width [mm]	Height [mm]	Area [mm]	Max Load [N]	Bending Stress [MPa]
1	20.97	15.32	321.26	1468.8	44.765
2	20.77	15.35	318.82	1561.3	47.854
3	20.95	15.44	323.47	1568.2	47.098
4	20.31	15.36	311.96	1328.3	41.581
5	20.79	15.28	317.67	1370.0	42.336
6	20.94	15.43	323.10	1231.6	37.057

Visualization of bending test result in Figure 3 show that 6 samples experienced cracks in the weld area. This indicates that the weld area is the weakest point of the specimen.

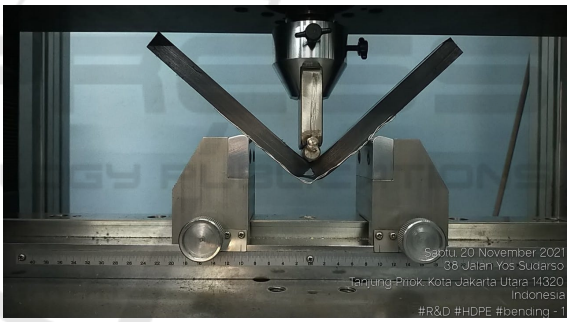

Figure 3: Bending test in Laboratory.

3.2 Tensile Test (Base Material)

The results of tensile test (base material) aim to see whether the raw material used meets the requirements standard of HDPE material or not. Since there are fact that counterfeit material exist on market. The acceptance criteria used are the standards from (Turk Lloyd Class, 2014) and (IRS, 2021) where the minimum ultimate tensile stress requirement is 24 MPa. The results of the 2 specimens tested were 24.07 MPa and 24.78 MPa, which means that the raw material used meet with the standard. See Table 4 for ultimate stress result and Figure 4. For elongation-load behavior

Table 4: Tensile test result for base material.

ID	Width [mm]	Thickness [mm]	Max Load [N]	Max. Stress [MPa]
1	30.19	15.35	11154	24.07
2	30.16	15.43	11532	24.78

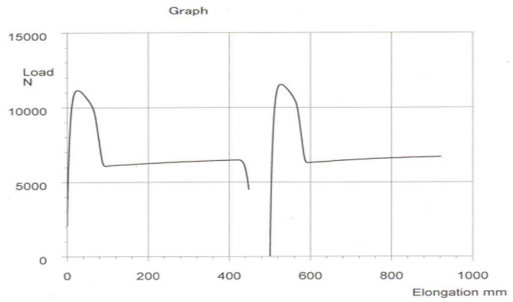

Figure 4: Elongation base metal of Tensile test.

This has been also confirmed by similar tests performed in (Jamal and Aryawan, 2015) which obtained a determination that the magnitude of the yield strength of HDPE plastic is at 17.12 MPa and Tensile strength is at 24.82 MPa. Those known as standard properties of HDPE.

3.3 Tensile Test (Transverse Joint)

The results of the tensile test (Transversal) aim to see the strength of the weld joint compared to base material. From 5 tested specimens, all failed/broken at the welded area with tensile strength of around 19-22 MPa. This means that the strength of weld joint is lower than minimum tensile strength of raw material (24 MPa). This indicates that the welding process carried out was poor so that the bevel is not completely filled (see Figure 5), which affects the strength of the weld itself.

Table 5: Tensile test result for transverse weld joint.

ID	Width [mm]	Thickness [mm]	Max Load [N]	Max. Stress [MPa]	Elongation [%]
1	30.03	15.34	9054	19.65	3.48
2	30.15	15.44	8315	17.86	3.47
3	30.26	15.31	10411	22.47	2.53
4	30.31	15.30	9815	21.16	2.13
5	30.26	15.34	9655	20.80	2.62

From a technical point of view, fracture in the weld area is allowed if the tensile strength of the weld exceeds the value of the tensile strength of the raw material, so it can be concluded that the welding process carried out does not meet the (Turk Lloyd Class, 2014) and (IRS, 2021).

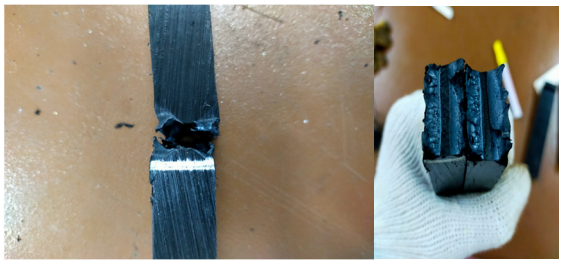

Figure 5: Tensile test result (transverse weld joint).

3.4 Tensile Test (Longitudinal Joint)

Longitudinal tensile test aims to see the strength at weld area. However, in this case, the cut specimen leaves raw material beside the weld area. When compared with other mode of tensile test, this longitudinal tensile test is less able to conclude the actual results because the tensile specimen is not pure from the weld area.

Table 6: Tensile test result for longitudinal weld joint.

ID	Width [mm]	Thickness [mm]	Max Load [N]	Bending Stress [MPa]
1	25.28	15.52	10798	27.522

4 CONCLUSIONS

In testing materials and HDPE weld joints, the standards commonly used by domestic builders are (DVS 2202-1, 2008) for imperfection criteria of welded joints and (DVS 2203-5, 1999) for bending test criteria. While the tensile test can refer to (ASTM D638-14, 2014) and (ISO-527, 2019).

By referring to the standard above, it can be concluded that HDPE welded joints failed to DT test, due to weld imperfection and not full penetration of the bevel. Poor welding quality can be caused by inappropriate travel speed. Travel speed that is too fast causes the filler to not penetrate completely, allowing the formation of cavities inside the joint. On the other hand, a travel speed that is too slow will cause large area of base material that affected by heat (Maki, 2015). It is clear that the quality of the weld is importance and a bad weld can be catastrophic for the structure.

To avoid such welding defects, things that must be considered regarding the welding process are as follows:

- Regarding specimen preparation, it must be ensured that the weld material fully penetrates so that it fills the bevel completely and

thoroughly. This can be evaluated at the time of making pre-WPS, if the welding test results do not meet the requirements, the WPS will be returned and to be revised with new welding parameters.

- References related to thermoplastic joints/welding can follows the international standards mentioned in Table 4.3.3 of the (IRS, 2021) Guidelines (EN, ISO, PD CEN/TS)

Lastly, Due to the different nature from steel, NDT testing of steel cannot be applied to HDPE. According to the (ASTM E3044, 2016) standard, the UT test for polyethylene butt fusion joints can be carried out using the PAUT and TFOD methods. However, so far there has not been found a laboratory that capable of conducting NDT tests for HDPE materials using the PAUT and TFOD methods in Indonesia. Commonly, PAUT is used for pipe NDT test. However, in practice PAUT can be done through conventional UT by modifying the prob.

ACKNOWLEDGEMENTS

Our sincere gratitude and appreciation to Iqra Visindo Shipyard who support in providing material and specimen as well as share their knowledge and experience of building boat HDPE based material.

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