INTERNATIONAL JOURNAL OF METACENTRE
MARITIME APPLICATION, TECHNOLOGY, ENGINEERING, AND TRANSPORTATION
www.ijm-nasp.unhas.ac.id eISSN: XXXX-XXXX

The Effect of Immersion on Tensile Strength of Fiberglass-Polyester Composites for Shipbuilding Materials

Andika Dwi Prasetio[1], Alamsyah[1*], Taufik Hidayat[1], Amalia Ika Wulandari[1], Andi Mursid Nugraha Arifuddin[1], Muhammad Uswah Pawara[1]

[1]*Naval Architecture of Program, Kalimantan Institute of Technology, Indonesia*

Received: 11/11/2021
Revised: 03/12/2021
Accepted: 15/12/2021
Published:25/12/2021

* Corresponding author:
alamsyah@lecturer.itk.ac.id

Abstract

The use of fiberglass-based composites is often found in shipbuilding because it has many advantages. The advantages of fiberglass-based composites are lightweight, resistant to corrosion, easy to shape, and affordable prices. However, fiberglass also has undesirable properties, namely hygroscopicity due to its chemical constituents. Moisture absorption by these composites has several detrimental effects on their properties, and thus affects their long-term performance. For example, increased humidity reduces their mechanical properties. The purpose of this study was to determine how the difference in absorption rate between sea water and fresh water in fiberglass-polyester material and how the effect of immersion on the tensile strength of fiberglass-polyester material for shipbuilding materials. The method used in this study is an experimental method that uses a tensile testing machine by varying the differences in immersion methods on the test specimen for 30 days. The tensile testing process is carried out shortly after the specimen is removed from the water, and first weighed so that the percentage of water absorption can be found. The result of the percentage of composite water content tended to increase with the length of immersion time but the increase was 0.073% in the specimens with sea water immersion and 0.220% in the specimens with the immersion process of fresh water. Whereas in the tensile test of fiberglass-polyester material for shipbuilding materials immersed in water for 30 days, it was 3.75 kgf/mm^2 in the seawater immersion process and 3.14 kgf/mm^2 in the fresh water immersion specimen.

Keywords: Fiberglass-Polyester; Submersion; Tensile Strength.

1. Introduction

The use of fiberglass-based composites is often found in shipbuilding because it has many advantages. The advantages of fiberglass-based composites are light weight, corrosion resistance, easy to form, good insulator conductor properties and affordable prices [1]. However, fiberglass also has undesirable properties, namely hygroscopicity due to its chemical constituents where this can affect its long-term performance for example, increase humidity and decrease mechanical properties [2].

The effects that most influence the mechanical behavior of the composite are changes in temperature and water content. However, the analysis of the mechanical behavior of polymer composites that is often presented by researchers is based on the assumption of constant environmental conditions (humidity).

Whereas in reality, the application of composite materials is often in an environment that is not constant or always changing, such as wind turbine blades, fish cool box panels and boats made of glass fiber which always work in changing humidity and temperature conditions [3].

Based on the description above, it can be concluded that the use of fiberglass material for shipbuilding has many advantages, but because the ship (boat) operates in an area that is in direct contact with water, this can affect the decrease in mechanical properties. So in this study the author will discuss "Analysis of the Effect of Immersion on Tensile Strength of Fiberglass-Polyester Composites for Shipbuilding Materials". This research is a follow-up study from a previous study entitled "The Effect of Comparison of Resin and Catalysts on Tensile Strength of Fiberglass-Polyester Composites for Shipbuilding Materials".

2. Methods

Broadly speaking, this research was carried out using an experimental method using a tensile testing machine where the specimen before going through the tensile testing process was soaked for 30 days in sea water and fresh water. This research was conducted with the initial stage, namely the study of literature as a source of information related to research. This literature study is intended to understand the concepts and appropriate methods to solve the problems that have been formulated in the previous stage and to realize the intended goals. Then the next stage is the preparation of tools and materials, where at this stage all the tools and materials needed for research are prepared to facilitate the research process. The tools used for the manufacture of composites are gloves, masks, Glass mold with a size of 19 cm x 15 cm x 0.5 cm, Marker, Ruler, Scissors, Digital scale, Measuring cup or container, Injection, Clamp clip, Cutter, Grinding machine, Cutting grinder and sanding grinder, Caliper, Immersion tub or container, UTM Tensile Testing Machine (Universal Testing Machine). The material used in this study consisted of ETERNAL polyester resin. Polyester resin is one of the most widely used thermosetting polymer matrices, especially in the manufacture of modern composites. This resin has distinctive characteristics, namely transparent, waterproof, colorable, flexible, resistant to extreme weather and chemical resistance. The working temperature of polyester can reach 700 C or more depending on the need [4]. The second ingredient is MEPOXE catalyst. Catalyst is a trigger material (initiator) which serves to shorten the curing reaction or hardening process at room temperature. The use of a catalyst in the resin serves to accelerate the process of hardening of the resin liquid. The catalyst used as a curing process in the manufacture of FRP comes from organic peroxides such as methyl ethyl ketone peroxide ($C_8H_{18}O_6$) and acetylacetone peroxide ($C_5H_6O_4$). The use of too much catalyst can cause excessive heat during the hardening process. Where the excessive heat reaction between these two materials will result in damage to the material yield [5]. Then the next material is glass fiber chopped strand mat. There are two functions of the first fiber to contribute to the high strength and stiffness of the composite. Then the second is as a load-bearing [1]. The constituent materials of this composite can be seen in Figure 1.

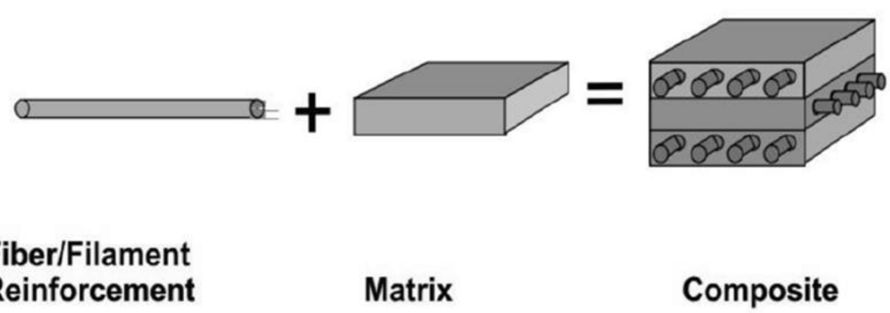

Figure 1. Composite composition material.
Source: [6]

Then the last material for this research is sea water and fresh water as the main ingredients for soaking the specimen before the tensile test process is carried out. In this study, the sea water used is sea water in Balikpapan waters, while the fresh water used is Balikpapan wine fresh water. Next, the composite manufacturing stage where the composite is made with a 1.5% catalyst percentage in each variation of the immersion process. Composite manufacture using prepared molds can produce 3 specimens, because 6 specimens are needed for each immersion process where 3 specimens are the main ingredient and 3 other specimens are as backup, so that if during the testing process a failure occurs, then a backup specimen can be used. Therefore it takes 4 composites to meet the total number of 12 specimens. Composites are made using the hand lay-up method. The process of making composites with this hand lay-up method is the manufacture of composites using layer by layer so that the specified or desired thickness is obtained. The layer contains resin and reinforcing material (reinforcement). After obtaining the desired thickness, the next step is to use a roller to be able to flatten and remove trapped air on it. The hand lay-up method can be seen in Figure 2.

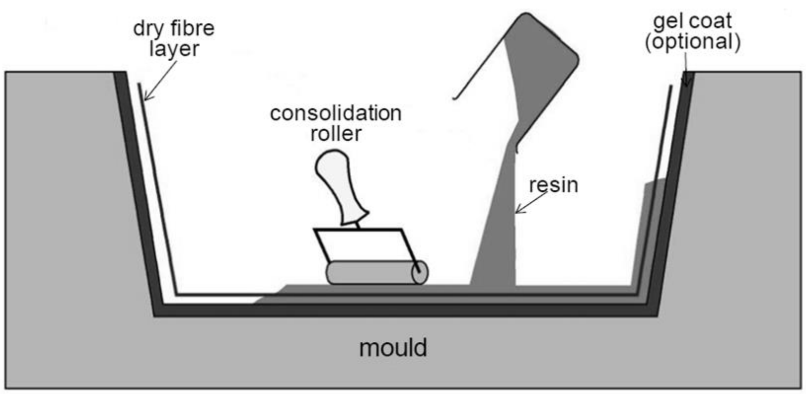

Figure 2. Hand lay-up method.
Source: [1]

The composite that has been made is then formed into a tensile test specimen according to the ASTM D638-14 standard. The shape and dimensions of the test specimen can be seen in Figure 3 and Table 1.

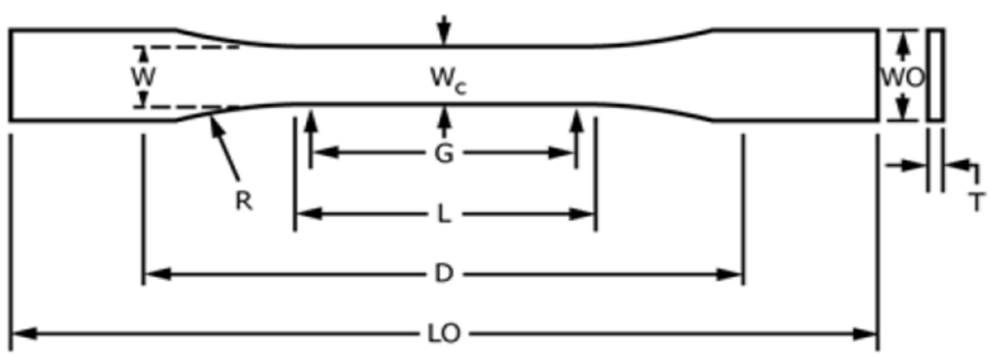

Figure 3. Shape of tensile testing specimens.
Source: [7]

Tabel 1. Dimension of tensile testing specimens. Source: [7]

Dimension (See drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerance
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W-Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L-Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO-Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	…	+6.4 (+0.25)
WO-Width overall, min[G]	…	…	…	…	9.53 (0.375)	+3.18 (+0.125)
LO-Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G-Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	…	7.62 (0.300)	±0.25 (±0.010)[C]
G-Gage length[I]	…	…	…	25 (1.00)	…	±0.13 (±0.005)
D-Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R-Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO-Outer Radius (Type IV)	…	…	…	25 (1.00)	…	±1 (±0.04)

After the glass fiber-reinforced composite has been formed, the next step is the immersion of the specimen. In this process, it begins by taking water as a material for soaking the specimen using a jerry can. Then the specimen that has been formed is weighed and the initial weight is recorded before the immersion process is carried out. After the weighing process, the specimens were marked using markers AL1, AL2, AL3 (for specimens to be immersed in seawater), and AT1, AT2, AT3 (for specimens to be immersed in fresh water). Then the specimens that have been weighed and marked are placed in a container, and then the immersion process is carried out for 30 days. After the soaking process was carried out for 30 days, the specimen was lifted and re-weighed, and the results of the weighing were recorded again as final data. Specimens that have gone through the immersion process are then tested for tensile using a tensile testing machine at the Workshop of the Mechanical Engineering Department of the Balikpapan State Polytechnic Heavy Equipment Study Program using a UTM (Universal Testing Machine) machine. This tensile test aims to determine the average tensile strength and strain of each specimen in each immersion variation that has been carried out. Tensile test is a method used to test the strength of a material or material by providing an axial force load. One of these composite tests is in terms of tensile strength using the Universal Testing Machine. By pulling a material it will be known how the material reacts to the pulling force and knowing the extent to which the material increases in length. The tensile test specimen withdrawal scheme can be seen in Figure 4.

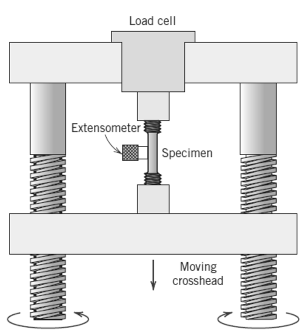

Figure 4 Tensile test scheme.
Source: [8]

3. Results and Discussion

3.1. Water Absorption

Water absorption testing is carried out to determine the optimum water absorption possessed. By immersing the composite in water for a certain time, the amount of water absorbed into the composite can be determined. Furthermore, the weight gain of the composite is recorded and the percentage is calculated using the following equation:

$$WA = \frac{Ba - Bm}{Bm} \times 100\% \quad (1)$$

where WA = Water Absorption (%), Ba = Final weight (grams), Bm = initial weight (grams) [3]. Based on the results of the study, there were differences in the weight of the specimens before and after being immersed in seawater and river water with a long soaking time of 30 days as shown in Table 2 and Table 3.

Tabel 2. Seawater absorption data.

Percentage of seawater absorption	**Initial weight (g)**	**Weight gain after 30 days (gr)**	**Percentage (%),** $WA=\frac{Ba-Bm}{Bm}\times 100\%$
AL 1	22.18	22.19	0.045
AL 2	23.45	23.47	0.085
AL 3	22.40	22.42	0.089
Average weight gain			0.073

Tabel 3. Fresh water absorption data.

Percentage of calm water absorption	**Initial weight (g)**	**Weight gain after 30 days (gr)**	**Percentage (%),** $WA=\frac{Ba-Bm}{Bm}\times 100\%$
AL 1	22.25	22.28	0.135
AL 2	21.95	21.97	0.091
AL 3	23.00	23.10	0.435
Average weight gain			0.22

From Table 2 it can be described the average percentage rate of seawater absorption as shown in Figure 5 and than from Table 3 it can be described the average percentage rate of fresh water absorption as shown in Figure 6.

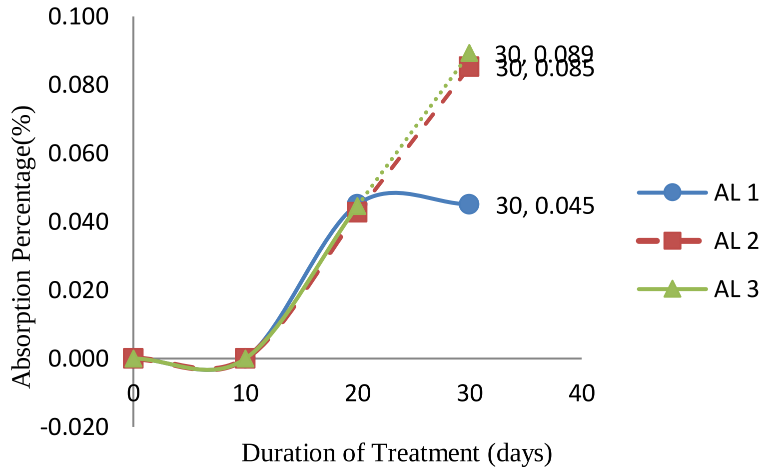

Figure 5. The average percentage of seawater absorption.

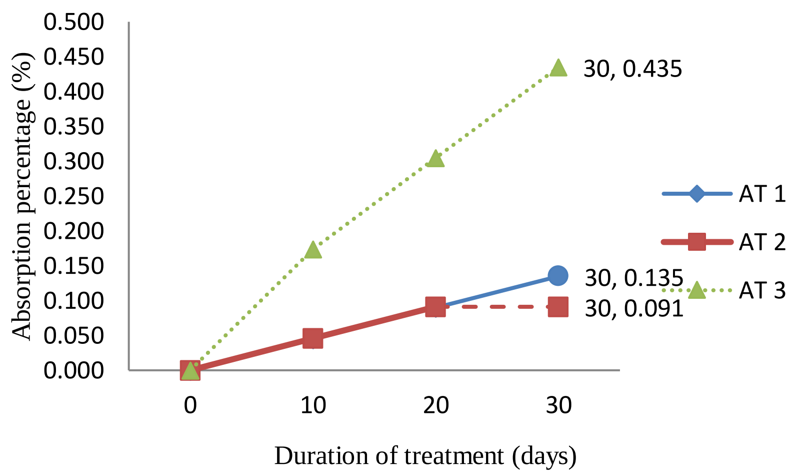

Figure 6. The average percentage of calm water absorption.

From Tables 2 and Table 3, it can be seen that the percentage of water absorption in the glass fiber reinforced polymer composite for tensile test specimens treated by immersion in sea water and river experienced a slightly different weight gain. Where the increase in weight can be caused by the presence of voids in the specimen so that water diffuses into the specimen, but the percentage of water absorption is not too large, namely 0.073% for specimens immersed in seawater and 0.220% for specimens immersed in fresh water. When viewed from the average value of the absorption percentage of the two types of immersion water, it can be seen that the absorption of specimens to seawater is not too large compared to the absorption of specimens to fresh water. From the data in Tables 2 and Table 3, it can also be seen that the diversity of water absorption data can be caused by the non-uniformity of the density of the specimen when printed, so that the absorption rate is different. However, from Figures 5 and Figures 6 it can be seen that the longer the immersion time, the higher the water absorption rate.

3.2. Composite Material Tensile Test

In the tensile test carried out, the result is a graphic print-out of the relationship between the load and the increase in length. To be able to calculate the tensile strength and strain from the test, use the following formula:

1) Tensile Strength can be defined as the force per unit area of the material subjected to the force. To be able to obtain the tensile strength of a material can be calculated using the following Equation 2:

$$\sigma = \frac{P}{A} \tag{2}$$

Where σ is tensile strength (kgf/mm^2), P is load (kgf) and A is cross-sectional area (mm^2).

2) Tensile strain is a measure of the change in length of a material after a tensile test, so that the results of the tensile test can be used to find the strain value of a material. To find the tensile strain can be calculated using the following Equation 3:

$$\varepsilon = \frac{\Delta L}{Lo} \tag{3}$$

Where ε is the strain, ΔL is the increase in length (mm) and Lo is the initial length (mm)

3) The modulus of elasticity (Young's Modulus) is the ratio between stress and strain. To find the modulus of elasticity can be calculated using the following Equation 4:

$$E = \frac{\sigma}{\varepsilon} \tag{4}$$

Where E is the modulus of elasticity (kgf/mm^2), σ is the stress (kgf/mm^2) and ε is the strain [8].

This tensile test was carried out at the Workshop of the Department of Mechanical Engineering, Heavy Equipment Study Program, Balikpapan State Polytechnic with a total of 6 tensile test samples. In this test, the results obtained in the form of print-out data of the relationship between stress and strain during the test. Basically the specimens are made with reference to the ASTM D638-14 type 1 standard, but the results of the specimens made have slightly different shapes and sizes from those found in the standard so that the values resulting from the tensile testing process are different for each sample. composite. The data obtained on specimens with a 1.5% catalyst amount and have gone through the immersion process can be seen in Table 4 and Table 5.

Table 4. Results of tensile test data for seawater immersion.

Seawater Immersion	Sample	Yield Strength (kgf/mm^2)	Tensile Strength (kgf/mm^2)	Elongation (%)	Modulus of Elasticity (kgf/mm^2)
AL	1	1.56	4.62	1.43	3.23
	2	1.17	3.46	1.14	3.03
	3	2.68	3.15	1.14	2.76
Average		1.80	3.75	1.42	3.01

From the data contained in Table 4, a graph of the relationship between stress and strain can be made for the specimen with the seawater immersion process. The graph of the relationship between stress and strain on seawater immersion specimens can be seen in Figure 7.

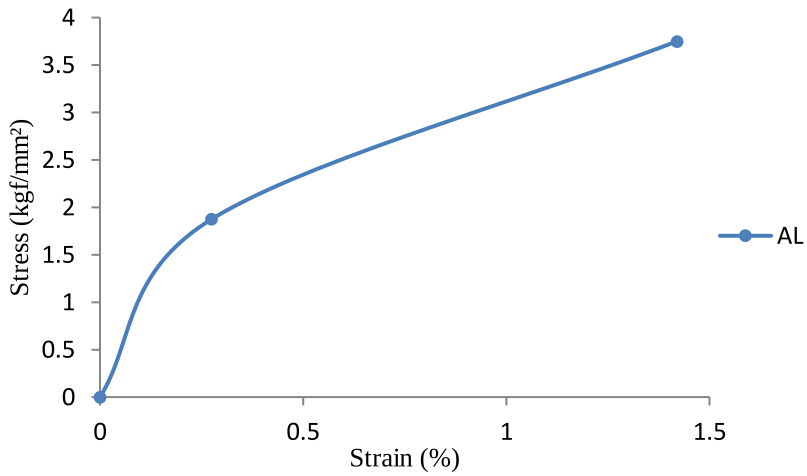

Figure 7. Stress-strain graph of seawater immersion specimen.

Table 5. Results of tensile test data for fresh water immersion.

Calmwater Immersion	Sample	Yield Strength (kgf/mm^2)	Tensile Strength (kgf/mm^2)	Elongation (%)	Modulus of Elasticity (kgf/mm^2)
AT	1	1.72	2.17	1.26	1.72
	2	3.45	4.26	1.94	2.19
	3	1.87	4.98	1.97	2.52
Average		2.35	3.14	1.72	2.15

From the data in Table 5, a graph of the relationship between stress and strain can be made for the specimen with the river water immersion process. The graph of the relationship between stress and strain on river water immersion specimens can be seen in Figure 8.

From the graph of the relationship between stress and strain with the difference in the immersion process, a combined graph of the two graphs can be made. The purpose of making the combined graph is to compare the stress and strain values of the two different specimen immersion processes. The combined stress-strain graph of the 2 specimen immersion processes can be seen in Figure 9.

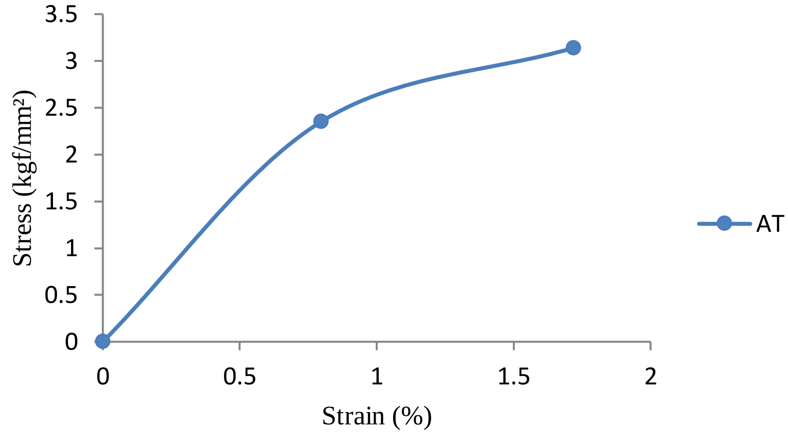

Figure 8. Stress-strain graph of fresh water immersion specimen.

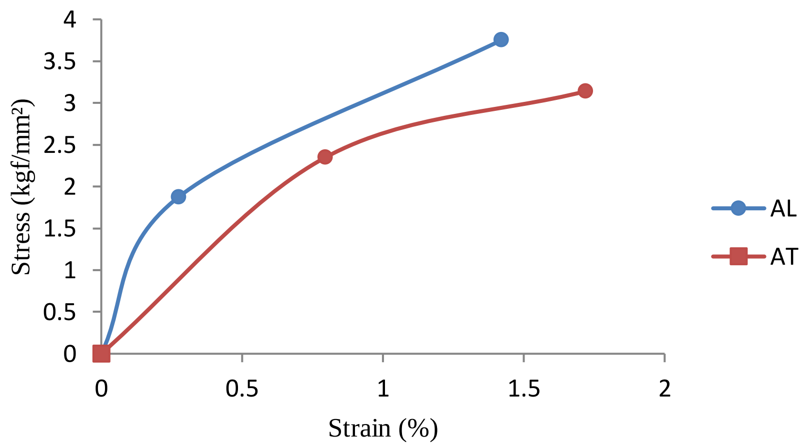

Figure 9. Graph of combined stress-strain.

From Table 4 and Table 5, it can be seen that the average strain value in the specimens with the seawater immersion process is 1.42%, and in the fresh water immersion process it is 1.72%. Higher strain values are found in specimens with fresh water immersion processes. Whereas in specimens that did not go through the immersion process as in previous studies, it could produce even higher strains of 1.97% [5].

And from Table 4 and Table 5 it can be seen that the average stress value on the specimen with the seawater immersion process is 3.75 kgf/mm^2, and the fresh water immersion process is 3.14 kgf/mm^2. While the composites that did not go through the immersion process as in previous studies, can produce a higher stress of 5.49 kgf/mm^2 [5]. This data illustrates that the water environment can cause the tensile strength to decrease due to the diffusion of water into the composite so that the interfacial bonds of the matrix fibers become weak. This can be caused by water wetting the interface between the fiber and the matrix. From Table 4 and Table 5 it can also be seen that the difference in strength values in each specimen is different, some are high and some are low in value, where this can happen because at the time of printing the composite mixture of fiber and matrix is not mixed evenly, the thickness and size of the matrix are not evenly distributed. The width of the specimen is not the same, and the non-uniformity of the test specimen from various aspects, especially the results of the formation, causes the composite strength to vary. To determine the effect of immersion and non-immersion treatment on the tensile strength of composites, it is necessary to graph the relationship between the effect of immersion and non-immersion treatments with the stress-strain of the composite which can be seen in Figure 10.

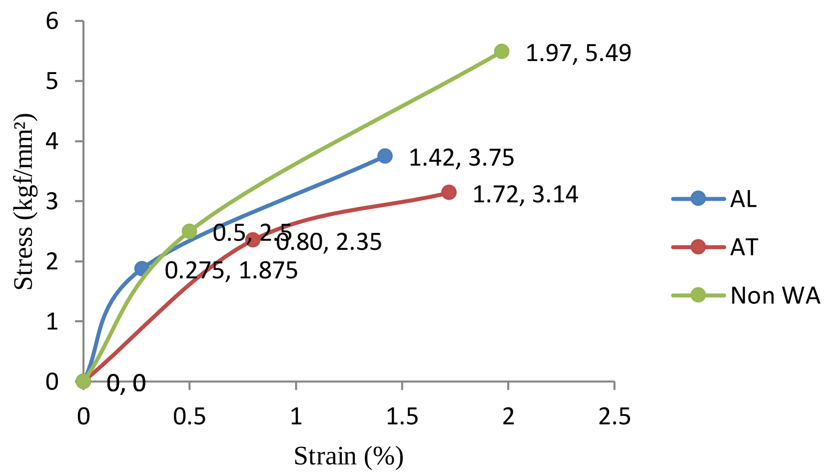

Figure 10. Graphs the relationship between the effects of immersion and non-immersion treatments.

In tensile testing, the specimen being tested is given a tensile load until the specimen breaks. The results of the tensile test specimen fracture can be seen in Figure 11.

Figure 11. Fracture of composite tensile test specimen.

From Figure 11, it can be seen that the fracture results in each specimen are different. Where the fracture that occurs in the specimen varies, ranging from a fracture in the middle of the specimen to a fracture at the gage length. This is because during the composite manufacturing process, the fibers used as reinforcement do not have the same amount on each surface. So that when the composite is cut into three parts, the number of fibers contained in each composite is not the same. In addition, during the composite manufacturing process, there are air bubbles that cause the composite to become hollow. These air bubbles are produced from the process of stirring the resin liquid when mixed with the catalyst. This is what allows the cause of water to diffuse into the composite so that the interfacial bonds of the matrix fibers become weak. So this affects the results of the fracture of the specimen when tested for tensile and makes the fracture results in the specimen different after the tensile test is carried out. Then when viewed from the tensile test process itself, the lack of accuracy when placing the specimen on the clamp grip can also affect the fracture results of the test object itself.

From the data processing that has been carried out in this study, the results obtained that the immersion process and the type of water to soak can also affect the tensile strength of the fiberglass-polyester composite, and in this study the specimens soaked in seawater had a more optimal strength value than the specimens soaked in fresh water. Where the average value of the tensile strength of the fiberglass-polyester composite material that has gone through the immersion process using seawater is 3.75 kgf/mm^2.

4. Conclusions

From the results of the research that has been done, it can be concluded that the rate of water absorption in the fiberglass-polyester material for shipbuilding materials is 0.073% in the specimen with seawater immersion and 0.220% in the specimen with the fresh water immersion process. While the tensile strength of fiberglass-polyester material for shipbuilding materials immersed in water for 30 days is 3.75 kgf/mm2 for specimens with seawater immersion and 3.14 kgf/mm2 for specimens with calm water immersion.

Acknowledgements

We would like to thank those who have assisted in this writing, namely the ITK Naval Structures Engineering laboratory research team, ITK Ship Engineering and Construction Design Drawing Planning Laboratory and the International Journal Metacentre reviewer team that we anonymous, so that this paper can be published.

References

[1] S. M. Sapuan. Composite Materials. Oxford: Elsevier, Inc., 2017.

[2] P. A. C. W. Wang, M. Sain. Study of moisture absorption in natural fiber plastic composites. *Compos. Sci. Technol.*, vol. 66, pp. 379–386, 2006.

[3] J. B. Tododjahi. Effect of Immersion on Mechanical Properties of Glass Fiber Reinforced Polyester Composites. *LONTAR J. Mech. Eng. Undana*, vol. 1, no. 2, 2014.

[4] J. M. Berthelot. Mechanics of Composite Materials and Structures. Vallouise: Compomecha, 2015.

[5] A. N. I. Alamsyah, T. Hidayat. Effect of Comparison of Resin and Catalyst on Tensile Strength of Fiberglass-Polyester Composites for Shipbuilding Materials. *Zo. Laut J. Inov. Sains dan Teknol. Kelaut.*, vol. 1, no. 2, pp. 26–63, 2020, doi: https://doi.org/10.20956/zl.v1i2.10760.

[6] Y. K. Kumar. Influence of Aviation Fuel on Mechanical Properties of Glass Fiber-Reinforced Plastic Composite. Chennai: IARJSET, 2016.

[7] ASTM. Standard Test Method for Tensile Properties of Plastics D638-14. Philadelphia: American Society for Testing and Materials, 2014.

[8] W. D. Callister. Materials Science and Engineering: An Introduction. Hoboken: John Wiley & Sons, Inc., 2010.