

Investigation of Tensile and Impact Properties of Pineapple Leaf Fiber-Glass Fiber Reinforced Polymer (GFRP) Hybrid Composites

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Paper History

Received: 13-June-2024

Received in revised form: 17-June-2024

Accepted: 30-July-2024

ABSTRACT

Kontes Kapal Cepat Tak Berawak Nasional (KKCTBN) held by *Pusat Prestasi Nasional (Puspresnas) Kemendikbudristek RI* aims to encourage innovation in the design and performance of shipping-maritime technology prototypes. The selection of the right material for the catamaran hull is very important because it affects the strength and weight of the ship. Materials such as fiber reinforced polymer, which uses glass fiber, are often used due to their good mechanical strength. However, natural fibers such as pineapple leaf fiber also have potential as composite reinforcement. The combination of natural and synthetic fibers, such as pineapple leaf fiber and glass fiber, in hybrid composites can improve the mechanical properties of the material. The purpose of this study was to investigate tensile and impact properties of pineapple leaf fiber-glass fiber reinforced polymer (GFRP) hybrid composites. Fiber preparation was carried out by separating pineapple leaf to produce fibers, alkaline treatment using 10% NaOH with a soaking time of 24 hours, and oven drying at 100°C for 60 minutes. Polymer as the matrix used was 50% while the percentage variations of pineapple leaf fiber and glass fiber were sequentially as follows 5%:45%, 10%:40% and 15%:35%. It was found that the tensile strength of the 10% pineapple leaf fiber composite was about 114 MPa and impact strength 49.96 J/mm², density 1.19 g/cm³. The results of this study indicate that the resulting composite can be used as an alternative material in the prototype hull of a catamaran type unmanned speedboat.

KEYWORDS: *GFRP, pineapple leaf fiber, hybrid composite.*

1.0 INTRODUCTION

KKCTBN organised by the Ministry of Research and Technology's *Puspresnas* encourages innovation in shipping-maritime technology. One of the competition regulations is that ships use catamaran-type hulls. To fulfill the KKCTBN requirements, the hull must be watertight, lightweight and strong to avoid cracking and damage to the electronic equipment inside [1].

Catamaran hull materials are generally made of Fiber Reinforced Polymer (FRP) such as glass fiber [2]. Glass fiber are synthetic fibers that function to provide tensile strength to the material, reinforced with polymers in the form of polyester or epoxy which function as a matrix that binds the fibers. Glass fibers are most commonly used for maritime structures mainly due to their performance advantages based on cost [3]. Glass fibers in material science fall into the category of thermoset polymer composites and glass fibers still account for over 95% of the utilisation in maritime applications [4].

The development of composites in Indonesia is still directed by non-renewable natural resource materials derived from earth excavations such as glass, carbon, aramid. For this reason, it is necessary to develop raw materials for composite reinforcement materials that are environmentally friendly, such as natural fibers. Pineapple leaf fiber is a natural fiber that has high potential as a reinforcing fiber [5].

Pineapple leaf fiber has been widely used as a composite reinforcement for several applications such as automotive components, ship hulls, and civil construction. Based on data from *Badan Pusat Statistik (BPS)* Riau in 2021, pineapple fruit production reached 354.8 thousand tones. Pineapple plants after two or three harvests must be replaced with new pineapple plants, so the leaf is discarded as waste [6]. This condition causes more pineapple leaf waste to be produced so that it has not been utilised optimally. The utilisation of pineapple leaf waste in Riau, especially *Desa Kualu Nenas Kecamatan Tambang*, is only used as animal feed, organic fertiliser, and textile materials [7].

Previous studies have shown that pineapple leaf fibers provide significant tensile strength and impact resistance, although they have limitations such as high moisture absorption and poor compatibility with polymer matrices. The combination of pineapple leaf fiber with synthetic fibers such as glass fiber in hybrid composites increases the mechanical properties of the composite, as is known from several studies that show hybrid fiber composites increase the tensile strength and impact toughness of the material.

This research aims to determine the characteristics of a hybrid composite of pineapple leaf fiber and glass fiber as a reinforcing material with a matrix of 50%, variations in the percentage of pineapple leaf fiber and glass fiber, respectively, 5%:45%, 10%:40% and 15%:35 %. Pineapple leaf fiber was chosen because it is easy to find in Indonesia, especially in Riau. Pineapple leaf fiber has good mechanical properties, glass fiber was chosen because it improves the shortcomings of pineapple leaf fiber. The combination of pineapple leaf fiber and glass fiber is an alternative material to increase the tensile strength and impact toughness of hybrid composite materials.

2.0 EXPERIMENTAL METHOD

2.1 Preparation of Fiber, Alkaline Treatment and Drying Process

Figure 1 shows the preparation of pineapple leaf fiber. Pineapple leaves were obtained from a pineapple plantation in Desa Kualu Nenas, Kecamatan Tambang, Riau. The pineapple leaves used in the study, was the leaf in the middle and the bottom [8]. Pineapple leaves were separated one by one, the thorns on the edge of the pineapple leaves were cut and cleaned using flowing water. Pineapple leaves were manually separated in the air flow until long fibers were produced. Pineapple leaf fibers were washed and drained, and then the fibers were dried in the sun for 8 hours. Figure 2 shows the alkaline treatment process of pineapple leaf fiber. Sodium hydroxide and distilled water were determined based on the needs of the composite fiber. Sodium hydroxide and distilled water were put into a container and then dissolved using a magnetic stirrer. A total of 200 g of pineapple leaf fiber was put into an alkaline solution with a soaking time of 24 hours to remove the skin of the outer layer of the leaf [9]. After the soaking was complete, the fibers were drained and rinsed using distilled water to remove the alkaline solution to a neutral pH (7 ± 0.5).

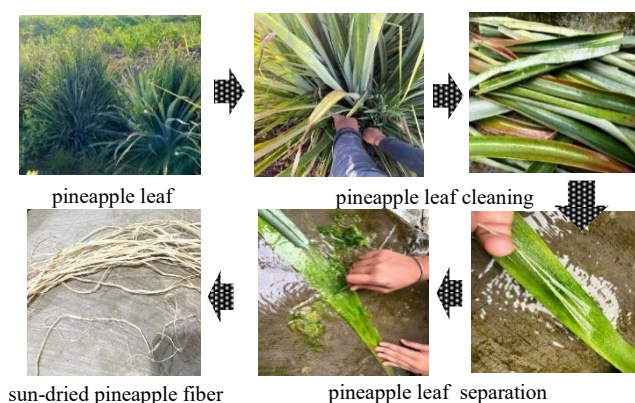


Figure 1: Preparation process of pineapple fiber process

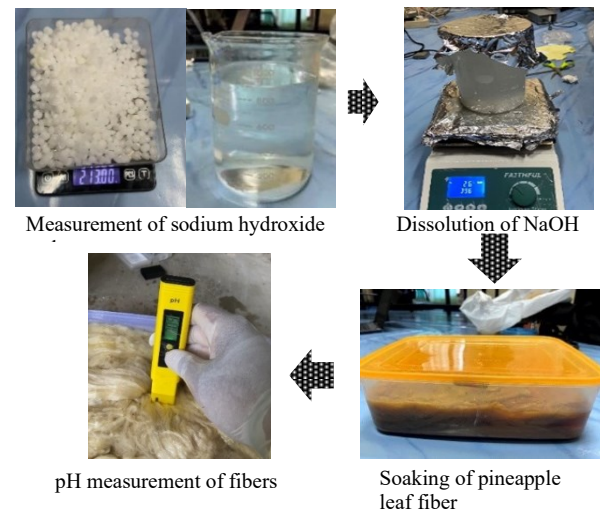


Figure 2: Alkaline treatment of pineapple leaf fiber

The drying process was carried out to remove the remaining alkaline solution and moisture content in the fibers. Figure 3 shows the pineapple leaf fibers separated individually. Pineapple leaf fibers were dried using an oven at 100°C for 60 minutes. Every 5 minutes the fibers were removed from the oven and weighed, until the mass of the fibers was constant. A constant mass indicates 0% moisture content in the fiber.

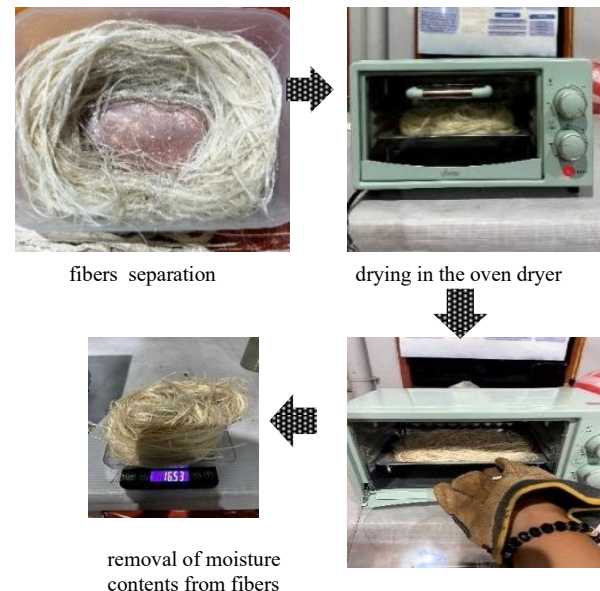


Figure 3: Drying process of pineapple leaf fibers

2.2 Fabrication of Test Specimen

The specimen fabrication process has the following methods. Pineapple leaf fiber was cut into 2 cm lengths [10]. The composite composition used was calculated based on the fabrication needs of the test specimens. Figure 4 shows the fiber cutting and mass measurement of fiber and matrix.



Figure 4: Mass measurement of fiber and matrix

The molds were fabricated for 10 test specimens. The mold was smeared with wax and PVA to make it easier to remove the specimen from the mold. The epoxy resin is mixed with a catalyst with a weight percentage based on the measured requirements and then stirred for ± 5 minutes. Figure 5 shows the laminate layers of pineapple leaf fiber, glass fiber and composite matrix. The test specimen fabrication process was carried out using the hand lay-up method. The lamination process is based on predetermined variations. Pineapple leaf fiber volume fraction: glass fiber (5%:45%, 10%:40%, 15%:35%).

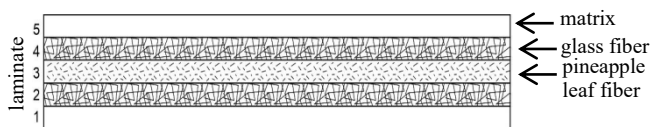


Figure 5: Laminate layer

After the lamination process using the hand lay-up method, it is followed by a vacuum bagging process with a pressure of 0.8 bars for 2 hours [11]. The specimen is left for 8 hours until it hardens completely. The next process is to remove the specimen from the mold. The specimens were marked and cut using a grinder based on standard dimensions of the test specimen.

2.3 Density Measurement

The density measurements in this study used the ASTM D792 standard. Density testing was carried out at Laboratory of Materials and Corrosion, Chemical Engineering, Universitas Riau. Figure 6 shows the density test specimen. The dimensions of the test specimen are 10 mm x 10 mm x 3 mm.

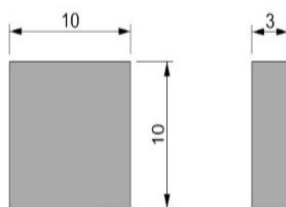


Figure 6: Dimension of the density test specimen

The fluid used is distilled water with $\rho = 1$ (g/cm³). The mass of the specimen is measured in air (m_a), the mass of the specimen is measured in water (m_w). Actual results are obtained from specimen mass data measured in air (m_a) and specimen mass measured in water (m_w).

2.4 Tensile test

In this research, tensile testing used ASTM D3039/D3039M standards. Tensile testing was carried out at Laboratory of Material Testing, Politeknik ATMI Surakarta. Figure 7 shows the dimensions of the tensile test specimen. The dimensions of the test specimen are 250 mm x 25 mm x 3 mm.



Figure 7: Tensile test specimen

The addition of clamps at both ends of the specimen with the aim of reducing damage to the ends of the specimen when clamped by the tensile test equipment. Installation of the extensometer on the specimen to be tested. Extensometers are used to measure changes in length or strain in specimens during the tensile testing process. The tensile load is applied in the longitudinal direction slowly and then increases until failure. Tensile loading test speed 10 mm/minute. Test result data is obtained after testing the force or tension and increasing the length of the specimen.

2.5 Impact Test

Impact testing of pineapple leaf fiber and glass fiber reinforced polymer composites using ASTM D6110 standards. Impact testing was carried out at Laboratory of Material Testing, Politeknik ATMI Surakarta. The dimensions of the test sample were 127 mm x 12.7 mm x 3 mm, notch depth 2 mm, and notch angle 45°. Figure 8 shows a Charpy impact test specimen.

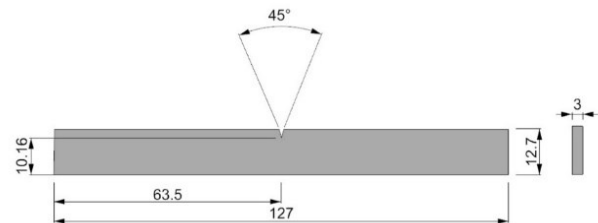


Figure 8: Charpy impact test specimen

Impact testing uses the Charpy method. The angle α is determined first. After testing, the β angle is measured. The result data was obtained after impact testing was carried out.

3.0 RESULT AND DISCUSSION

3.1 Result

3.1.1 Density

From the density test obtained from this research, a control chart was determined with variations in the volume fraction of pineapple leaf fiber: fiberglass (5:45, 10:40, 15:35). Figure 9 shows that the density decreases as the percentage of pineapple leaf fiber increases by 18.05%.

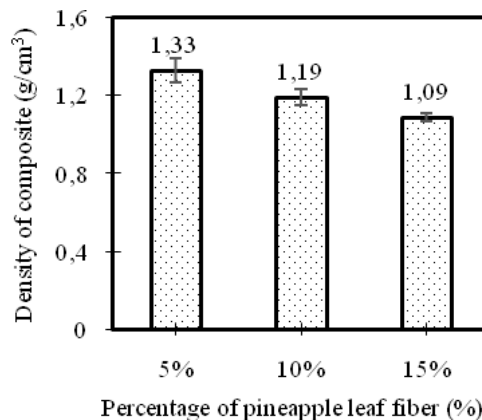


Figure 9: Density of pineapple leaf fiber-glass fiberreinforced hybrid composites

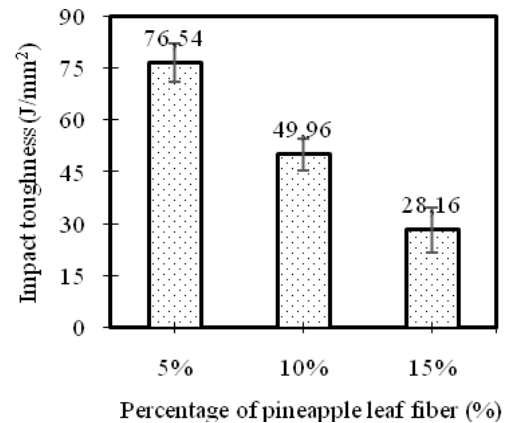


Figure 11: Impact toughness of pineapple leaf fiber-glass fiberreinforced hybrid composites

3.1.2 Tensile Strength

For the hybrid composite reinforced with 5% pineapple leaf fiber, the test data showed an elastic modulus of around 2.72 GPa, a tensile stress of 97.7 MPa, and a tensile strain of 3.5%. For the hybrid composite reinforced with 10% pineapple leaf fiber, an elastic modulus of around 3.91 GPa, a tensile stress of 114 MPa, and a tensile strain of 3.2% were obtained. For the hybrid composite reinforced with 15% pineapple leaf fiber, the elastic modulus values were around 2.21 GPa, tensile stress of 55.4 MPa, and tensile strain of 3%.

Figure 10 shows that the tensile stress increases by 30.7% when the fiber percentage increases from 5% to 10%. The tensile stress decreased by 61.4% when the fiber percentage increased from 10% to 15%.

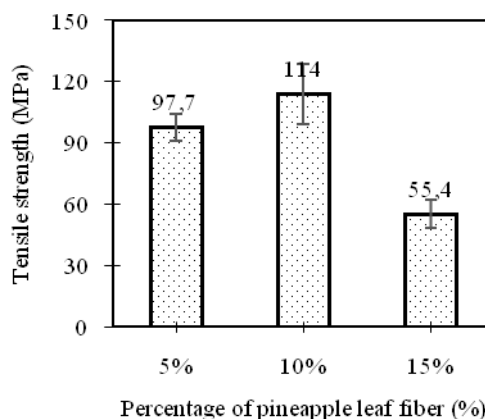


Figure 10: Tensile strength of pineapple leaf fiber-glass fiberreinforced hybrid composites

3.1.3 Impact Toughness

Figure 11 shows the change in impact toughness due to different percentage of pineapple leaf fiber in hybrid composites. The impact toughness decreased as the percentage of pineapple leaf fiber increased to 17.9%.

3.2 Discussion

Based on the test results, the density of the specimens increased with the addition of glass fiber and decreased with the addition of pineapple leaf fiber, indicating that glass fiber has a higher density than pineapple leaf fiber. This result is consistent with composite theory where the density of pineapple leaf fiber is lower at 1.072 g/cm³ [12], compared to glass fiber whose density is 2.53 g/cm³ [13] and shows how changes in fiber ratio affect the overall composite density.

Figure 12 (a) shows the tensile test fracture with 5% pineapple leaf fiber percentage. The hybrid composite with 5% pineapple leaf fiber percentage shows voids in the fracture and detached fibers from both pineapple leaf fiber and glass fiber. This specimen has a high modulus of elasticity, high tensile stress, and low tensile strain, so it can withstand large tensile loads.

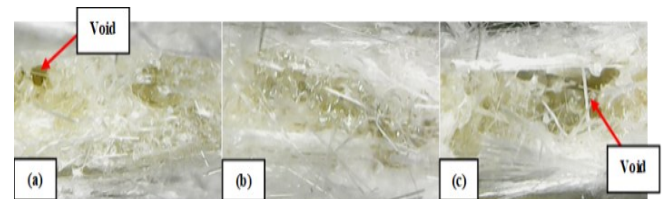


Figure12: Tensile fracture of hybrid composites with pineapple leaf fiber percentage: (a) 5%; (b) 10%; (c) 15%

Figure 12 (b) presents the specimen with 10% pineapple leaf fiber percentage. This specimen has a higher modulus of elasticity, higher tensile stress, and lower tensile strain compared to 5%, so it is able to withstand greater tensile loads from the fracture there are voids, besides that in hybrid composites with lamina layers there are also fibers that break off and are pulled out. if there are fibers that are pulled out, it shows the low bonding of fibers and matrix [14]. Figure 12 (c) shows the specimen with 15% pineapple leaf fiber percentage. This shows that there are voids in the fracture and detached fibers are visible in the fracture area.

The area with voids is more than the 5% specimen. This specimen has a lower modulus of elasticity, lower tensile stress, and lower tensile strain compared to 5%, so it is able to withstand lower tensile loads. Voids can affect the bond between fibers and matrix due to gaps in the fibers or imperfect fiber shape, so that when loading areas with many voids will reduce the strength of the composite [15].

As the percentage of pineapple leaf fiber increases, the elastic modulus, tensile stress, and tensile strain show different trends. The elastic modulus and tensile stress increased with an increase in fiber percentage, while the tensile strain decreased. The tensile load that the material can withstand also increases with an increase in fiber percentage, but the tensile strain decreases. The highest tensile stress was found in the specimen with 10% pineapple leaf fiber percentage with a value of 114 MPa followed by the specimen with 5% pineapple leaf fiber percentage with a value of 97.7 MPa and the lowest in the 15% specimen with a value of 55.4 MPa.

The decrease in tensile strength at 15% specimen indicates that there is an optimum limit for the addition of pineapple leaf fiber, after which the strength of the composite starts to decrease. The addition of pineapple leaf fiber increased the tensile strength of the composite, but the density of the composite decreased [16]. This shows that the addition of pineapple leaf fiber can increase the tensile strength, but the lower density can reduce the overall tensile strength.

Figure 13 (a) shows a photograph of the impact test fracture of the 5% pineapple leaf fiber hybrid composite. The fracture shape of the impact test specimen of 5% pineapple leaf fiber percentage does not show any voids and the fracture surface of the test specimen is shiny. Based on the test results, the highest impact strength is found in this specimen with a percentage of 5% pineapple leaf fiber with an impact strength value of 76.54 J/mm².

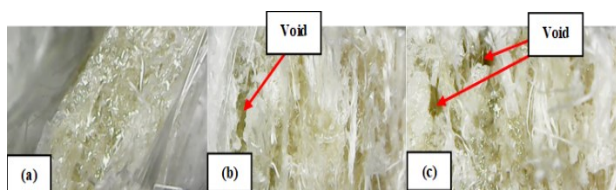


Figure 13: Impact fracture of hybrid composites with pineapple leaf fiber percentage: (a) 5%; (b) 10%; (c) 15%

Figure 13 (b) shows the impact fracture of the 10% pineapple leaf fiber hybrid composite where voids are visible and the fibers appear to be pulled out. Due to the presence of voids in this specimen, the impact strength value is slightly lower with an impact strength value of 49.96 J/mm². In Figure 13 (c) the impact test specimen of 15% pineapple leaf fiber percentage is seen in the fracture of voids and the void area that occurs is more than the 10% specimen, so this specimen has the lowest impact strength value with an impact strength value of 28.16 J/mm². In specimens with voids, the matrix cannot transfer stress to the reinforcement. The stress concentration occurs in the void which causes the part to fail first. Therefore, parts that have many voids will reduce the impact strength [14].

Figure 13 (c) shows the impact fracture of the hybrid composite with 15% pineapple leaf fiber percentage. In this fracture, voids can be seen and the void area is more than the 10% specimen. This specimen has the lowest impact strength

value with an impact strength value of 28.16 J/mm². In specimens with voids, the matrix cannot transfer stress to the reinforcement. The stress concentration occurs in the void which causes the part to fail first. Therefore, parts that have many voids will reduce the impact strength [15].

Increasing the volume fraction of pineapple leaf fiber causes a decrease in impact strength, as pineapple leaf fiber cannot replace the toughness and impact energy absorbing ability of glass fiber. The addition of pineapple leaf fiber decreased the impact strength of the composite because pineapple leaf fiber does not have as high toughness as glass fiber [17]. This shows that higher density can increase the impact strength, but the addition of pineapple leaf fiber which has a lower density can reduce the impact strength.

From the KKCTBN race guidelines, the hull must use lightweight materials with the minimum possible load with a minimum weight of 5 kg so that it meets the race regulations. The hull must also use strong materials to prevent cracking of the hull. Low density is an advantage for fast boats as it increases speed. However, a density that is too low can reduce the strength of the material. The specimen with 10% pineapple leaf fiber percentage has a density value of 1.19 g/cm³ which is good enough for this application. The highest tensile stress of 114 MPa exceeds Biro Klasifikasi Indonesia (BKI) standard with a minimum value of tensile stress of 98 MPa.

A high tensile stress is required to ensure that the hull can withstand the stresses and deformations that occur during operation. Low tensile strain indicates that the material has good resistance to deformation. The results show that the specimen with 10% pineapple leaf fiber percentage has a low tensile strain, so it is able to withstand greater tensile loads without undergoing considerable deformation. High impact strength is important to protect the hull from damage due to impact or collision and prevent cracking of the hull.

The specimen with 5% pineapple leaf fiber percentage has the highest impact strength value of 76.54 J/mm². Although the impact strength value of the specimen with 10% pineapple leaf fiber percentage is lower at 49.96 J/mm², this value is still suitable for ship hull prototyping applications.

Based on the test results, the specimen with 10% pineapple leaf fiber percentage had the highest tensile stress, 114 MPa, which exceeded the BKI standard. The specimen with 10% pineapple leaf fiber percentage had an impact strength value of 49.96 J/mm², with a density of 1.19 g/cm³. These values meet the requirements of the BKI standard in ship hull prototyping applications. Therefore, the specimen with 10% pineapple leaf fiber percentage is an optimal choice for the hull material of an unmanned fast boat catamaran. It offers adequate tensile strength and impact resistance, which are important to ensure the safety and durability of the vessel during operation.

4.0 CONCLUSION

The hybrid composites with 10% pineapple leaf fiber percentage meet the material standard for ship hull prototypes. From this study, it was found that the tensile stress of pineapple leaf fiber-glass fiber reinforced polymer hybrid composites is about 114 MPa and the impact strength is 49.96 J/mm², with a density of 1.19 g/cm³. The results of this investigation indicate that the resulting hybrid composites can be used as a prototype material for the hull of a catamaran-type unmanned fast boat.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge Lembaga Penelitian dan Pengabdian kepada Masyarakat Universitas Riau (LPPM UNRI) which supported this research by Riset Unggulan Universitas Riau (RUUR) Batch 2 program in 2024, contract no. 989/UN.19.5.1.3/AL.04/2024.

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