Mechanical Characteristics of Glass Fibre Vessels

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***Abstract*— Glass fibre vessels in Indonesia, which has thousands of islands, are increasingly used due to their relative low price, light weight, corrosion resistance, and low maintenance costs. However, the aggressive marine environment such as exposure to salt water, ultra violet light, temperature changes, and repeated mechanical loads, affect the service life of this material. Determining the mechanical characteristics of glass fibre vessels is important to prevent structural damage that compromises safety and operations. The purpose of this research is to identify and analyse the condition of shipyards, fibreglass vessels that have been in operation, and examine the mechanical characteristics of glass fibre vessels. The research methods used are literature studies and field surveys to shipyards, glass fibre ships, and testing mechanical characteristics with tensile tests and bending tests. The results obtained from this study are the identification of the condition of the glass fibre shipyard, the condition of the operating glass fibre ship, and the mechanical characteristics of glass fibre ships mostly do not meet the standards of the Indonesian Classification Bureau. Recommendations to improve the quality of production are the location, method, labour, design and materials such as ship resin and laminate layers used during the production process have met and obtained certification set by the Indonesian Classification Bureau.**

Keywords— *lifetime; glass fibre; tensile test; bending test*

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I. INTRODUCTION

Glass fibre vessels have become a popular choice in the shipyard industry, especially for small and medium-sized vessels, due to their advantages such as light weight, corrosion resistance, and relatively low maintenance costs. Okuma et al stated that glass fibre can replace metal in the marine industry with various advantages such as durability, stiffness, corrosion resistance, strength, and weight [1]. Potential applications of glass fibre beyond ships include ship components, offshore oil and gas structures, marine renewable energy, and underwater repair [2]. Hamzat et al discussed the need for the design, manufacture, durability, and reliability of glass fibre-based structures and components for the aerospace, marine, and energy industries in harsh operating environments [3]. However, glass fibre materials have specific characteristics that make determining their lifespan a challenge. Factors such as exposure to aggressive marine environments (including saltwater, ultraviolet light, and temperature changes), repeated mechanical loads, and potential damage from long-term use need to be taken into account in estimating the lifetime of glass fibre vessels [4] [5] [6].

Other factors that affect the service life of glass fibre vessels are the manufacturing method and the type of material used. Common manufacturing methods include hand lay-up, chopper gun, and vacuum infusion. The hand layup method is considered the simplest and is often used in the glass fibre shipbuilding industry [7]. The application of carbon fibre composites in glass fibre shipbuilding still does not accommodate sustainability aspects especially with end-of-life scenarios such as reuse and recycling, as well as ship life cycle assessment [8].

The management of glass fibre vessels and operating shipyards is very important, as most glass fibre vessels in Indonesia are designed, built and operated based on experience and not according to classification bureau standards. If not managed properly, this can lead to structural failures that potentially jeopardise the safety of the vessel, crew, passengers and cargo.

Several glass fibre ship accidents can be identified from online media including: the sinking of a glass fibre ship in the waters of Hamlet Hundihuk Centre, Hundihuk Village, Rote Ndao Regency [9]; the sinking of a glass fibre ship in Araraw Waters, Muara Iruwa, Mimika Regency, Central Papua [10]; a speedboat carrying North Maluku Governor Candidate Benny Laos, exploded and caught fire at Bobong Port, West Taliabu District, North Maluku [11].

Most glass fibre vessels in Indonesia are constructed using the hand layup method of WR (woven roving) and CSM (chopped strand mat) fibre combination [7], which has lower tensile and bending strength characteristics compared to the use of multiaxial materials [12]. The selection of appropriate manufacturing methods, the use of high-quality materials, environmental and operational conditions and periodic maintenance greatly affect the service life of glass fibre vessels [13].

Several non-destructive and destructive testing methods are used to determine the characteristics of glass fiber composites so that the service life of fiber glass ships can be estimated. Gholizadeh reviewed non-destructive testing (NDT) methods for composite

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evaluation, which consist of visual testing (VT or VI), ultrasonic testing (UT), thermography, radiography testing (RT), electromagnetic testing (ET), acoustic emission (AE), and shearography testing regarding the advantages and disadvantages of these methods [14].

Destructive testing methods were also conducted to determine the mechanical characteristics of glass fibre composites. Menail et al conducted experiments on the effect of water aging after mechanical fatigue on glass fibre composites, compared with Kevlar fibre composites [15]. The tested specimens were subjected to fatigue for various cycles (100 to 50,000). After that, the specimens were immersed in tap water and simulated with seawater for different periods (4, 20, and 40 days). The results obtained showed that the tensile characteristics were affected by the immersion treatment and fatigue loading. The residual stiffness and residual strength decreased as the immersion time and number of fatigue cycles increased.

Other factors affecting glass fibre composites are ultraviolet (UV), humidity, and cyclic loading, prompting Afshar et al. to investigate these factors. Their results indicate that UV and humidity can interact synergistically with fatigue damage mechanisms and accelerate fatigue damage accumulation [16]. The fibre layout configuration of glass fibre composites is a factor that needs to be studied by Vizentin et al [17]. They subjected tensile test specimens to this fibre layout configuration for 6 and 12 months at sea. All specimens showed an increase in mass, the growth of attached algae and marine microorganisms, resulting in a significant reduction in tensile strength. The study of fibre layout configuration was continued by Vizentin and Vukelic with optical and electron microscopic investigations, which revealed that the dynamics and extent of tensile strength reduction depended on the fibre layout configuration and changes in matrix morphology caused by the formation of salt crystals and the impact of marine microorganisms embedded in the resin [18] [19].

Furthermore, Vizentin et al conducted S-N curve modelling for standard composite materials classified by parameters of material property degradation due to water absorption, marine organisms, and prolonged exposure to marine environments [20]. The results of a two-year regression analysis concluded that all submerged composite materials with different fibre layout configurations exhibited significant losses in ultimate tensile strength (UTS). Omana et al also used ultrasonic inspection and shear testing to observe material behaviour under wet and dry conditions [21]. They found that in dry conditions, the material lost stiffness as the damage density increased, and its shear strength also decreased, as did the displacement at maximum load. In wet conditions, the material exhibited higher displacement at maximum load, while the shear strength decreased with increasing stiffness.

Research on the effect of humidity by Afshar et al [16] and expanded by Harle by adding chemical reaction factors and microstructural changes to the physical and mechanical properties of glass fibre composites showed that humidity significantly reduces strength and interlayer shear strength, affecting joint performance [5].

Yalçınkaya et al improved the mechanical characteristics of glass fibre by reinforcing glass fibre (GFRP) and carbon fibre (CFRP) using hand layup and hot-pressing methods, resulting in superior mechanical properties for CFRP compared to GFRP [22]. El Bahaoui et al found that fiber type, manufacturing method, and span significantly influence mechanical performance [23].

In addition to non-destructive and destructive testing methods to determine the characteristics of glass fibre composites, Zainudin and Arifin identified the structure and characteristics of composites used in marine applications using impact and flexure tests through simulations using ANSYS Workbench software. This software was used to verify the results of non-destructive and destructive testing methods [24].

One of the drawbacks of glass fibre is its lack of environmental friendliness, so researchers are seeking environmentally friendly fibres. El Hawary et al reviewed the use of natural fibre composites for marine applications, including the criteria, mechanical properties, maintenance, manufacturing processes, and advantages and disadvantages of natural fibres [25]. Lopez-Arraiza et al evaluated the sustainability of bio composite materials and identified recommendations for the ecological design of recreational boats using the ISO 14.040 methodology using Open LCA 2.0.4 software and the Ecoinvent v.3.9.1 database [26]. The research results produced a Life cycle assessment of the bio composite ship hull showing a positive environmental impact for all indicators except Terrestrial Ecotoxicity (TETP), which increased by 357% due to the use of fertilizers in hemp production. In addition, local hemp fibre production and the use of recyclable bio resin can improve the environmentally friendly design of the ship hull. An example of the use of natural fibres such as basalt to reinforce conventional glass fibre was carried out by El Bahaoui et al in a flexural test and obtained fibre type, manufacturing method, and span significantly affect mechanical performance [27].

Regarding sustainability, Cristea et al stated that composites designed for shipbuilding applications are suitable [28]. However, composites have slight differences in energy absorption during low-velocity impacts and significant maximum force reduction. A balance between technical, economic, environmental, social, and governance aspects and the glass fibre waste stream is necessary to maintain the sustainability of glass fibre [29].

Although various studies have been conducted on the mechanical characteristics of glass fibre boats, including destructive and non-destructive methods, software simulations, environmentally friendly fibres, and sustainability, the differences in these studies relate to the methods and materials used to construct the boats, environmental conditions, and the specimens obtained from glass fibre boats that have been in operation for more than 20 years. Therefore, the mechanical characteristics obtained reflect the actual environmental and operational conditions of glass fibre boats.

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II. METHOD

This research uses literature study, field survey and experimental approaches to determine the mechanical characteristics of glass fibre ships. The research method applied includes several stages. (Figure 1).

The first stage of the literature study aims to obtain information and references about testing to determine the age limit of glass fibre ships that have been published based on the results of previous research. The literature used is in the form of journals and articles as an academic basis, regulations as a reference to applicable standards, previous reports as additional references and collection of secondary data supporting this research.

The second stage conducted a field survey aimed at collecting primary and secondary data from the condition of shipyards and glass fibre vessels in operation, as well as collecting samples of test materials from vessels. The classification of the surveyed ship samples is related to regulatory compliance, quality, operation, and maintenance. The surveyed ships are ships that have been operating for more than 5 years and the sampling is random.

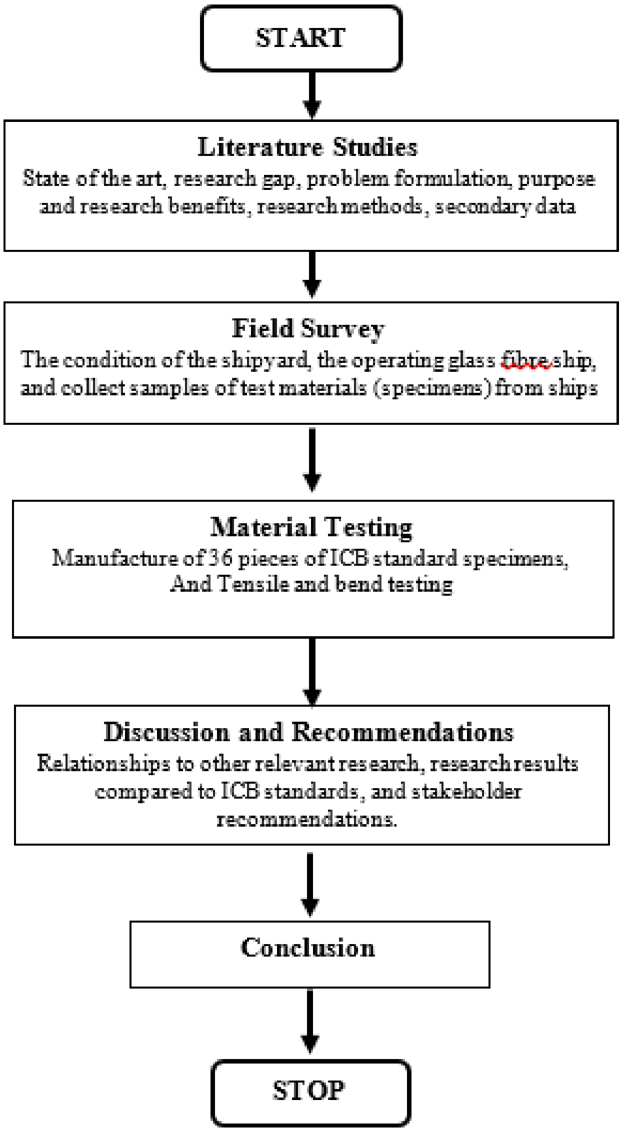

Figure 1. Stages of the research method

The third stage was destructive testing with tensile and compressive tests. Specimens are made based on the applicable classification at the Indonesian Classification Bureau (ICB). This test aims to obtain data on the mechanical characteristics of the material. The results of this test are then compared and analysed with the standards of the Indonesian Classification Bureau. Recommendations are needed to improve the quality of production so that it meets ICB standards.

III. Results and Discussion

A. *Condition of Glass fibre Shipyard*

Based on the survey results to several fibreglass shipyards, the following conditions were identified.

1) The types of resin and glass fibre on the market are quite numerous and varied and can be used for marine use or general construction. However, there is a tendency for builders to use low-quality or non-marine materials to reduce costs, which in turn can reduce the strength and durability of the vessel. Another fact is that not many resin and glass fibre brands are certified by ICB. Although ICB already requires only qualified materials for shipbuilding, such as E-glass for glass fibre types and the resin used (polyester, vinyl ester, or epoxy) must be resistant to seawater, weather, and not easily degraded. However, strict supervision is still required for their use during the fibreglass shipbuilding process.
2) There is a lack of labour that has a certificate of competence in the fibreglass shipbuilding process (hereafter referred to as fibreglass Applicator) in accordance with the requirements of the Society. In small fibreglass shipyards, labour often comes from local workers without formal training, so skills develop through hands-on work experience (learning by doing). As a result, the quality of fibreglass vessels produced is inconsistent, especially in the aspects of lamination precision and vessel finishing.
3) Standard operating procedures for glass fibre shipbuilding are often violated. That is, such as during the lamination process and drying time. The lamination process is often done sloppily or not in the order of the layers (e.g. the number of layers is too small). During the drying process, it is common to speed up the drying process without ensuring that the resin has completely hardened to the standard.
4) The fibreglass shipbuilding process should be carried out in a covered area to avoid exposure to ultraviolet light. Direct exposure to ultraviolet light can cause surface degradation, susceptibility to delamination, and damage to the gelcoat. To address the above issues, an education and certification programme for fibreglass applicators specific to the fibreglass shipbuilding process is required.
5) Not testing glass fibre boat samples. The shipyard should make samples of resin mixture and fibreglass ship coating for quality testing. Quality testing is conducted to ensure that glass fibre vessels meet the required strength, durability and safety standards in accordance with ICB I requirements.
6) In accordance with the classification regulations, the builder must make test specimens and record all detailed procedures in making the test specimens until the samples are approved by the ICB for use in ship construction. Furthermore, the tested procedure must be applied in the fibreglass shipbuilding process and the classification society must assign a surveyor so that the process is used during the shipbuilding process. In practice this is quite difficult to implement because it requires the assigned classification surveyor to always be at the shipyard to monitor compliance with the implementation of approved shipbuilding methods.

B. *Glass Fibre Ship Condition*

The condition of glass fibre ships, especially the ship construction section, is perceived to be maintenance-free and more durable when compared to wooden ship construction. However, in reality on glass fibre there are often discontinuities with increasing age of the ship, the influence of weather conditions, damage or collisions between the ship and the dock. Damage that often occurs due to the glass fibre manufacturing process that is not in accordance with the standard glass fibre manufacturing procedures. Damage caused by weather and manufacturing process mismatches include delamination, blister, fatigue, curvature, damage to frames and stiffeners, gelcoat layer damage, fracture, osmosis, and major damage due to accidents such as breaks and cracks in the hull. These types of damage should be socialised to relevant parties to help control the condition of glass fibre so that it can be restored to its proper condition.

Glass fibre ship damage conditions identified by type consist of:

1) Delamination which occurs due to water ingress into the hull damaging the resin layer and causing separation of the layers (delamination) (Figure 2).
2) Blisters are bubbles and bumps caused by trapped water or air droplets under the paint layer. If the bubbles burst, they can expose the laminate to water that will penetrate into the hull (Figure 3).
3) Fatigue, which occurs due to waves and vibrations that cause cracks in the hull (Figure 4).
4) Warping, which occurs due to continuous sun exposure and causes separation of the coating (delamination). The use of a canopy or temporary cover prevents warping (Figure 5).
5) Frame and Stringer Damage, which occurs due to wear and tear, stringers and frames require regular maintenance. If the stiffeners pass through the transverse frame, the frame depth should be kept sufficient (50 to 60 per cent) (Figure 6).
6) Surface damage (gelcoat layer), which occurs due to wear and tear, requires regular inspection,

maintenance, and repair (Figure 7).

7) Major damage (breakage), in the form of cracks and damage that penetrates the entire construction of the glass fibre ship is major damage (Figure 8).
8) Osmosis caused by water in the laminate and deterioration of the polyester resin. Osmosis can be seen in the black spots and white pockets on the laminate (Figure 9).
9) Hull damage caused by insufficient laminate thickness can lead to structural failure. The vessel is beyond repair and must be replaced for safety reasons (Figure 10).
10) Stress damage, damage to joints between glass fibre structures and fixed parts of other materials can cause stress, weakness, and cracking in fibreglass vessels (Figure 11).
11) Bottom damage, is damage that can occur due to shipping and seawater abrasion which results in cracks, holes, and delamination (Figure 12).
12) Operational damage, which causes wear and water absorption, water ingress into the laminate, gelcoat does not inhibit water absorption, water in the laminate reduces hull stiffness in a period of 5 - 15 years.
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Figure 2. Delamination

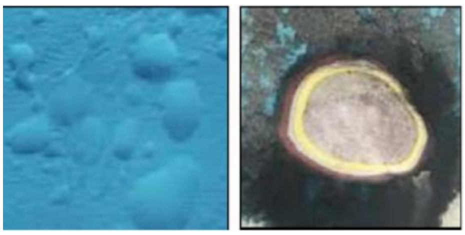

Figure 3. Blister

Figure 4. Fatigue

Figure 5. Warping

Figure 6. Frame and Louder Damage

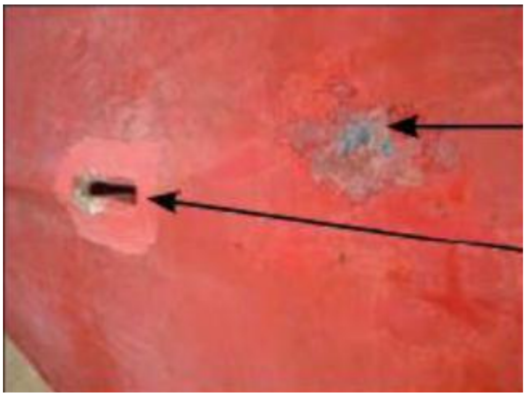

Figure 7. Surface Damage

Figure 8. Major Damage

Figure 9. Osmosis

Figure 10. Hull Damage

Figure 11. Sterss Damage

Figure 12. Bottom Damage

C. Mechanical Characteristics of Glass Fibre Vessels

Field surveys aim to collect primary data and information on the current condition of glass fibre vessels operating in Indonesian waters, as well as collecting purposive samples of test materials from fibreglass vessels that are more than 20 years old.

Material testing aims to determine the relationship between f glass fibre material characteristics and strength and durability. Specimens were made based on the applicable classification at the Indonesian Classification Bureau. The types of tests carried out are: tensile, and bending tests to obtain data on the mechanical characteristics of the material. The test results were then analysed to determine the lifetime of the tested fibre glass variants.

Data collection has been conducted through surveys to several glass fibre vessels in Surabaya, vessels "AIII", "M01", and "M02", and vessel "T" in Gresik. The data of the surveyed fibre glass vessels, sampled parts that were immersed and not immersed in water for material tests can be seen in table 1.

TABLE 1.
LIST OF GLASS FIBRE VESSELS

Ship Name	Age (Year)
AIII	39
M01	23
M02	22
T	23

Table 1 shows that the vessels sampled for the material test are of varying ages, which will result in mechanical characteristics with different values and trends. Samples that will be used as specimens will be cut according to the transverse and longitudinal directions of the ship. A summary of the specimens and their numbering can be seen in Table 2.

The minimum standard of test results and specimen formation of glass fibre ship hulls according to the classification bureau standard used is Part 3 Volume V "Rules for Glass fibre Reinforced Plastic Ships" in 2021 Section 1-C no.4 and Annex 1 [30]. The tensile test specimen can be seen in Figure 11, and the testing specimen can be seen in Figure 12. The number of specimens is 18 pieces consisting of 8 sections with transverse and tapered variations.

D. Tensile Test and Bending Test Results

Tensile tests and bending tests were carried out on 18 specimens each in the transverse and longitudinal directions. The results of tensile and bending tests can be seen in Figures 15 and 16.

Based on Figures 15 and 16, Ship AIII has an average tensile strength of 86.858 MPa and an average bending strength of 99.49 MPa. Ship M01 has an average tensile strength of 68.24 MPa and an average bending strength of 69.77 MPa. Ship M02 rated its tensile strength with an average of 83.45 MPa and an average bending strength value of 88.485 MPa. TS1 vessels had an average tensile strength of 62.227 MPa and an average bending strength of 34.558 MPa. On average, none of the glass fibre vessels tested for tensile and bending strength met the ICB standards for tensile strength (98 MPa) and bending strength (150 MPa). Some parts of the glass fibre vessels tested in the tensile and bending tests did meet the ICB standards, namely specimens AIII over water, M02 over water, M02 under water, TS1 aft over water. The fibre vessel section that meets the ICB standard for bending test is specimen AIII above water.

E. Discussion

The results of research conducted by NASA [31] and UC Berkeley [32] can determine the initial value of ship construction conditions at the age of 5-20 years. When compared to this study, the initial value of tensile and bending strength at the beginning of the ship is not known. In addition, in this study, only tensile and bending tests could be conducted due to limited equipment, time, and sampling of glass fibre vessels. However, these tests are are considered sufficient to represent the testing of fibreglass ship specimens to determine the service life of fibreglass ships built and operating in Indonesian waters.

The initial condition of the ship construction is unknown so that the tensile and flexural strength test results are only compared with the class standard (ICB). Overall, most of the ship sections tested were not fulfil the ICB standards for tensile strength (98 MPa) and flexural strength (150 MPa). Only a few specimens, however, showed tensile test results above the standard. However, the bending test results were consistently lower, indicating a weakness in resistance to bending loads.

Sampling was taken under different conditions. These different conditions included samples taken in different water zones, ship ages ranging from 5 - 20 years, and sampling construction locations on the ship. The character of the water zone shows the influence of natural factors (waves, water content, currents) on the condition of the ship material. The influence is in the form of external forces that hit the ship's body. The location of the sampling construction affects the thickness of the sample, which may be different in the hull below the waterline or the hull above the waterline.

TABLE 2.
SPECIMEN LIST OF GLASS FIBRE SHIP PARTS

Ship Part Name	
AIII over water	
Underwater AIII	
M01 over water	
M01 underwater	
M02 over water	
M02 underwater	
T over water	
T under water	

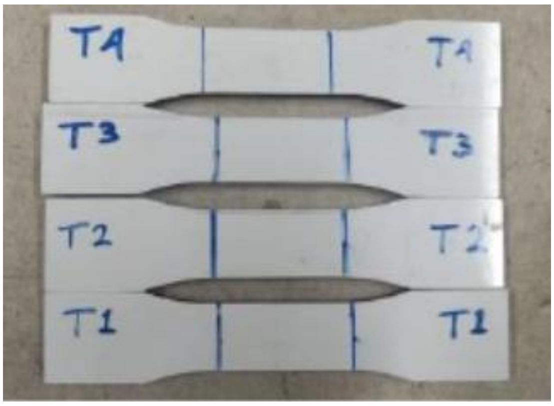

Figure 13. ICB standard test specimens

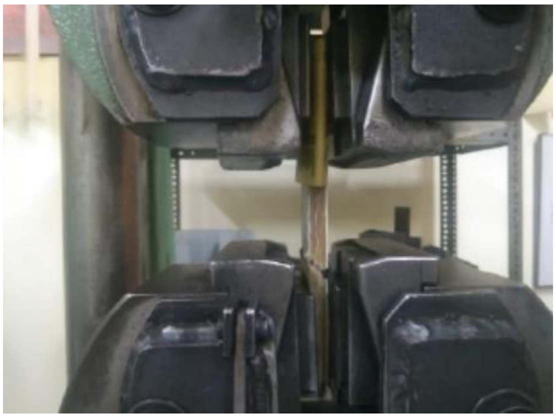

Figure 14. Testing Specimens

Tests conducted by NASA [31] and UC Berkeley [32] on fibre ships built using the vacuum infusion method, are difficult to apply to ships in Indonesia built using the hand layer method, because the resulting model does not allow for testing using the UC Berkeley method [32] which conducts moisture testing, tensile tests, shear tests, compressive tests, Poisson's ratio tests, static flexibility tests, flexural fatigue tests, and panel tests. So due to limited conditions, we can only conduct tensile tests and bending tests.

Some recommendations that need to be considered for shipyards, governments and classification bureaus are as follows.

1) The location, methods, labour, design and materials such as ship resins and laminate layers used during the production process, have met and obtained certifications that have been determined by the classification bureau to ensure production quality.
2) The shipyard must make samples of the resin mixture and coating of the glass fibre vessel for quality testing to ensure that the glass fibre vessel meets the required strength, durability and safety standards in accordance with the classification standards.
3) The glass fibre ship owner and the classification society should assign a surveyor to be present at the shipyard throughout the shipbuilding process to monitor compliance with the implementation of approved methods.

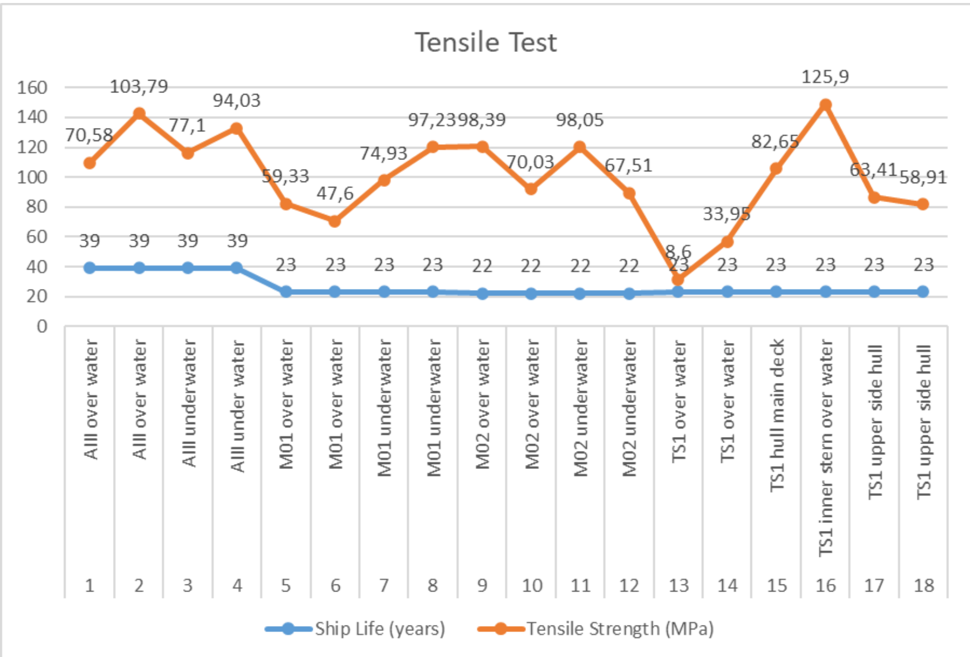

Figure 15. Tensile test results

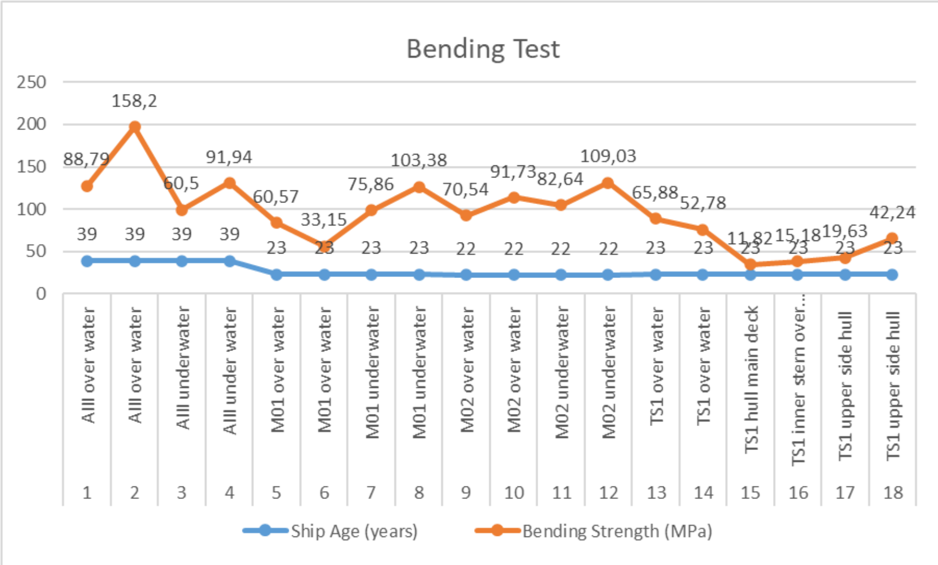

Figure 16. Bending Test Result

IV. CONCLUSION

The condition of glass fibre shipyards, in terms of materials, labor, workmanship, and shipbuilding methods, largely still does not meet classification bureau standards. Discontinuities in the condition of glass fibre ships in operation often occur due to the increasing age of the ship, the influence of weather conditions, damage, or collisions between the ship and the dock. Several sections (36 specimens) of glass fibre vessels with ages varying from 22 years to 39 years were subjected to tensile and bending tests to ICB standards. The test results showed that only 25% of the tensile test specimens and 6.25% of the compressive test specimens met the requirements of the ICB standard. So that the mechanical characteristics mostly do not meet the predetermined requirements.

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