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ANALYSIS OF TENSILE AND FLEXURAL STRENGTH OF HDPE MATERIAL JOINTS IN SHIP CONSTRUCTION

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The use of wood as the primary material in the fishing vessels construction has been use a lot in Indonesia. At present, there is a problem in the availability of wood materials which are increasingly difficult to obtain. For this reason, it is necessary to innovate good quality wood substitute materials. In this case, HDPE (High-Density Polyethylene) material is the suitable alternative as a substitute for the primary material for fishing vessels. However, further studies are needed due to the lack of regulation and research related to the joint of HDPE materials in ships construction. This study aims to determine the quality of various variations in tensile and bending strength. The method used is experimentation and data processing, while the research variation is V-Seam and X-Seam with hot gas and extrusion welding. Data were obtained by conducting tensile testing with the BS EN 12814-1-2000 standard and bending testing with the BS EN 12814-2-2000 standard. The study's results found that the seam and connection method affect the tensile strength and bending of the HDPE welding joint. The tensile and bending strengths for each variation of V-Seam hot gas, X-Seam hot gas and V-Seam extrusion welding are 14.07 MPa, 15.44 MPa, and 19.29 MPa, while the bending strengths are 29.22 MPa, 33.28 MPa, and 37.85 MPa, so the most optimum tensile and bending strength is obtained from the variation of the V-Seam extrusion welding joint with values of 19.29 MPa and 37.85 MPa, respectively.

Keywords: HDPE, fishing vessels, tensile, bending, welding

1 INTRODUCTION

Wood as the main material in the ship hulls construction has been widely used in fishing vessels in Indonesia. The increase of wood demand and large-scale exploitation, cause the scarcity of wood materials so the price of wood is relatively expensive. The use of wood as the main material in ship construction also has limitations compared to materials similar such as aluminium, fiberglass or plastic. The weaknesses of wood in ships construction is large expansion and shrinkage capacities, having a large enough deflection for long-term loading, homogeneous structures and less durable. In addition, the technical properties needed for the purposes of ship construction are strong properties and resistance to weathering or durability, these durable properties are related to the mechanical strength of the material, such as tensile and compressive strength. New lighter materials are needed to improve competitiveness with other modes of transportation and to minimize draft increases due to heavier cargo weight [1]. Just like in other construction area, the main struggle of ships contruction engineer is to achieve lighter structure with new or alternative material, like use polymer based composites, to construct some of ship structural elements [2]. Alternative materials are needed to replace wood materials which have many weaknesses, one of the materials that can be used as a material for ship construction is high-density polyethylene (HDPE). HDPE plastic material can be used as an alternative to wood in making fishing vessels [3]. Indeed, at this time the use of fiberglass reinforced plastic (FRP) material as a substitute for wood is widely used as the main material for fishing vessels, but due to environmental problems where FRP material cannot be recycled, and FRP are not degradable materials, it take more than 100 years to break down in nature [4]. HDPE material is one of the alternative materials to replace wood as ships hull construction. In addition, the boat made from HDPE has good structural integrity and quality control better than FRP boat [5].

In this case, high-density polyethylene (HDPE) is an appropriate alternative as a basic material for ships construction. The use of HDPE can substitute for the wooden shell of a boat hull that provides advantages both technically and economically [6]. HDPE can be considered as an alternative material for making ship hull, because HDPE has several advantages, including mechanical strength and durability [7]. But HDPE still has weaknesses in terms of toughness, strength and flexibility [8]. High density polyethylene (HDPE 100) primarily as sheet and pipe, the material which is high strength, light weight easily processable, good in corrosion resistance, and thermal stability is preferred for new and superior operational material requirements for boat [9]. Some of the advantages of HDPE plastic as a shipbuilding material are: first, HDPE plastic is durable against material aging and corrosion. Second, good crack resistance so that the impact damage is minimal. Third, HDPE is flexible and durable, withstanding the worst weather conditions, resistant to corrosion for approximately 50 years to decompose [10]. Fourth, it can be recycled and there are many more advantages. Not only that, HDPE material is lighter than wood, aluminum and fiberglass materials, for the same ship size HDPE material can reduce ship hull material in progressive calculations [11]. So, it can be concluded that the HDPE plastic material has good technical characteristics and can fulfill the lack of using the wood materials.

In the ship construction, the joint of material is one of the important things in a ships construction. In general, the joints in ship construction use the welding method. At this time, welding of HDPE materials mostly uses the butt fusion welding method [12]. Research related to HDPE welding in ship construction is minimal, so it is necessary to carry out further analysis regarding differences in HDPE welding joints in terms of tensile strength and flexural strength with variations in seams and connection methods. So, in this study will be discussed about the tensile and flexure tests on HDPE welded joints for ship construction.

2 METHOD

2.1 Boat Model

In this study the boat or vessels that used as the reference object for determining the HDPE plate thickness is 3GT fishing vessels with the following specifications, the data can be seen in Table 1:

Table 1. Fishing vessel principal dimension

Principal	Dimension (m)
Length Overall (LoA)	7.00 m
Length Waterline (Lwl)	6.33 m
Length PerPendicular (Lpp)	6.18 m
Breadth (B)	1.20 m
Height (H)	0.50 m
Draft (T)	0.30 m

The thickness of HDPE material is calculated using the equation in the DNVGL-ST-0342 Craft [13], from the formula in DNVGL-ST-0342 state that the thickness of the outermost bottom hull cannot be less than:

$$t_y = ks \sqrt{\frac{PFb}{L\ x\ 6{,}7}\ x\ (14 + 3{,}6\ L)} \quad (\text{mm}) \qquad (1)$$

where:

k = 0.72 for HDPE

s = stiffener spacing (for this case use the stiffener spacing 0.5 m)

PFb = bottom load factor = 15 kN/m^2

L = scantling length, L = $\frac{L_H + LWL}{2}$ = 6.67 m

$$t_y = 0.72\ x\ 0.5 \sqrt{\frac{15}{6{,}67x\ 6{,}7}\ x\ (14 + (3{,}6\ x\ 6{,}67))} \quad (\text{mm})$$

$$t_y = 8{,}62\ mm$$

The minimum HDPE thickness is 8.62 mm, in this study take the thickness HDPE material is 12 mm.

2.2 Plastic Welding

Plastic welding is one of the most commonly used thermoplastics joining methods and it is the best in plastic joints. The technique in this welding, it is to melt the base metal with an plastic welding rod, so that it can melt together when it is cold [14]. In plastic welding, butt fusion welding has prolonged great popularity for welding polyethylene plastic industry [15] .

2.2.1 Hot Gas Plastic Welding

Hot gas plastic welding is a manual process for joining materials by external heating methods. The process is to heat the area to be welded with a filler rod using a gas stream until it is soft enough and then the filler is pressed into the weld area [16]. Splicing occurs due to joint fusion between the plastic sheet substrate and the welding wire.

Hot gas welding equipment consists of a heater unit, a nozzle to direct hot air, and an air compressor, either integrated or separate. The temperature of the hot gas welder can be adjusted depending on the electricity supply to the heater and can usually be set to a temperature of 200-400 Celsius, depending on the type of plastic to be welded. The size and shape of the nozzle used is adjusted to the type of connection being prepared and the shape of the welding wire. Plastic welding wire or filler rod is adjusted to the material to be welded and is oval, rectangular or triangular in shape [17].

2.2.2 Extrusion Welding

Extrusion welding is one of the methods used to join thermoplastic and composite materials. In simple terms, the working system of this welding type is the machine heats and melts the plastic filler inside, which is extruded onto the heated base material. After the two materials have cooled, the base metal and filler will remain permanently bonded to each other [18].

The advantage of this type of welding is the bond of the welding is stronger because it is in one welding lane, and the processing time is faster due to the increased volume of filler material removed. However, the disadvantage of this welding process is the large weight and size of the equipment, making it difficult to do corner welding [18].

2.3 Tensile and Bending Test

The tensile test carried out in this study refers to the BS EN 12814-2-2020 standard [19], where from the tensile test, data is obtained in the form of the maximum load that the material can withstand before it increases in length and breaks. Tensile test specimens according to BS EN 12814-2-2020 can be seen in Fig. 1, where the length of the specimen is 300 mm with a width of 40 mm, and a material thickness of 12 mm.

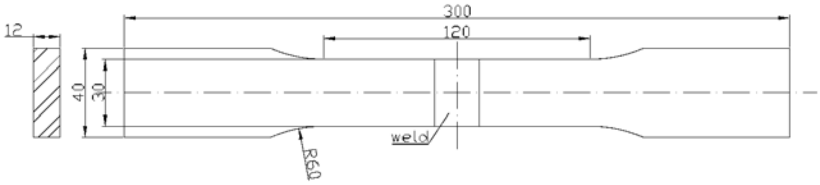

Fig. 1. Tensile test specimen according to BS EN 12814-2-2020 (in mm)

The flexural strength test in this study refers to the BS EN 12814-1-2000 standard [20] with the length of the support span being at least 100 mm, the width of the specimen is 20 mm and the specimen must be long enough so that the specimen does not come out of the support span. And the diameter of the minimum pressure mandrel is 12.5 mm. Bend test specimens according to BS EN 12814-1-2020 can be seen in Fig. 2, where the length of the specimen is 200 mm with a width of 30 mm, and a material thickness of 12 mm.

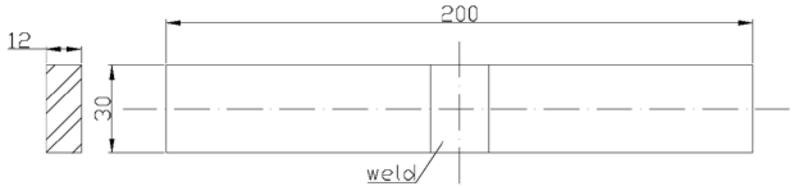

Fig. 2. Bend test specimen according to BS EN 12814-1-2020 (in mm)

The process of tensile and bend testing can be seen in Fig. 3, where the tests were carried out in a material testing laboratory.

Fig. 3. Tensile and bending test of HDPE Material in material testing laboratory

2.4 Welding Parameter

The welding process in this study is to use a butt joint, the thickness of material is 12 mm and the filler diameter is 4 mm. In this study, there are 3 variations of the joint welding process:

- Hot gas welding with V-Seam
- Hot gas welding with X-Seam (The double-V seam)
- Welding extrusion welding with V-Seam

In this study, the welding joint design of the V-Seam and X-Seam models can be seen in Fig. 4, where the 1G welding position with a Butt Joint.

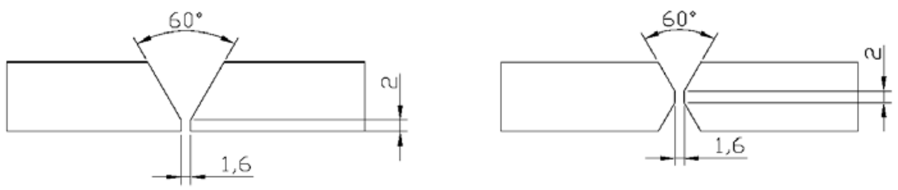

Fig. 4. Joint design V seam and X Seam

The welding parameters in this study can be seen in the table Table 2.

Table 2. The welding parameters

Parameters	Hot Gas Welding	Extrusion Welding
Travel speed	70 – 90 mm/min	300 mm/min
Hot gas temperature	300 – 320^0 C	210 – 300^{0}C
Hot gas volume flow	40 – 50 l/min	300 l/min
Welding force	20 – 25 N	-
Material temperature	-	210 – 230^0 C

3 RESULT AND DISCUSSION

3.1 Welding

The results of welding in this study with HDPE V-Seam and using hot gas plastic welding are shown in Fig. 5 below.

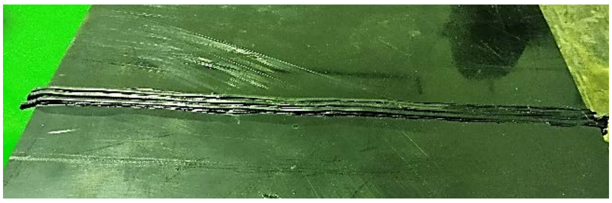

Fig. 5. Welding Results of V-Seam Hot Gas Plastic Welding

The results of the welding process of HDPE material with X-Seam and hot gas plastic welding are shown in Fig. 6 below.

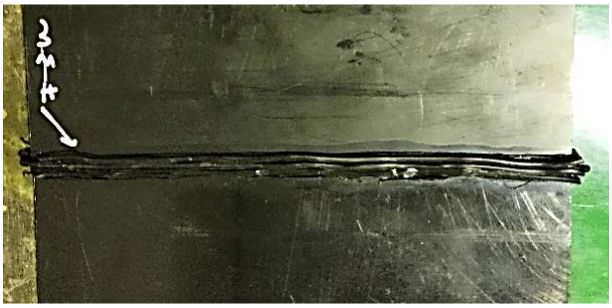

Fig. 6. Welding Results of X Seam Hot Gas Plastic Welding

The results of the welding process of HDPE material with V-Seams and extrusion welding are shown in Fig. 7 below.

Fig. 7. Welding Results of V-Seam Extrusion Welding

3.2 Visual Inspection

Visual testing is only carried out to inspect for defects on the weld surface only and only using the eye with the aid of a lighting device when necessary. Based on the BS EN 12814-2:2021 standard, after cutting the material a visual test must be carried out [19]. For acceptance criteria against imperfections in thermoplastic welding using standard BS EN 16296:2012 (Imperfection in thermoplastic welded joints – Quality levels)[21].

Based on the quality levels of classification, HDPE (High Density of Polyethylene) material is included in the symbol B (stringent requirement) in terms of manufacturing conditions, environment, and potential hazards in the event of failure. The following visual test results on hot gas welding and extrusion for each variation can be seen in Table 3 below

Table 3. Visual Test Results of Various Welding Variations

Specimen	Defect	Acceptance
V-Seam Hot Gas - Tensile (HVT)	No Defect	V
X-Seam Hot Gas - Tensile (HXT)	No Defect	V
V-Seam Extrusion - Tensile (EVT)	No Defect	V
V-Seam Hot Gas - Bending (HVB)	No Defect	V
X-Seam Hot Gas - Bending (HXB)	No Defect	V
V-Seam Extrusion - Bending (EVB)	No Defect	V

Visual testing is carried out to visually determine the results of the welding joint between the base metal and filler whether there are defects such as cracks, gas cavities, inclusions, incomplete penetration, excessive penetration, undercuts, linear misalignment, and angular misalignment. Based on the visual test results presented in Table 3, it can be analyzed that the connection results for each coding material HVT, HXT, EVT, HVB, HXB, and EVB did not reveal any visual defects. This can happen because in the process, if visual defects that often occur such as cracks, undercuts, porosity, and incompletely filled grooves are found after the welding process, then the material can no longer be used and will be re-welded with new material.

3.3 Tensile Test

After a visual inspection then a tensile test is carried out. Based on the standard, at least five test specimens shall be tested for each welded test piece. The standard used to determine the dimensions of the specimen and the tensile strength value of the HDPE material connection is BS EN 12814-2:2000. The results of the tests that have been carried out are presented in a stress-strain chart. The results of the tensile testing can be seen in Fig. 8 for the variation of the V-Seam hot gas welding, Fig. 9 for the variation of the V-Seam extrusion welding, and Fig. 10 for the variation of the X-Seam hot gas welding.

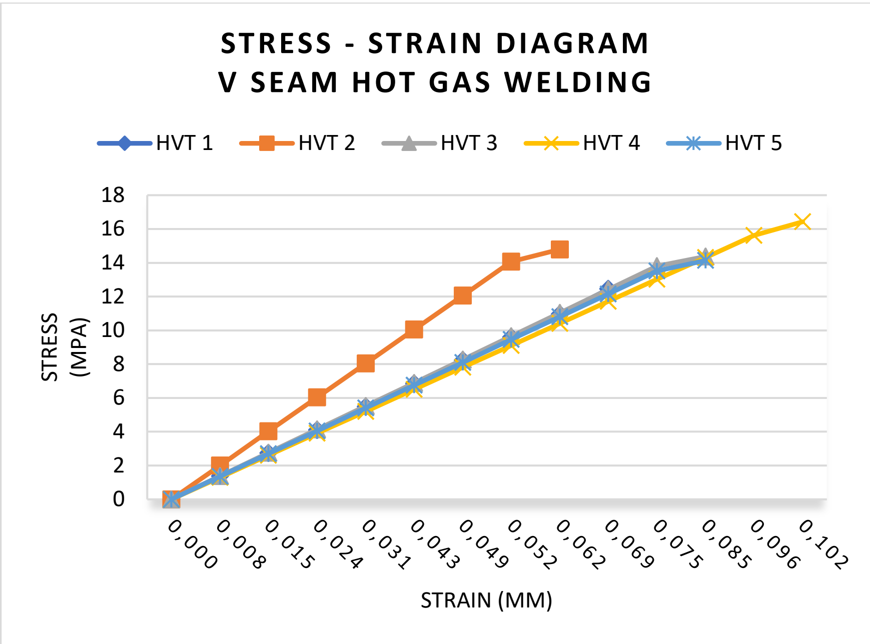

Fig. 8. Stress - Strain Diagram V Seam Hot Gas Welding

Based on Fig. 8 it is shown that each specimen has relatively the same value for stress and strain values, but the HVT-2 and HVT-4 specimens have different values. For HVT-2 the stress value shown is greater than the average specimen, but has the smallest strain elongation, while for the HVT-4 specimen it has the largest stress and strain elongation values.

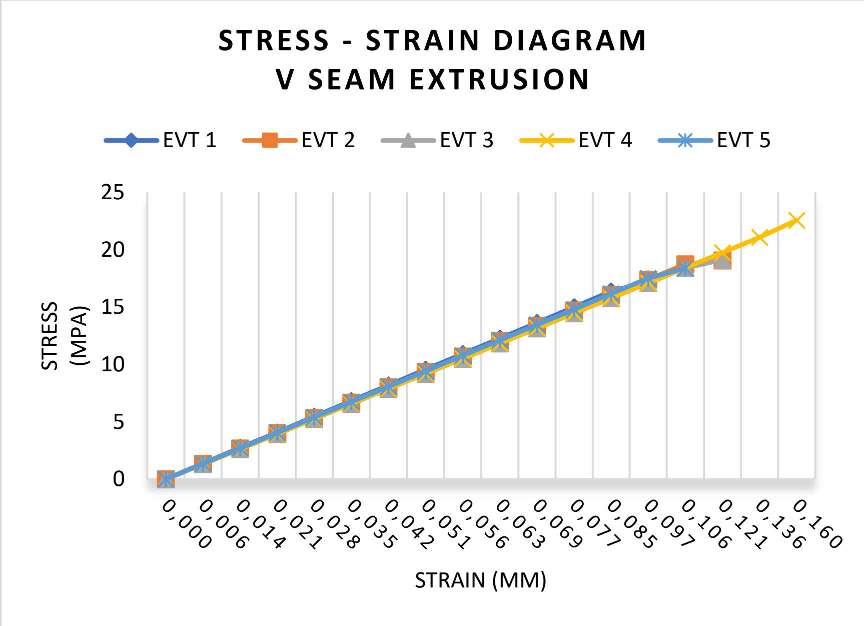

Fig. 9. Stress - Strain Diagram V Seam Extrusion

Based on Fig. 9, it is shown the distribution of the stress strain on each specimen with the notation EVT. It can be seen that the stress and strain values for each specimen are relatively the same value, but the EVT-4 specimen has a greater stress value and strain elongation than the other specimens.

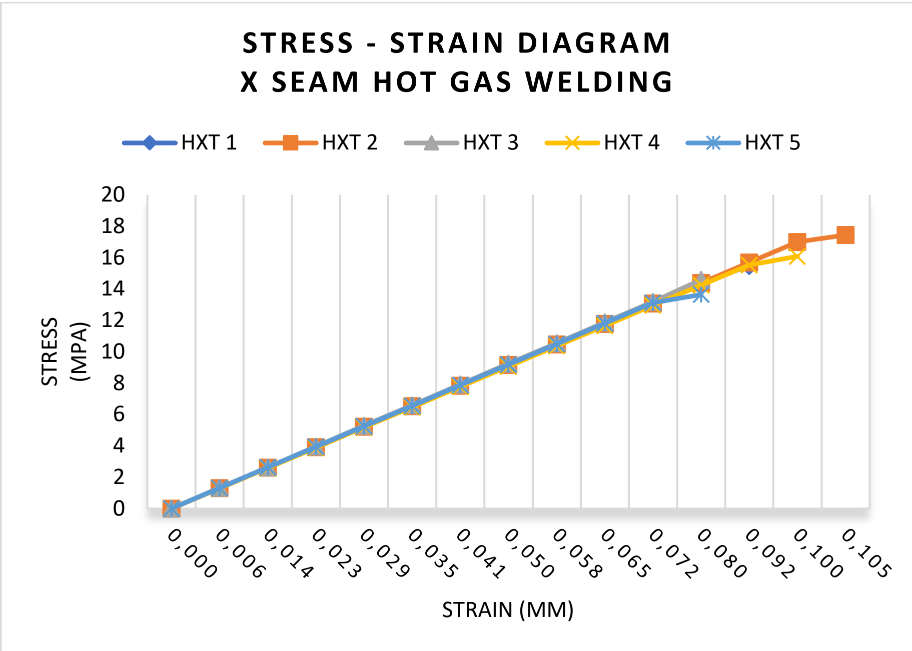

Fig. 10. Stress - Strain Diagram X Seam Hot Gas Welding

Based on Fig. 10, it is shown the distribution of the stress strain on each specimen with the HXT notation. It can be seen that the stress and strain values in each specimen are relatively the same, but the HXT-2 and HXT-4 specimens have stress values and strain elongation that are greater than the other specimens.

From the results of the tests that have been carried out, a comparison table can be made that compares the results of the three welds with variations in seams and connection methods. The following is a comparison of the average tensile strength test results of the three variations shown in Table 4.

Table 4. Average Tensile Strength

Welding Variation	Average Tensile Strength (MPa)	Elongation (%)
V-Seam Hot Gas Welding	14.07	8.12
V-Seam Extrusion Welding	19.29	12.28
X-SeamHot Gas Welding	15.44	8.94

If seen from the average results of tensile testing for each variation on each specimen, the specimens with V-Seam hot gas welding have the lowest average value of tensile strength test results, with a value 14.07 MPa. Whereas for specimens with V-Seam extrusion welding, the average value of the highest tensile strength test results, with a value 19.29 MPa. Specimens with X-Seam hot gas welding have an average value in the middle of the other two variations with a value 15.44 MPa. Test results on welding joints under raw material testing conducted by Setyawan et.al in 2022 with an average test result of 25 MPa [22] and under the results of raw material testing conducted by Aryawan in 2015 with test result of ultimate strength is 24.82 MPa [23]. Research conducted by U. Demir and E. Köse in 2018, stated that the strength of HDPE material joint has an average strength of 25 MPa with the electrofusion welding method [24].

Then by looking at the percentage of strain, the ductility value in each variation can be known. Based on the diagram, the average percent elongation in the variations of V-Seam hot gas welding, V-Seam extrusion welding, and X-Seam hot gas welding seams are respectively 8.12, 12.28, and 8.94 %. From these results it can be seen that the V-Seam extrusion welding is the most ductile variation compared to the other variations. While the V-Seam hot gas welding variation is the the lowest level of ductility.

Then by knowing the value of the elastic modulus of each variation, the level of stiffness of a material can be known. The greater the value of the modulus of elasticity, the higher the level of stiffness of the material. Based on the test results, the elastic modulus values for the variations of V-Seam hot gas welding, V-Seam extrusion welding, and X-Seam hot gas welding are respectively 180.27, 159.28, and 173.31 MPa. From these results it can be seen that the V-Seam hot gas is the variation with the highest degree of stiffness, and the V-Seam extrusion is the variation with the lowest stiffness level. The following is a fracture specimen from the tensile test results shown in Fig. 11 below. The results of the tensile testing that has been carried out, the fracture of the specimen is within the Calibrated and Parallel Length (Lo) according to the BS EN 12814-2-2000 standard [19]. All specimen types fractured within the Calibrated and Parallel Length (Lo) areas.

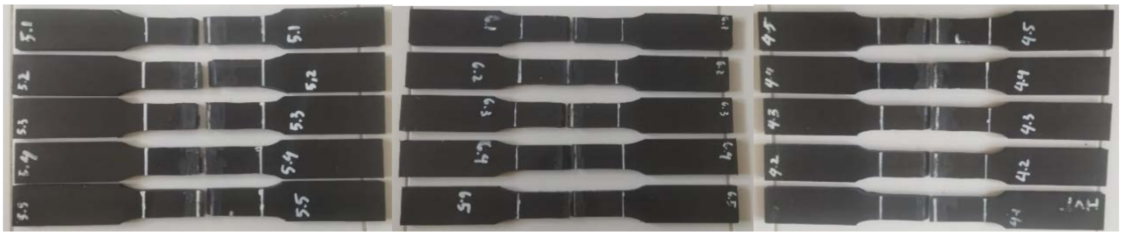

Fig. 11. Fractures of Tensile Test Specimens

Based on Table 4 above, it is shown that the average UTS (ultimate tensile strength) values for each variation of the V-Seam hot gas, V-Seam extrusion, and X-Seam hot gas are 14.07, 19.29, and 15.44 MPa. A similar study was carried out by Sulaiman and Samuel in 2022, the V-Seam hot gas variation, the tensile test showed the average UTS value is 17.21 MPa. [25]. Furthermore, research conducted by Tariq et all, in 2012 shows that for tensile testing the UTS value is shown at 13.5 MPa. [26]

In addition to research using a similar connection method, to find out the comparison with the other most widely used connection method, it is friction stir welding, the authors compared the test results with journals from research that conducted by Amir, and Ehsan Azarsa the research shows that the value tensile strength is 15.75 MPa [27]

Based on the relevant research results described above, a graph can be made showing the comparison of UTS test results. The following is a comparison of the test results with the average results from relevant studies shown in Fig. 12.

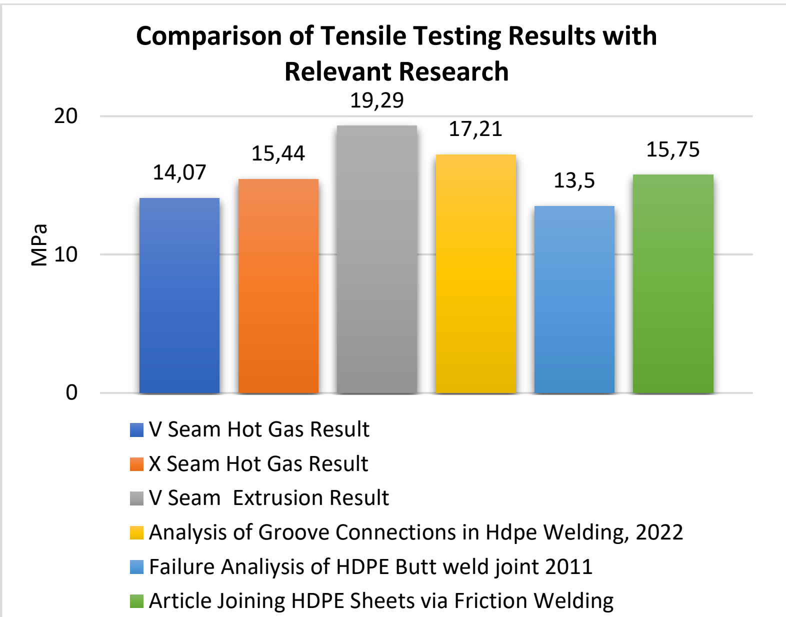

Fig. 12. Comparison of Tensile Test Results and Relevant Research

From Fig. 12 it can be concluded that the variation of V-Seam extrusion has the greatest ultimate tensile strength (UTS) value with a percentage of 42.8% higher than the UTS results in relevant research, while the variation of V-Seam hot gas and X-Seam hot gas has a value greater than the UTS results in the research conducted by Tariq et all, in 2012 with percentage is 4% and 14%, but smaller than the research conducted by Sulaiman in 2022 with percentage is 22% and 11.5%. Meanwhile, when compared to the friction weld connection method carried out by Amir in 2012, the variation of V-Seam and X-Seam hot gas s has a smaller UTS value with a percentage of 12% and 2%.

3.4 Bending Test

From these results, a comparison table can be made that compares the results of the three welding with seam variations and joining methods. The following is a comparison of the average bending strength test results of the three variations shown in Table 5.

Table 5. Comparison of Average Bending Strength Results

Specimen	Average Bending Strength (MPa)
V-Seam Hot Gas Welding	29.22
X-Seam Hot Gas Welding	33.28
V-Seam Extrusion Welding	37.85

If we look at the average bending test results for each variation in each specimen, the specimen with V-Seam hot gas welding has the lowest average bending test result, it is 29.22 MPa. Whereas for specimens with V-Seam extrusion welding, the average value of the highest tensile strength test results was 37.85 MPa. The specimen with X-Seam hot gas welding has an average value in the middle of the other two variations with a value of 33.28 MPa.

In the V-Seam extrusion welding variation, there is 1 specimen not cracked and not broken, 3 specimens cracked but not broken, and 2 specimens broken. Whereas in the X-Seam hot gas welding variation there were 4 specimens cracked but not broken, and 2 specimens broken. The following is a specimen fracture from the bending test results shown in Fig. 13 below. In the bending tests that have been carried out, the fracture occurs in the welding area. Bending tests were carried out on each variation of the seam and the joining with a total of 6 specimens in each variation. In the variation of V-Seam extrusion welding, there are 1 specimen that does not have crack and does not break, and 3 specimens have crack but does not break, and 2 specimens have broken. Whereas in the X-Seam hot gas seam variation there are 4 specimens cracked but not broken, and 2 specimens broken. and in V-Seam hot gas there are 4 broken specimens and 2 specimens cracked.

Fig. 13. Fractures of Bending Test Specimens

Based on Table 5 above, it is shown that the average bending strength values of each variation of V-Seam hot gas, V-Seam extrusion, and X-Seam hot gas welding are respectively 29.22 MPa, 37.85 MPa, and 33.28 MPa. A similar study was conducted by Sulaiman and Samuel in 2022, that the bending test showed an average value of 23.37 MPa [25]). Furthermore, research conducted by Tariq et al, shows that for bending testing the bending strength value is 27.4 MPa [26]

In addition to research using a similar connection method, to find out the comparison with the other most widely used connection method, it is friction stir welding, the authors compared the test results that conducted by Amir, and Ehsan Azarsa the results shows that the value bending strength is 22.5 MPa [27]. Based on the relevant research results described above, a comparison graph of the test results can be made with the results of the relevant research and the different connection methods shown in Fig. 14 below.

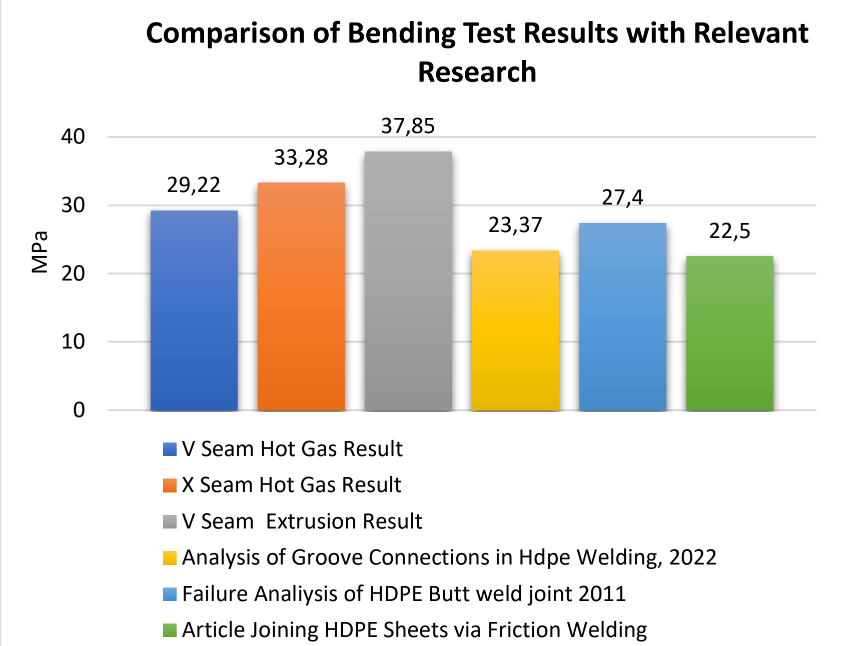

Fig. 14. Comparison of Bending Test Results with Relevant Research

From Fig. 14 it can be concluded that the overall variation has a greater value than the results of the bending strength of the relevant research and the friction welding method of joining. For variations of V-Seam and X-Seam hot gas welding has a percentage value of 25% and 42% higher than the relevant studies, and 30% and 48% higher than the friction welding method. Meanwhile, the V-Seam extrusion variation has a percentage of 60% higher than the relevant research, and 68% higher than the friction welding method.

4 CONCLUSION

Based on the research that has been carried out in the work on this research, the conclusion of this paper is as follows, the variation of seam and connection method during the welding process affects the value of the tensile strength and bending of the welded joint. The variation with V-Seam extrusion welding has a tendency of increasing by 37% compared to the V-Seam hot gas welding variation where the V-Seam extrusion and V-Seam hot gas welding values are 19.29 and 14.07 MPa. While the X-Seam hot gas welding variation has a tendency of increasing by 10% against the V-Seam hot gas welding variation where the X-Seam hot gas welding value is 15.44 MPa. So that the most optimal characteristics of the welded joints are obtained from joints with V-Seam extrusion welding with a tensile strength value of 19.29 MPa. In the bending test of the HDPE joint material, the V-Seam extrusion welding variation has a tendency to increase by 30% compared to the V-Seam hot gas welding variation where the V-Seam extrusion and V-Seam hot gas welding values are 37.85 and 29.22 MPa, while the X-Seam hot gas welding variation has tendency to increase by 14% for the variation of V-Seam hot gas, where the value of X-Seam hot gas weldng is 33.28 MPa. So that the most optimal strength characteristics of welded joints are obtained by joints with V-Seam extrusion welding with a bending strength value of 37.85 MPa. According to the results of the analysis that has been carried out, the optimum tensile and flexural strength is obtained from the variation of the V-shape with the extrusion joining method (V-Seam exrusion welding), which can be used as an alternative for connecting HDPE materials on ships.

For future work, the calculation of longitudinal strength on ships using HDPE should be carried out, because the test results of HDPE material connections are below the original value of HDPE material strength. So it is necessary to calculate the strength of ship structures that use materials made from HDPE.

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