THE EFFECT OF ALKALIZATION AND ESTERIFICATION TREATMENT ON MECHANICAL PROPERTIES OF WATER HYACINTH FIBER REINFORCED EPOXY-RESIN COMPOSITE

by Sulardjaka

This research investigates the effect of fiber pre-treatment on the mechanical and physical properties of unidirectional water hyacinth (WH) fiber reinforced epoxy resin composites. The water hyacinth fibers have been produced by mechanical processing. The 50–70 cm length of WH stems are brushed with an iron brush to mechanically extract the strands. The dry fibers then were pre-treated by alkalization and esterification. The alkalization ha ve been conducted by immersing the WH fibers on 2 %, 5 % and 10 % NaOH solution for 24 h. The esterification of WH fibers have been done using acetate anhydride. The composite with 15 %, 25 % and 35 % of unidirectional WH fibers was made by hand lay-up. After hand lay up process the WH composites then compacting with pressure compaction 5 MPa. Tensile test and was done based on ASTM D3039. The density of composites was tested based on Archimedes rule. Surface contaminants have been eliminated by fiber treatment. The NaOH treatment eliminated the surface's wax and cuticle. The surface of fibers treated with 10 % NaOH was cleaner than those treated with 5 % NaOH. Fiber treatment has the effect of reducing fiber thickness. The tensile test results of the composite reinforced with WH fiber with NaOH treated and acetate anhydride show that the tensile strength of untreated WH fiber reinforced epoxy resin composites increased with the increase of % WH fiber. The tensile strength results that acetate anhydride treatment of WH fiber reinforced epoxy resin composites showed increased WH fiber increase the tensile strength of composite. The highest tensile strength of epoxy resin reinforced with WH fiber with acetate anhydride treatment

***Keywords:** Composite, Natural Fiber, Epoxy-resin, Water Hyacinth, Alkalization, Esterification, Tensile Strength*

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Sulardjaka Sulardjaka
Corresponding author
Doctor of Engineering*
E-mail: sulardjaka@lecturer.undip.ac.id
Norman Iskandar
Master of Engineering*
Parlindungan Manik
Doctor of Engineering
Department of Naval Architectur Engineering**
Dwi Satrio Nurseto
Bachelor of Engineering*
*Department of Mechanical Engineering**
**Diponegoro University
Prof. Sudarto str., SH, Tembalang, Semarang, Indonesia, 50225

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1. Introduction

Water hyacinth (Eichhornia crassipes) is an aquatic plant that lives floating on the surface of a river, swamp, or lake. This plant grows aggressively and has been a nuisance on almost all continents for more than 100 years. High population growth of WH plants causes various problems related to ecosystem balance, loss of endemic organisms, caused sedimentation and decreased fish production [1–3]. Many researchers have researched to take advantage of the water hyacinth plants. Water hyacinth (WH) plants have been investigated to be used for biogas production, absorbing dye waste, absorbers of heavy metal, biofuel production, and reinforcing composites [4–10].

There have been investigations into the viability of utilizing water hyacinth fiber as reinforcement in natural fiber composite products. The tensile strength of water hyacinth fiber is one of the significant features that must be examined. The tensile strength of water hyacinth fiber is 313 MPa, and its elongation is 14 percent [10]. The tensile strength of a single water hyacinth fiber was investigated. Twenty specimens were tested using ASTM D3379-75 specifications [11]. The results of the tests indicate that the water hyacinth fiber extracted from a Philippine Lake has a tensile strength of 105 MPa and an elongation of 3 percent. The Cauvery River (India) water hyacinth fiber was evaluated according to ASTM D3822 for testing synthetic fibers [11]. The test findings indicate that water hyacinth fiber has a tensile strength of 220 MPa and an elongation of 2.8 % [12].

Using natural fibers as reinforcement composites has several disadvantages: hydrophilic properties, limited processing temperatures, low mechanical properties, and low matrix and fiber binding forces that are easily degraded [13–15]. Many studies have been carried out to improve the properties of natural fibers as reinforcement in composites. The properties of natural fiber as composite reinforcement can be increased by pre-treatment. Immersion, chemical, alkali, silane, acetylation, benzolization, peroxide, ultrasonic, microwave, thermal, mechanical, and boiling processes are pre-treatment methods to enhance the property of natural fibers [16–23]. Numerous fiber pre-treatment techniques have been investigated to improve the mechanical properties and reinforcement characteristics of water hyacinth fibers in composites. The findings indicate that pre-treatment of water hyacinth fiber could improve its physical and mechanical properties [24–29].

According to prior research, the disadvantages of using WH materials for composite reinforcement include low mechanical strength, ease of water absorption resulting in a weaker fiber-matrix link, and poor compatibility of the WH fiber with the polymer matrix. Previous investigations on the use of water hyacinth fiber as reinforcing composite continue to use stem, chopped stem, sawdust, and powder forms of WH. The Water hyacinth fiber has not yet been subjected to fiber pre-treatment techniques employed on natural fibers. Therefore, studies that are devoted improve the physical, chemical, and mechanical properties of water hyacinth fibers as composite reinforcements, are scientific relevance.

2. Literature review and problem statement

The water hyacinth growing in the Nile includes sixty percent cellulose, eight percent hemicellulose, and seventeen percent lignin [30]. Water hyacinth comprises 29 percent cellulose, 20 percent hemicellulose, 18 percent lignin, and 21 percent ash, according to a chemical analysis of water hyacinth fibers from Aranmanai Kulam Dindigul, Tamil Nadu, India [31]. The chemical composition of water hyacinth fiber from Payakumbuh, Indonesia indicates that this water hyacinth fiber has 43 % cellulose, 29 % hemicellulose, and 7 % lignin [29]. From several investigations on the chemical composition of water hyacinth fiber, it can be inferred that it comprises cellulose between 29 and 61 percent, hemicellulose between 16 and 29 percent, and lignin between 2.25 and 18 percent.

The extraction of fiber from the plant is a crucial component in manufacturing natural fiber composites. The extraction procedure influences the mechanical characteristics of the fiber and, consequently, the properties of the composite that is produced. This fiber extraction and production method aim to separate wax, pectin, hemicellulose, and lignin layers from plant fibers. Immersion, chemical, and mechanical techniques have all been used to remove plant fibers from their parent plant.

Soaking is a standard and straightforward process for producing fibers. This procedure involves immersing the plant in water. Stems of water hyacinth are immersed in water to remove lignin, waxy coating, hemicellulose, and other contaminants. Water will enter the plant's core, causing the plant's cells to swell until the fibers detach from the lignin. Stems of water hyacinth are immersed in water for seven days to remove lignin, waxy coating, hemicellulose, and other contaminants [11]. In these methods, fiber separation takes 14 to 28 days [17]. According to Manimaran, this technique yields fiber of poor quality [32]. In addition to being a prolonged operation, immersion has the potential to damage the environment [33].

Several studies have examined composites reinforced with water hyacinth plant fibers. The mechanical characteristics of biocomposite reinforced with water hyacinth. This study cut water hyacinth stems every 3 to 5 centimeters. The stems were combined with water, washed, and dried at 40 °C for 12 hours [34]. The water hyacinth plants are exploited in the creation of cement-based composites. The water hyacinth plant was dried and then crushed by hand [35]. The density of the material reduced as the quantity of water hyacinth grew, according to the results. Cement composites with a higher water hyacinth concentration have superior flexural properties compared to those without blends. The study of the polyester matrix's tensile and flexural strength reinforced with water hyacinth fibers was done. According to the results, increasing fiber volume fraction decreases composite tensile strength [36]. The method of manufacturing composites is performed by hand lay-up, which yields a composite with an impact resistance of 0.12 J/mm^2 [37]. In contrast to the trend observed in the tensile and flexural testing, the findings of the impact tests indicated that increasing the fiber volume fraction up to 30 percent could improve the impact strength of polypropylene composites reinforced with water hyacinth fibers. The highest impact strength measured was 0.05 J/mm^2 for a 30 percent fiber composite [37]. Studies show that The mechanical characteristics of biocomposite reinforced with WH decreases by increasing the WH. The low mechanical properties of WH and poor adhesive of the fiber matrix caused decreasing the mechanical properties of WH composites.

Water hyacinth fibers can be treated by soaking them in a toluene solution containing 5 percent isocyanate for 30 minutes at 50 °C. The fiber is then dried and treated with toluene that contains 6 % polyethylene glycol. This treatment reduced the fiber's hydrophilic characteristics, enhancing the tensile strength and modulus of elasticity of the LDPE/water hyacinth composite material. The composite ductility of untreated fibers is higher than that of treated fibers [38]. The silane treatment of water hyacinth fiber demonstrated that silane treatment decreased the contact angle between water hyacinth fiber and epoxy resin, resulting in an enhanced strength composite. Applying a silane coupling agent to a composite material increases its tensile and flexural strengths. Silane treatment improves the bond between water hyacinth fiber and epoxy resin [26]. The alkaline treatment method caused the surface of the water hyacinth fiber to become rougher [34]. Losing some pectin, lignin, wax, hydroxyl groups, and other contaminants causes surface modifications [36]. Changes in surface roughness result in enhanced fiber-matrix interlocking forces. Polyvinyl alcohol can be used to improve the characteristics of water hyacinth fiber (PVA). The water hyacinth fibers were soaked in a mixture of ethanol and 6 % PVA powder, and the soaking time was 24 hours. The test's findings showed that modification with PVA increased the tensile strength, modulus of elasticity, and ductility of water hyacinth fiber composites with LDPE matrix up to a mass fraction of 25 percent. Water hyacinth fibers can also be treated by soaking them in a toluene solution containing isophorone diisocyanate for 30 minutes at a temperature of 50 °C. Compared to no treatment, this treatment increased the composite's tensile strength by 100 percent [24]. It can be concluded that fiber treatment can improve the mechanical properties of natural fiber composite.

The use of natural fiber as a composite reinforcement impacts the mechanical properties of the composite, as does the form of the reinforcement. The mechanical properties of water hyacinth-reinforced natural fiber composites can yet be enhanced and developed. This can be achieved by developing fiber processing techniques, manufacturing yarn from water hyacinth fiber, or implementing pre-treatment to strengthen the fiber. All this allows to assert that it is expedient to conduct a study on examines the effect of fiber pre-treatment on the mechanical and physical properties of unidirectional WH fiber reinforced epoxy resin composites.

3. The aim and objectives of the study

The aim of the study is to investigate the effect of fiber treatment on the mechanical properties of Water Hyacinth reinforced epoxy resin.

To achieve this aim, the following objectives are accomplished:

– to investigate the effect of the fiber pre-treatment on morphology and fiber thickness of Water Hyacinth fiber;

– to investigate the effect of the fiber pre-treatment and % wt. of WH fibers on density and porosity of Water Hyacinth reinforced epoxy resin composite;

– to investigate the effect of the fiber pre-treatment and % wt. of WH fibers on tensile strength of Water Hyacinth reinforced epoxy resin composite.

4. Materials and Methods

4. 1. Object and hypothesis of the study

This research aims to investigate the effect of fiber pre-treatment of WH fibers on the morphology and fiber thickness of Water Hyacinth fiber. This research also investigated the effects of fiber pre-treatment on composites' tensile strength, density and porosity. The study's main hypothesis is that fiber pre-treatment increases the tensile strength of the fiber and the adhesive bonding of fiber and matrix and increases the composite's mechanical properties. The assumptions made in the work are that the properties of WH fibers are homogenous.

4. 2. Materials

The epoxy Bakelite® EPR 174 and resin hardener V-140 were used as a matrix and hardener. Water hyacinth fibers were extracted from water hyacinth water hyacinth plants with the length of stems about 50–70 cm. The water hyacinth plants were harvested from swamps in Tanggul Village, Demak Regency, Central Java, Indonesia.

The water hyacinth plants with the length of stems about 50–70 cm have been mechanically extracted to produce the WF fibers. The WH stems are brushed with an iron brush to mechanically extract the strands. This process resulted in WH Fibers through a mechanical procedure, the WH Fibers were then sun-dried. The WH fibers produced by this process are depicted in Fig. 1. Mechanical processing of WH stem has resulted in hair-like fiber shapes.

Fig. 1. Water Hyacinth Fibers

The WH fiber was then alkalization pretreated by immersing it in 5 %, 10 % NaOH or esterification treated by immersing in CH_3COOH (acetate anhydride). Fiber treatments were conducted for 24 hours. After pre-treatment, WH fibers were washed using aquadest and dried in the sun.

4. 3. Methods

The composites tensile specimens were constructed with WH fiber reinforcement in configurations: 0 %, 15 % wt., 25 % wt. and 35 % wt. The tensile test specimens of composite were made by hand lay up using a mold with dimension 250×185×10 mm. The epoxy resin and WH fiber were manually bonded onto the exposed mold surface one by one until the desired specimen's thickness. After hand lay up process the composites then compacting with pressure compaction 5 MPa. To obtain the specimen's dimensions and shape in accordance with the test standard, the specimen is cut using a water jet cutting. The manufacture of the tensile specimen photos is shown in the Fig. 2.

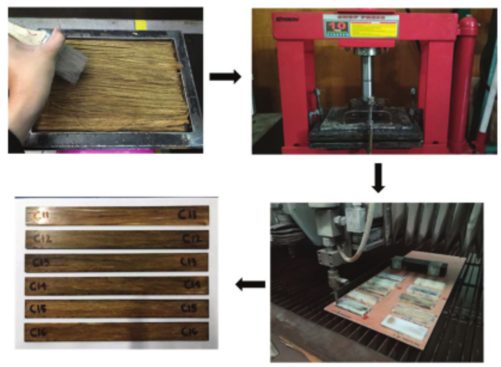

Fig. 2. The manufacture of composites test specimens

SEM used to determine the thickness of the fibers; each thickness was measured from thirty WH fiber specimens. According to ASTM D2734, the porosity can be calculated using the relative difference between the composite's theoretical density (ρ_{th}) and its measured density (ρ_m). Archimedes' Principle can be used to measure the composite's density using the buoyancy of water (ASTM D792). The porosity of composites were calculated using equation (1):

$$Porosity = 100 - \rho_m \left(\frac{W_r}{\rho_r} + \frac{W_f}{\rho_f} \right), \quad (1)$$

where W and ρ represent the weight percentage and the density, and subscripts r and f stand for resin and fiber, respectively. For each parameter, there are six specimens were tested. The ASTM D638 standard was used to evaluate the tensile strength of the epoxy resin material. The tensile test of composites was carried out according to the ASTM D3039 standard. The fracture surfaces of the composite from the mechanical tests were examined by scanning electron microscopy (SEM).

5. Results of the effect of fiber treatment on mechanical properties of composite

5. 1. The effect of the fiber pre-treatment on fiber thickness and fiber morphology

In this study, morphological changes that occurred after treatment (fibers) were examined. Fig. 3, *a* shows the SEM micrograph of an untreated WH fiber. Untreated WH fibers clearly contain impurities and wax. The SEM micrograph of treated fiber as shown in Fig. 3, *b–d* show that the treated fibers more cleanliness than un-treated fiber (Fig. 3, *a*). The treatment with NaOH changed the morphological structure of the WH fibers. It was observed that the fiber had become cleaner which almost all impurities have been removing from the fiber surface. On the NaOH treatment the wax and cuticle in the surface was removed by the interaction with sodium. Fiber treatment using 10 % NaOH (Fig. 3, *c*) resulted cleaner surface than treatment by 5 % NaOH (Fig. 3, *b*). Cleaner of fiber surface reducing the fiber thickness.

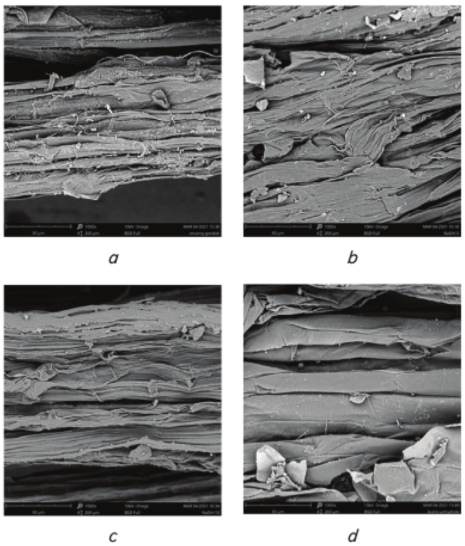

Fig. 3. The surface morphology of untreated and treated of water hyacinth fibers: *a* — Untreated fiber; *b* — 5 % NaOH fiber treatment; *c* — 10 % NaOH fiber treatment; *d* — Acetate anhydride fiber treatment

Fig. 4 shows the effect of fiber treatment on fiber thickness. Immersing WH fiber in 5 % NaOH solution reduced the fiber thickness from 0.270 mm to 0.189 mm. Treatment with 10 % NaOH reduced the fiber thickness by about 52 %. Acetic anhydride fiber treatment reduced fiber thickness by 62 %.

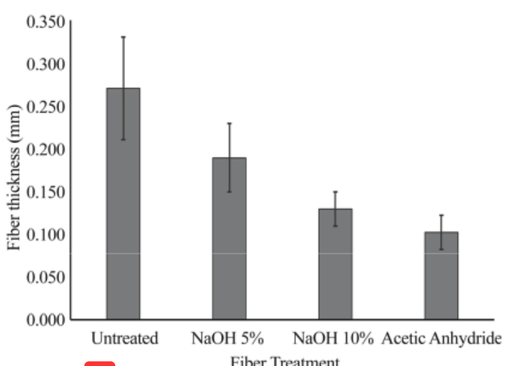

Fig. 4. The effect of fiber treatment on fiber thickness

Fibers treated with esterification had a higher reduction in thickness than those treated with alkali. Fiber treatment with acetate anhydride causes fibers to swell and causes structural changes, mass loss and reduced fiber thickness. Immersing in NaOH solution decreases fiber thickness due to the elimination of impurities.

5. 2. The effect of the fiber pre-treatment on the density and porosity of water hyacinth fiber reinforced epoxy resin composites

Fig. 5 shows the density and porosity of WH fiber reinforced epoxy resin composites. It can be observed that increasing the WH fiber content tended to increase the percentage porosity WH fiber reinforced epoxy resin composites. Adding fiber from 0 to 15 % substantially increased the composite's porosity.

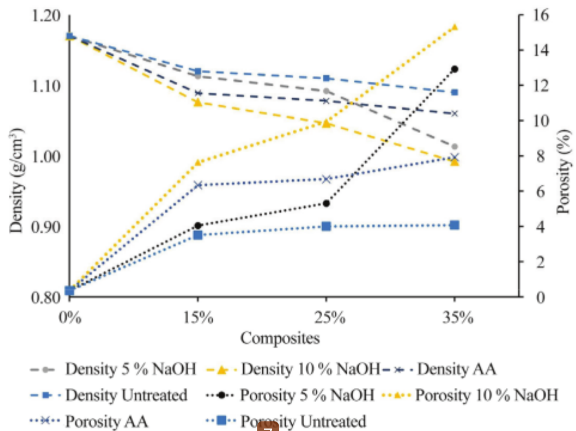

Fig. 5. Density and porosity of water hyacinth fiber / epoxy resin composites

The porosity of epoxy resin reinforced with alkali-treated of WH fiber composites have the same trend. The porosity of composites increases almost linearly. The untreated fiber and esterification fiber treatment, the rise of % wt. WH fiber from 15 % to 35 % did not increase the porosity significantly.

5. 3. Results the effect of the fiber pre-treatment on the tensile strength of water hyacinth fiber reinforced epoxy resin composites

Fig. 6 shows the tensile test results of the NaOH fiber treated and CH_3COOH fiber treated of WH fiber composites reinforced with epoxy resin. It can be observed that the tensile strength of untreated WH fiber reinforced epoxy resin composites increased from 45 MPa to 67 MPa at 25 wt. % and 35 wt. % respectively. Increasing WH fiber from 0 % wt. to 25 % wt. did not increase tensile strength significantly. The tensile strength results of the effect of acetate anhydride treatment of WH fiber reinforced epoxy resin composites showed that increasing WH fiber from 0 % wt. to 15 % wt. increased tensile strength of composites from 41 MPa to 59 MPa (44 %). Highest tensile strength of epoxy resin reinforced with WH fiber with acetate anhydride treatment achieved at composite with 25 % wt. is 61 MPa. Increasing WH fiber from 25 % wt. to 35 % wt. increased the tensile strength about 7 %. Similarly, the tensile strength values of 5 % NaOH treated WH fiber composites from 41 MPa to 55 MPa, 58 MPa at 15 % wt. and 25 % wt. respectively. The tensile strength reduced to 51 MPa (12 %) due to increasing WH fiber to 35 % wt. Differently, the characteristic of tensile strength values of 10 % NaOH treated WH fiber composites. Increasing % wt. WH fiber to 25 % wt. did not affect on the tensile strength of composites, the tensile strength decreased to 35 MPa by the rise of % wt. WH fiber to 35 % wt.

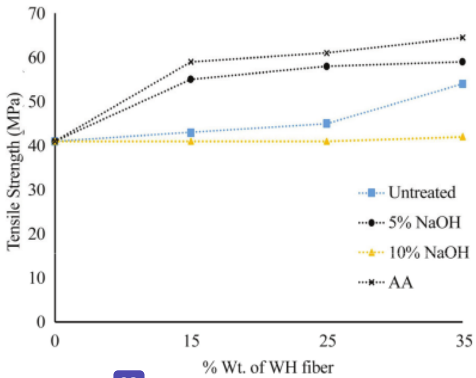

Fig. 6. Tensile strength of water hyacinth fiber/epoxy resin composites

It shows in Fig. 7 elongation of epoxy resin is 8.2 %, the elongation of untreated WH fiber composite with 15 % wt. fiber is 2.18 %, it's decreased about 73 %. The elongation of untreated fiber composite with 15 %, 25 % and 35 % WH fibers are 2.2 %, 2.6 % and 3.7 % respectively. The elongation composites with 15 % wt. of treated WH fiber decreased about 52–60 %. Alkalization treatment using 5 % NaOH, increasing % wt. WH fiber from 15–35 % wt. decreased elongation of composite. The elongation of epoxy resin reinforced with WH fiber treated using NaOH 10 % decrease about 52 % by adding 15 % wt. WH fiber. There are not significantly changing of elongation caused by increasing of WH fiber up to 35 % wt. The effect of acetate anhydride fiber treatment on elongation of composite as depict at Fig. 7 shows that elongation of epoxy resin reinforced 15 %, 25 % and 35 % of wt. fiber are 3.4 %, 3.5 % and 3.3 %. Chiefly noted was the uniform elongation behavior on acetate anhydride fiber treatment.

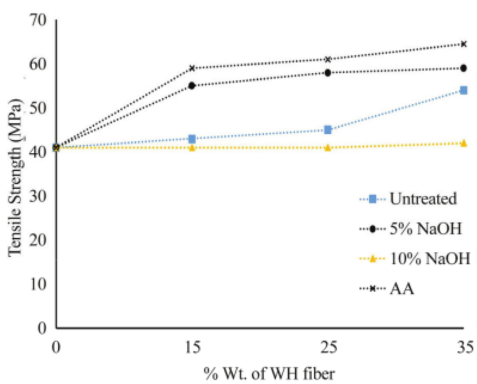

Fig. 7. Elongation of water hyacinth fiber/epoxy resin composites

Fig. 8 show the fracture surface of tensile tested composites. SEM images in Fig. 8 show that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Fig. 8, *a* depict the fracture surface of untreated WH fiber composite, it shows that the fracture of the specimen is mainly brittle failure of matrix and the WH fibers are debonded from the matrix and at some place fibers are also being pulled out the matrix. The fracture surface of alkali treated WH fiber composites are show in Fig. 8, *b*, *c*. Fiber fracture and fiber pull out. Fig. 8, *d* shows fracture surface of acetate anhydride WH fiber treated, the figure shows fiber fracture failure occurs in acetate anhydride fiber treated composite.

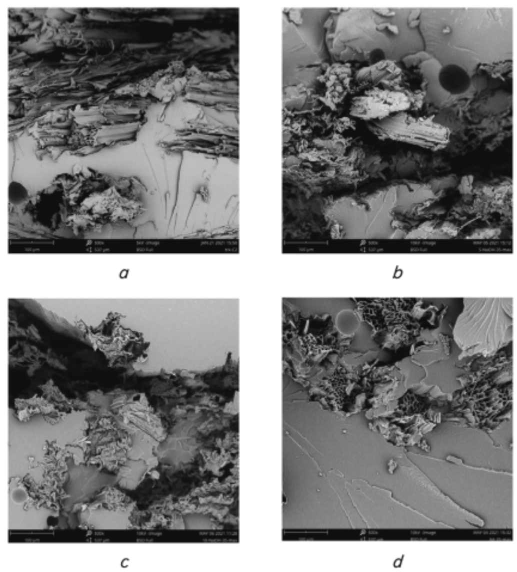

Fig. 8. Fracture surface of tensile tested water hyacinth composites: *a* – Fracture surface of untreated fiber composite; *b* – Fracture surface of 5 % NaOH fiber treated composite; *c* – Fracture surface 10 % NaOH fiber treated composite; *d* – Fracture surface of acetate anhydride fiber treated composite

6. Discussion of the effect of alkalization and esterification treatment on mechanical properties of water hyacinth fiber reinforced epoxy-resin composite

Fig. 3 depicts the morphology of WH fibers after treatment. Fig. 3, *a*–*d* shows the surface of untreated and treated WH fibers. Untreated WH fibers contain contaminants and wax. Fig. 3, *b*–*d* indicate that treated fibers are cleaner than untreated fibers (Fig. 3, *a*). The NaOH treatment altered the morphological structure of WH fibers. It was found that the fiber had become cleaner due to the removal of substantially all contaminants from the fiber surface. Fig. 4 shows the effect of fiber treatment on WH fiber thickness. Alkaline treatment results in surface modifications due to removing pectin, lignin, wax, hydroxyl groups, and other contaminants [18, 20, 36]. The reduction in fiber thickness results from eliminating contaminants or physical changes to the fiber. The esterification reaction with CH_3COOH generally degrades part of the fiber structure and this mass loss is due to the hydrolysis of cellulose (preferably the amorphous fraction) and hemicellulose that occurs during the reaction. This is because acetate anhydride is a solvent that causes fibers to swell, causing structural changes to occur more rapidly [24, 39].

Fig. 5 shows the effect of fiber treatment and percent mass fiber on the density and porosity of composites. Increasing % mass of WH fiber increase porosity of composite. Composites' porosity grows roughly linearly. The research shows that the rose percent weight of fiber increased from 15 % to 35 %, the porosity of composites reinforced with untreated fiber and composites reinforced with CH_3COOH fiber treated did not significantly increase. The primary source of porosity is air entrapment between the surface of WH fiber and epoxy resin [17, 23, 40]. SEM micrograph shows (Fig. 3, *a–c*) that fiber treatment caused that treatment process with alkali causes the surface of the water hyacinth fiber to become rougher, and it caused increasing air entrapment at the fiber surface.

Fig. 6 shows the tensile test results of the composite reinforced with WH fiber with NaOH treated and acetate anhydride. It can be observed that the tensile strength of untreated WH fiber reinforced epoxy resin composites increased with the increase of % WH fiber. The tensile strength results of the effect of acetate anhydride treatment of WH fiber reinforced epoxy resin composites showed the rise of % WH fiber increase the tensile strength of composites. The highest tensile strength of epoxy resin reinforced with WH fiber with acetate anhydride treatment achieved at composite with 25 % wt. is 61 MPa. The tensile strength values of 5 % NaOH treated WH fiber composites increase by increasing the % wt of WH fiber up to 25 %. The tensile strength reduced due to increasing WH fiber to 35 % wt. Differently, the characteristic of tensile strength values of 10 % NaOH treated WH fiber composites, increasing WH fiber to 25 % wt. did not affect the tensile strength of composites. The tensile strength decreased to the rise of WH fiber to 35 % wt. In this investigation, the tensile strength of WH fiber composites with fiber pre-treatment ranged between 41 and 67 MPa. Fiber pre-treatment increases the tensile strength of water hyacinth fiber and the adhesion between water hyacinth fibers and epoxy resin [22–24, 26–34]. This result exceeds the findings of Ajithram et al. [41], who created WH composites with a tensile strength between 18 MPa and 24 MPa. The tensile strength of matrix composite (WH) fibers composite with polyester matrix is 25.8 MPa [36]. Fig. 7 depicts the effect of acetate anhydride fiber treatment on composite elongation. Principally observed was the consistent elongation behavior of acetate anhydride-treated fibers. There was a decrease in elongation due to the addition of fiber. It is due to an increase in porosity due to the addition of fiber. The fracture of tensile tested composites specimens show in Fig. 8, *a–d*. Fig. 8, *a* shows the brittle fracture of the matrix material and the failure due to fiber debonding. Fig. 8, *b–c*. showed fracture surfaces in composites with WH fiber reinforcement treated with NaOH. The figure shows that the amount of debonded fiber is less than the untreated fiber. The treatment with acetate anhydric showed that the number of fibers debonded from the matrix decreased (Fig. 8, *d*). Treatment of water hyacinth fiber with NaOH and acetate anhydric reduced the contact angle between water hyacinth fiber and epoxy-resin, increasing the mechanical properties of composite. Fiber treatment can improve the tensile strength of composite materials. The limitation of this study is the different properties of water hyacinth fiber depending on the growth location. The use of WH fiber composite can be developed by developing a variety of fiber treatments. Focusing on green composites research using matrices that can be recycled, easily degraded, or using natural matrices.

7. Conclusions

1. The fiber treatment has been removing impurities from the fiber surface. The NaOH treatment removed the wax and cuticle in the surface was. Fiber treatment using 10 % NaOH resulted cleaner surface than treatment by 5 % NaOH. The effect of fiber treatment reduces the fiber thickness.

2. Increasing the WH fiber content tended to uniformly increase the percentage porosity in the alkali treated WH fiber reinforced epoxy resin composites. The untreated fiber and esterification fiber treatment, the rise of % wt. fiber from 15 % to 35 % did not increase the porosity significantly.

3. The tensile strength of untreated WH fiber reinforced epoxy resin composites increased from 45 MPa to 67 MPa at 25 wt. % and 35 wt. % respectively. Increasing WH fiber from 0 % wt. to 35 % wt. did not increase tensile strength significantly. The effect of acetate anhydride treatment of WH fiber reinforced epoxy resin composites showed that increasing WH fiber from 0 % wt. to 15 % wt. increases tensile strength of composites from 41 MPa to 59 MPa (44 %). The tensile strength of 5 % NaOH treated WH fiber composites increases from 41 MPa to 55 MPa, 58 MPa at 15 % wt. and 25 % wt. respectively. The tensile strength reduced to 51 MPa (12 %) due to increasing WH fiber to 35 % wt. The characteristic of tensile strength values of 10 % NaOH treated WH fiber composites. Increasing % wt. WH fiber to 25 % wt. did not affect on the tensile strength of composites, the tensile strength decreased to 35 MPa by the rise of % wt. WH fiber to 35 % wt.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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