Mechanical Properties and Water Absorption of Ramie-Glass fibre-based Hybrid Composite

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Abstract

Combining natural fiber and fiberglass as a hybrid composite is promising to reduce the utilization of synthetic (glass) fiber, which is costly in the manufacturing process. Ramie (R) fiber is abundant in Indonesia and has the potential to substitute fiberglass (F) as reinforcement material. However, both materials have distinct fundamental mechanical properties. This study aimed to produce ramie and fiberglass composite and then investigate the mechanical properties (tensile, flexural, impact) and water absorption. Hybrid composites with five stacking layers were produced using the hand lay-up method with the variation of layer orientation. The result showed that the F-R-F-R-F layer and 90°/60° orientation present the highest tensile strength accounting for 60.92 MPa while the highest modulus elasticity was the F-R-F-R-F layer with 45°/90°, 3064 MPa. The flexural test shows that the F-R-F-R-F composite layer 45°/90° provides the highest flexural strength with a strength value of 177.51 MPa. The impact test also showed the highest value in the F-R-F-R-F layer with 45°/90° specimen, with an impact energy of 2.95 J/mm^2. In addition, the water absorption achieved the lowest by F-R-F-R-F layer with 90°/60° with 0,48%.

Keywords: Natural Composite, Ramie fiber, Mechanical Properties, Water Absorption

Abstrak

Kombinasi serat alam dan serat kaca sebagai material komposit hibrid dapat mengurangi pemakaian serat sintetis (kaca) yang mahal dalam proses manufaktur. Indonesia memiliki sumber serat rami yang melimpah dan potential menggantikan serat kaca sebagai bahan penguat. Namun kedua material memiliki sifat mekanis dasar yang sangat berbeda. Penelitian ini membuat komposit hibrid rami-komposit kemudian menginvestigasi sifat-sifat mekanis (tarik, fleksural, impak) dan karakteristik penyerapan air dengan variasi urutan dan orientasi serat. Komposit hibrid dengan 5 lapisan dibuat menggunakan metode hand lay-up dimana orientasi setiap lapisan juga divariasikan. Hasil investigasi menunjukkan bahwa komposit dengan lapisan F-R-F-R-F dan orientasi 90/60° memberikan kekuatan tarik tertinggi sebesar 60 MPa sedangkan modulus elastisitas terbesar ditunjukkan oleh komposit F-R-F-R-F dengan orientasi 45°/90° sebesar 3064 MPa. Kombinasi komposit dengan urutan F-R-F-R-F dan 45°/90° menghasilkan kekuatan fleksural sebesar 177.51 MPa yang disertai dengan kemampuan menahan impak sebesar 2.95 J/mm^2. Sedangkan komposit dengan kombinasi F-R-F-R-F memberikan daya serap air yang terendah sebesar 0.48%.

Kata kunci: *Komposit Alam, Serat Rami, Sifat Mekanis, Daya Serap Air (DSA)*

1. Introduction

There has been a substantial increase in the application of composite materials. Carbon fiber and glass fiber-based composite dominate the application of technology due to their various advantages. Nevertheless, the aforementioned materials costs are high, raising a final product's price. In general, composite materials combine two or more materials with different mechanical, physical, chemical properties and compositions into one material so that they acquire new mechanical properties that are not possessed by the constituent materials. Composite materials are often used as an alternative to metal substitutes in the industrial world. Synthetic fiber, such as glass, is usually used as reinforcement. They give good mechanical properties but are costly due to their complex manufacturing process. Thus, it should be alternative ways to minimize the utilization of fiberglass yet achieve suitable mechanical properties. Combining the two types of reinforcing materials between synthetic and natural could be the option.

The use of ramie fiber is currently increasing where this fiber is used as reinforcement (fiber reinforcement) in a composite. This amount of fiber required in composites to substitute fiberglass is up to 120,000 MT. The use of natural fibers as a composite material has increased by 10% every year in European countries. One of the natural fibers found in Indonesia is ramie fiber. Ramie fiber is one type of reinforcement in the fabrication of composite materials. The main composition of ramie fiber is cellulose (72-97%). Ramie fibers are usually combined with a matrix material such as polyester or epoxy to improve mechanical properties. In military applications, composites made from ramie fiber are used for bulletproof material. The formation of the ramie fiber composite is combined with the ramie fiber and glass fiber to increase the mechanical properties of the two materials. Composite is non-isotropic material. Therefore, the mechanical properties depend on the layers stacking and the direction of the lamina layers. Numerous works regarding the effect of the number of composite layers and the layer direction in the natural composite have been reported. However, they focused on the properties of the unidirectional layer of natural composite. The natural composites were also focused on the coconut, husk, walnut shell, silk, banana, and kenaf. Up to now, composite materials are dominated by carbon fiber and glass fiber reinforcement.

Nonetheless, those fibers are expensive and non-sustainable. Alternatively, partially substituting the carbon or glass fiber with natural composite, in this case, ramie, will open a new alternative in creating a hybrid composite. Therefore, this research aims to fabricate a hybrid composite between glass and ramie fiber with varied stacking orders and fiber directions. The fabricated composite's mechanical and water absorption properties will be investigated.

2. Materials and Methods

This research used ramie and glass fiber as reinforcement, and polyester resin (BQTN-157) was used as the matrix. Methyl Ethyl Ketone Peroxide (MEKP) catalyst was used as the hardener to bind the resin and improve the strength of the composites. The ramie-glass fiber was laid up in the direction of 0°, 45°, and 60°. The hand lay-up method was used to fabricate the laminates of five layers of fibers. Firstly, the release agent was applied to the mold. Polyester resin and hardener were set in a 20:1 ratio by weight and mixed. Polyester was poured onto the mold surface and spread uniformly on an aluminum plate in 300x300 mm^2 of the mold area. The first layer of fiber was embedded on the mold surface of polyester and adhered to the polyester by using a roller and aluminum plate. Then again, polyester was poured on the fiber's surface, and then the second layer of fiber was embedded on top of the first layer of fiber. This method was repeated until all fifth layers of fibers were stacked and embedded in polyester resin completely. Layer and angle orientation in this research are shown in figure 1.

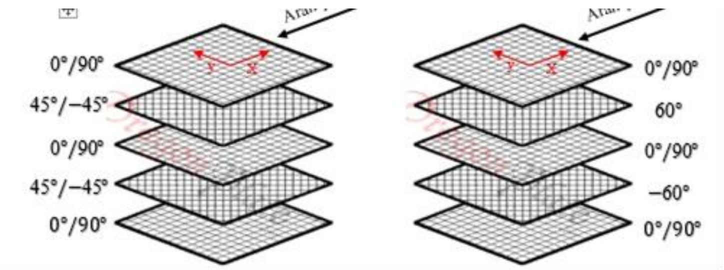

Figure 1. Composite fiberglass – ramie stacking.

Mechanical properties were evaluated using tensile, bending, and impact test. The tensile and bending test was performed using an automatic universal testing machine (UTM) with ASTM D 638 and ASTM D 790 standards. Meanwhile, the impact test was performed using the Charpy method (ASTM D 6110).

In addition, the water absorption test was evaluated based on ASTM D 570. The mass of the specimen was measured before being submerged. 24 Hours Immersion procedure was applied where the specimen shall be placed in a container of distilled water maintained at a temperature of 23 °C. At the end of 24 + ½ hours, the specimens were taken out from the water and continued by surface cleaning using running water and dry cloth. The mass was immediately measured.

3. Results and Discussion

The tensile test was conducted to analyze specimens' strength and modulus elasticity. Experimental results of tensile specimens of various composites with different layers and angles of reinforcement are presented in table 1.

Table 1. The result of tensile test

Layer Variation	Angle	Tensile Strength (MPa)	Elastic Modulus (MPa)
R-F-R-F-R	Ramie 90° / Fiber 45°	32,85	2004,19
R-F-R-F-R	Ramie 90° / Fiber 60°	35,29	2381,69
F-R-F-R-F	Fiber45° / Ramie 90°	56,66	3046,95
F-R-F-R-F	Fiber 90° / Ramie 60°	60,92	2424,04

The highest and lowest tensile strength of the composite is demonstrated in table 1. The highest tensile strength value was obtained in the F-R-F-R-F layer with the angle of 90° and 60° of ramie, which was 60.92 Mpa. The lowest tensile strength value was found in the R-F-R-R layer with a 90° flax weave angle and 45° fiber, 32.85 MPa. The modulus of elasticity in composites with more fiberglass layers is also higher than those with more flax fiber layers. According to previous research, fiberglass has a much higher elastic modulus than any natural fiber. Therefore, the more fiberglass in the composite, the higher the modulus of elasticity [2, 3]. The layer variation and the woven direction influence the tensile strength value. Composites with more fiberglass layer variations have higher tensile strength than composites with more ramie fiber layer variations. Bavan (2013) stated that fibreglass tensile strength's mechanical properties are higher than ramie and other natural fibers [4]. The tensile strength at an angle of 90/60° is also higher than the angle of 90°/45° in any type of layer. Fibers with an angle of 90°/60° tend to be more tilted from the direction of attraction than the angle of 90/45°. The slope of the fiber's direction from the tensile's direction will affect the magnitude of the tensile strength value where the fiber that is more tilted from the force direction requires a higher tensile force to achieve a fracture, thus having higher tensile strength. On composites of ramie and fiberglass with layer sequences Fiber - Ramie – Ramie – Fiber (Fiber 90° , Ramie 45°) and Ramie – Fiber – Fiber – Ramie (Ramie 90°, Fiber 45°). Khans obtained tensile strength of 58.73 MPa and 76.22 Mpa. The tensile strength value tends to be smaller than the tensile value of fiber layer - Ramie - Fiber - Ramie - Fiber with an angular direction of any fiber 90° and ramie 60°, which is 91.39 Mpa [5]. The post-test condition of the tensile test is shown in the following figure 2.

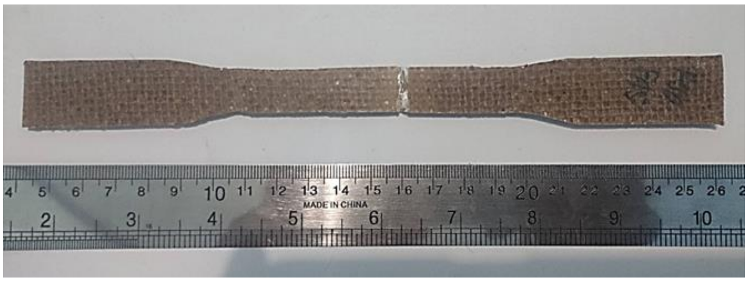

Figure 2. Post-test tensile specimen.

Figures 3a – 3d display the fractured specimen after the tensile test. Figure 3a – 3b shows more fiber coming out from the fractured area. This appears in the specimen where the ramie is placed on the top layer. Figure 3c – 3d demonstrates that only a tiny portion of the fiber comes out from the fractured region. This indicates that the stacking sequence influences the fracture mode of the composite. The composite with the top layer containing ramie fiber has a lower tensile strength value than fiberglass, which is the inner layer of the composite [4]. This is because ramie has a lower tensile value than fiberglass. Therefore, during tension, the ramie fiber at the outer layer will break first, reducing the overall strength of the composite. The ramie fibers layer breakup is also influenced by the angle of the fiber, where the angle of 90° will break as it is in the direction of the tensile load. The breakup of ramie fiber causes the specimen to lose resistance to the tensile load, where only fiberglass material is left inside the specimen to withstand the tensile load. The fibers in the glass are cut off one by one while holding the tensile load, which causes the glass fibers to come out as in the 3. The gradual disconnection of fiberglass also affects the evolution of the stress-strain diagram. Figure 3a – 3d displays the stress-strain diagram of composite materials with different layer and angle combinations.

Figure 3. Fractured specimens showing pull out of the fiberglass layer. a) R-F–R–F–R, R90°/F45°, b) R–F–R–F–R, R90°/F60° c) F–R–F–R–F F90°/R60°, d) F–R–F–R–F F90° R45°.

Figures 4a and 4b show the stress-strain diagram of glass fiber – ramie materials. The plots display jagged lines for R-F-R-F-R material around the highest point. This phenomenon indicates a gradual breakup of the fiber until the specimen is fractured. Figure 4a also demonstrates more extended strain capability in the specimen with a fiber angle of 60° as compared to the specimen with a fiber angle of 45°. This indicates that the failure energy required is larger for a higher angle because the substitution effect is effective in the angle between 60° - 75° [5, 6]. Figure 4b displays the plot of the stress-strain test from a hybrid composite of F-R-F-R-F.

Contrary to graph in 4a, the plot shows rising to the highest point and then fracture, where the composite fiber with the fiberglass surface layer immediately failed after the test machine reached the highest point [7]. Substitution of 30% layer causes the drop of tensile strength to 65 MPa. For comparison, the tensile strength obtained for the F-F-F-F-F combination is 172 MPa. It is also worth mentioning that composite hybridization glass fiber – ramie shows a more negligible effect on the strain causing the hybrid composite to be a good candidate for impact absorber material [8, 9].

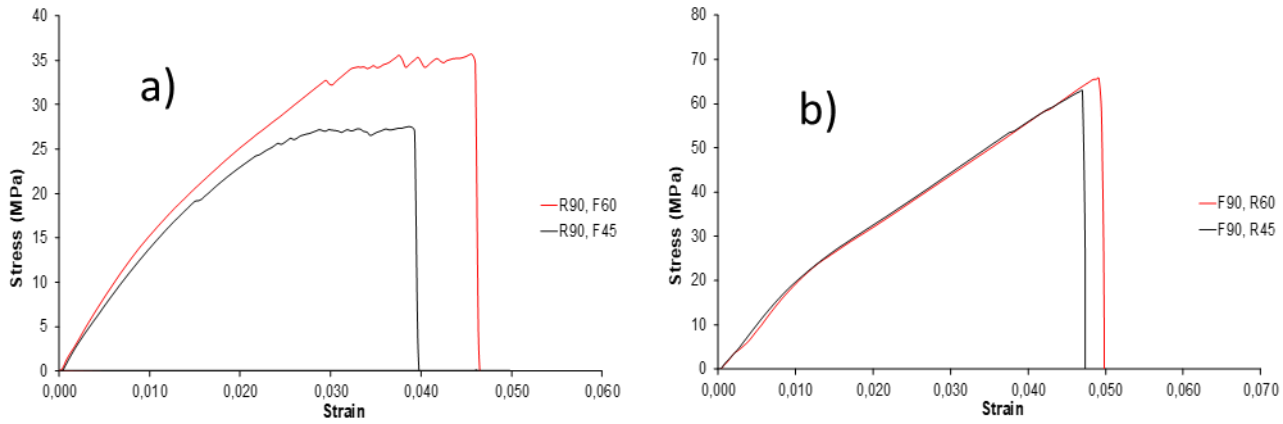

Figure 4. Stress-strain of hybrid composite with stacking a) R-F-R-F-R. b) F-R-F-R-F.

Table 2. Hybrid Composite Flexural Strength.

Layer stacking	Angle stacking	Flexural Strength (MPa)	Elastic Modulus (MPa)
R-F-R-F-R	Ramie 90° / Fiber 45°	89,60	20,715
R-F-R-F-R	Ramie 90° / Fiber 60°	101,62	28,332
F-R-F-R-F	Fiber 90° / Ramie 45°	177,51	52,038
F-R-F-R-F	Fiber 90° / Ramie 60°	149,56	51,69

Table 2 lists the hybrid composite's highest and lowest flexural strength obtained via a three-point bending test. The highest bending strength value is 177.51 MPa shown in the F-R-F-R-F with fiber direction 90° and Ramie 45°, while the lowest bending strength is in the layers of R-F-R-F-R with the direction of Ramiee fiber 90° and Fiber 45° which is 89.60 MPa. The hybrid composite specimens with three layers of fiberglass have a higher flexural strength value than specimens with three layers of ramie fiber. Moreover, the modulus is also higher in specimens with three layers of fiberglass. This is caused by the contribution of fiberglass layer, which is higher flexural strength than the ramie [10, 11]. Figure 5 displays the hybrid composites after the flexural test. It can be seen that the hybrid composites with more glass fiber layers (5c -5d) show more resistance to bending force. The materials exhibit a relatively straight form.

On the other hand, the hybrid composites combined with less glass fiber exhibit a higher bending angle, suggesting a decreasing effect in the flexural strength [12]. The ability of the hybrid composite to absorb impact energy is shown in figure 6a. It is found that the stacking variation of F–R–F–R–F with fiber direction 90° and Ramie 45° has the highest average impact power of 2.95 (J/mm^2). In contrast, the variation of the R-F-R-F-R with the direction of ramie 90°, fiber 45° has the lowest impact strength value of 1.65 (J/mm^2).

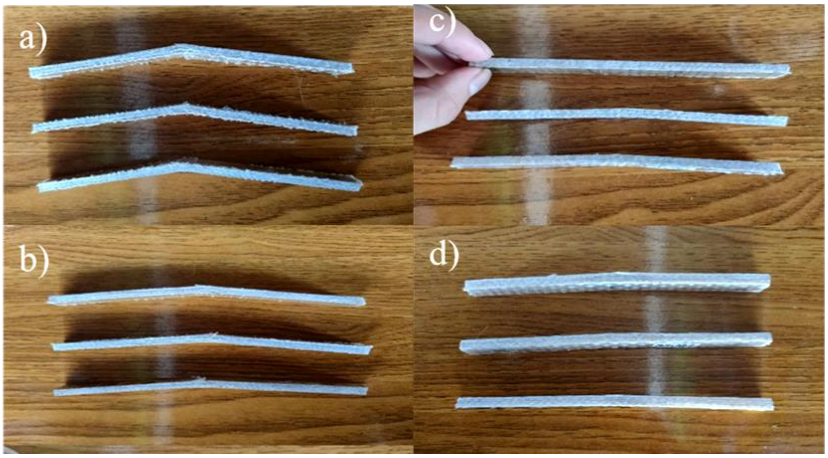

Figure 5. Hybrid composite after flexural test a) R–F–R–F–R Ramie 90° dan Fiber 45°, b) R–F–R–F–R Ramie 90° dan Fiber 60°, c) F–R–F–R–F Fiber 90° dan Ramie 45°, d) F–R–F–R–F Fiber 90° dan Ramie 60°.

Figure 6b displays water absorption test results based on layer variation. It is shown that the combination of F-R-F-R-F layer with a fiber angle of 90° and ramie 45° in specimen number 2 is 0.48%. The lower percentage value indicates high water-resistance of the specimen. On the other hand, the R–F–R–F–R with a fiber angle of 90° and ramie 60° shows the lowest water absorption, 0.78 %. More experiments are needed to verify whether the layer angle plays a role in determining the water absorption. The average water absorption per specimen variation is 0.48% to 0.78%. The high water absorption in the hybrid composite can be caused by the different number of ramie layers or natural fiber in the composite [13, 14]. Based on the Indonesian National Standard (SNI) on the quality of particle boards (composites), the percentage of water absorption allowed does not exceed 14%, where the water absorption value in ramie and fiberglass composites obtained still meets the criteria of SNI.

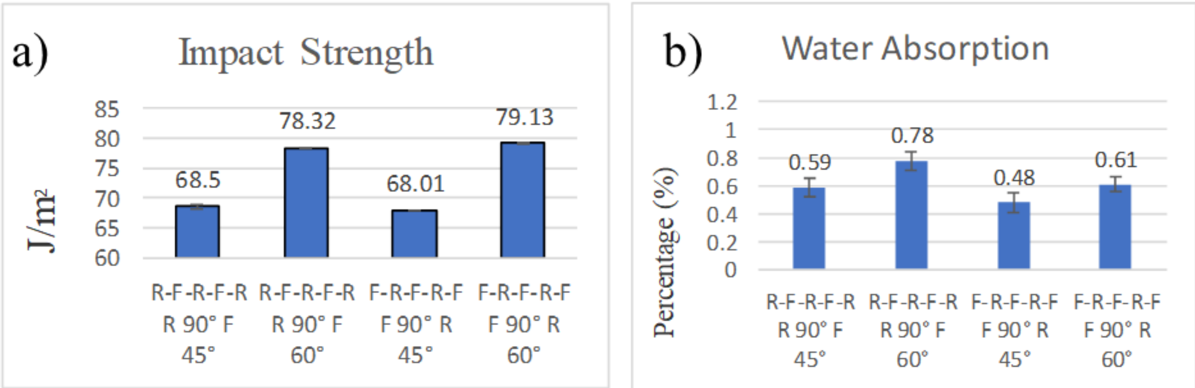

Figure 6. a) Impact energy vs layer stacking orientation. b) Water absorption vs layer stacking orientation

4. Conclusion

Based on the results of the hybrid composite research of rami fiber and fiberglass, the following conclusions can be drawn: (1) Variation of layer number and angle significantly affects the tensile strength. F–R–F–R–F combination with fiber angle of 90°, ramie 60° has the highest average tensile strength value of 60.92 (MPa). In comparison, the variation of the R-F-R-F-R with a rami angle of 90°, fiber 45° has the lowest average tensile strength value of 32.29 (MPa). Tensile strength values with more fiber layers with an angle of 60° angles tend to be higher than the layers' angle of 45°; (2) The highest flexural strength is in the F-R-F-R-F with fiber direction of 45° and ramie 90°, which is 177.51 (MPa), while the lowest flexural strength is found in the R-F-R-F-R with the direction of rami 90° and Fiber 45° which is 89.60 (MPa). The variation of the R-F-R-F-R layer at an angle of 60° has a higher flexural value than the 45° angle. In contrast, the flexural strength value at the 45° angle variation is higher in the F-R-F-F layer variation. (3) The number of layer stacking and the composite angle influence the average impact strength value obtained. The highest impact strength value is in the F-R-F-R-F with fiber direction 45° and ramie 90° which is 2.95 (J/mm^2) while the lowest impact power value is in the F-R-F-R-F with the direction of ramie 90° and fiber 60° which is 1.65 (J/mm^2). (4) Variations of layer numbers influence the water absorption properties. The average water absorption value is best indicated by the variation in F-R-F-R-F with a fiber angle of 90° and rami 45°, which is 0.48%. The average value of the highest water absorption is indicated by variations in the R–F–R–F–R with a fiber angle of 90° and rami 60°, which is 0.78%. A small percentage value indicates the specimen's high water resistance.

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References

[1] Rafiquzzaman, M., Zannat, M., Roy, R., & Sultana, M. N. (2017). Jute-glass fiber based composite for engineering application. *European Journal of Advances Engineering and Technology*, *4*(7), 510-15.

[2] Yudhanto, F., Sudarisman, S., & Ridlwan, M. (2016). Karakterisasi kekuatan tarik komposit hybrid lamina serat anyam sisal dan gelas diperkuat polyester. *Semesta Teknika*, *19*(1), 48-54.

[3] Wallenberger, F. T., Watson, J. C., & Li, H. (2001). Glass fibers. *Materials Park, OH: ASM International, 2001.*, 27-34.

[4] Bavan, D. S., & Kumar, G. C. (2013). Finite element analysis of a natural fiber (maize) composite beam. *Journal of Engineering*, *2013*.

[5] Dong, C. (2021). Flexural behaviour of carbon and glass reinforced hybrid composite pipes. *Composites Part C: Open Access*, *4*, 100090.

[6] Raghavendra, G., Naidu, P. P., Ojha, S., Vasavi, B., Pachal, M., & Acharya, S. K. (2019). Effect of bi-directional and multi-directional fibers on the mechanical properties of glass fiber-epoxy composites. *Materials Research Express*, *6*(11), 115353.

[7] Zhang, D., & Hayhurst, D. R. (2014). Prediction of stress–strain and fracture behaviour of an 8-Harness satin weave ceramic matrix composite. *International Journal of Solids and Structures*, *51*(21-22), 3762-3775.

[8] Petrucci, R., Santulli, C., Puglia, D., Nisini, E., Sarasini, F., Tirillò, J., ... & Kenny, J. M. (2015). Impact and post-impact damage characterisation of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured by vacuum infusion. *Composites Part B: Engineering*, *69*, 507-515.

[9] Khan, H. M., Shukla, S. R., Shukla, S., and Gupta, A. K. (2017). Enhancing mechanical properties of jute fibre/glass fiber and epoxy combined hybrid composite laminates. International Research Journal of Engineering and Technology (IRJET), 2.

[10] Ashik, K. P., Sharma, R. S., & Patil, S. (2017). Evaluation of tensile, flexural and Impact strength of natural and glass fiber reinforced hybrid composites. *Renew Bioresour*, *5*(1).

[11] Sanjay, M. R., Arpitha, G. R., & Yogesha, B. (2015). Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: A review. *Materials today: proceedings*, *2*(4-5), 2959-2967.

[12] Ragunath, S., Velmurugan, C., Kannan, T., & Thirugnanam, S. (2018). Evaluation of tensile, flexural and impact properties on sisal/glass fiber reinforced polymer hybrid composites.

[13] Muñoz, E., & García-Manrique, J. A. (2015). Water absorption behaviour and its effect on the mechanical properties of flax fibre reinforced bioepoxy composites. *International journal of polymer science*, *2015*.

[14] Fiore, V., Calabrese, L., Miranda, R., Badagliacco, D., Sanfilippo, C., Palamara, D., ... & Proverbio, E. (2022). On the response of flax fiber reinforced composites under salt-fog/dry conditions: Reversible and irreversible performances degradation. *Composites Part B: Engineering*, *230*, 109535.

[15] SNI 03-2105-2006. Papan Partikel Datar. Dewan Standarisasi Nasional Indonesia.