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The Effect of Alkalization Duration on the Tensile Properties of Starch-Based Bioplastic Reinforced with Water Hyacinth Fiber

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Abstract. Nowadays, many researchers are studying bioplastic fabrication to address conventional plastic limitations. This study investigated the effect of water hyacinth fiber (WHF) alkalization duration on the tensile properties of produced bioplastics. The dried WHF was soaked in a 10% NaOH solution at 40°C for durations of 1, 2, 3, 4, and 5 hours. Following this, bioplastics were fabricated by mixing cassava starch (CS), WHF, and glycerol by using the melt intercalation method. FTIR characterization results revealed a strong-broad absorption band at 3288 cm^{-1} and a medium-sharp band at 1419 cm^{-1}. These findings confirm the hydrogen interaction between the hydroxyl groups on the fiber surface and the matrix. The tensile strength of the bioplastics increased with the duration of WHF delignification. Notably, bioplastics fabricated with WHF delignified for 5 hours exhibited the highest tensile strength, reaching 1.349 MPa. Therefore, the duration of WHF delignification directly impacts the tensile strength of the bioplastics.

Keywords : alkalization, delignification, starch-based bioplastic, tensile strength, water hyacinth

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Introduction

The issue of environmental pollution due to solid waste is escalating due to population growth [1], [2]. Conventional plastics, especially plastic bags, are a primary contributor. Despite being economical, lightweight, and readily available, these plastics pose a serious threat to ecosystems and the environment. Their non-degradable nature by microorganisms makes them the largest source of solid waste [2]–[4]. A report by the United Nations Center for Regional Development (UNCRD) indicates that Indonesia ranks second globally in plastic waste mismanagement, with 88% of its plastic waste ending up in water bodies [5].

Nowadays, many researchers are studying bioplastic fabrication to address conventional plastic limitations. While starch-based bioplastics are widely fabricated and considered environmentally friendly [6], [7], they suffer from low tensile properties and high water adsorption. To overcome these limitations, some researchers have added fillers to the starch matrix.

According to Sydow & Bieńczak [8], fiber fillers improve composite mechanical properties by transferring stresses from the starch polymer matrix. Many researchers have fabricated starch-based bioplastics using fillers like corn husk, grapefruit seed, palm, and sisal leaf fibers, all of which contain lignocellulosic components [9]–[13].

Water hyacinth (WH) is an abundant aquatic plant in Indonesia. It thrives in open water areas like swamps, rivers, and lakes, often considered a weed due to its rapid growth that disrupts water transportation. Despite the issues it causes, water hyacinth has been widely utilized as fertilizer [14], [15], for handicrafts [16], [17], bioethanol production [18], [19], and as an adsorbent for organic and inorganic pollutants [20], [21]. Similar to other plants rich in cellulose as their main fiber component, water hyacinth shows promise as a filler in starch-based bioplastics due to its high fiber content of around 61% [22]–[24].

Starch-based bioplastics reinforced with natural fibers often exhibit lower tensile and flexural strength compared to those with synthetic fibers. This is primarily because insoluble components in natural fibers, such as lignin and pectin, surround the cellulose and lead to weak adhesion between the matrix and the fiber surface. Specifically, lignin blocks the hydroxyl groups on the fiber, preventing them from effectively binding with the matrix. To address this, the delignification process using an alkaline solution can remove these unnecessary components. Soaking the fiber in an alkaline solution reduces lignin content, increasing the availability of hydroxyl (OH) groups. This enhanced availability leads to a stronger adhesion force between the fiber and the matrix, consequently improving the tensile strength of the resulting bioplastic [25], [26]. Therefore, this article will investigate the effect of alkaline solution treatment duration during the water hyacinth fiber (WHF) delignification process and its implications for the tensile strength of the resulting bioplastics.

Experimental

Materials. Water hyacinth (WH) was collected from the Kedukan River, Banyuasin Regency, Indonesia. Water hyacinth fiber (WHF) was prepared by separating the stems from the leaves and roots. The stems were then washed, cut into small pieces, crushed, and sun-dried. Cassava starch (CS), commercially available under the Cap Pak Tani brand, was used as the bioplastic matrix. Other chemical reagents included sodium hydroxide (p.a, Merck Millipore), acetic acid (p.a, Merck Millipore), and glycerol (food grade, Harmoni Indah). Distilled water was sourced from the Integrated Laboratory of Universitas Islam Negeri Raden Fatah Palembang.

Preparation of WHF. The dried WHF was soaked in a 10% NaOH solution at 40°C for durations of 1, 2, 3, 4, and 5 hours. Following treatment, the fibers were neutralized with acetic acid and thoroughly washed with water. The treated fibers were then sun-dried and designated as alkaline-treated water hyacinth fiber [26].

Fabrication of bioplastic. For the fabrication of bioplastics, a CS and WHF composition ratio of 60:40 was used. Initially, CS was dissolved in distilled water (500 grams: 3000 cc) and brought to a boil. Subsequently, 2 mL of glycerol and WHF were gradually incorporated into the mixture with continuous stirring. Once a homogeneous composite was formed, it was molded molded into 0.5 mm thick sheets on a glass plate and sun-dried [26].

FTIR characterization. To determined the functional groups of untreated fiber (UT-WHF), alkali-treated fiber (AT-WHF) were subsequently characterized by Fourier Transform Infrared using Bruker,

Alpha Series. Sampels were scanned in the wavenumber range 4000-475 cm^{-1}.

Tensile property testing. For tensile property testing, all samples were initially cut to a size of 12 cm x 2 cm. The tensile properties of all bioplastics were then evaluated using a Hung Ta Instrument (HT-8172) with a crosshead speed of 55 mm/min and a test temperature of 25°C. Each sample was tested in duplicate [26].

Morphology photography. For morphology testing, all samples were initially cut to a size 1 cm x 1 cm. Morphology photography of bioplastics was performed by using digital microscope Hirox RH-2000.

Result and Discussion

FTIR spectra. The FTIR spectra of the dried WHF are presented in Figure 1. Delignification was aimed to eliminate lignin components that reduce the adhesion between the CS matrix and WHF.

Figure 1 shows that both the UT-WHF and AT-WHF FTIR spectra exhibit characteristic absorption bands at 3333-3327 cm^{-1} (O-H stretching), 2916-2918 cm^{-1} (C-H stretching), 1602-1606 cm^{-1} (C=C aromatic stretching), 1020-1029 cm^{-1} (C-O stretching). However, the absence of a C=O ester stretching band at 1726 cm^{-1} in the AT-WHF FTIR spectra signifies the successful delignification process. This finding is consistent with Syamsuri et al. [26], who also reported that the disappearance of C=O ester stretching absorption near the aromatic ring indicates the occurrence of delignification in lignocellulose.

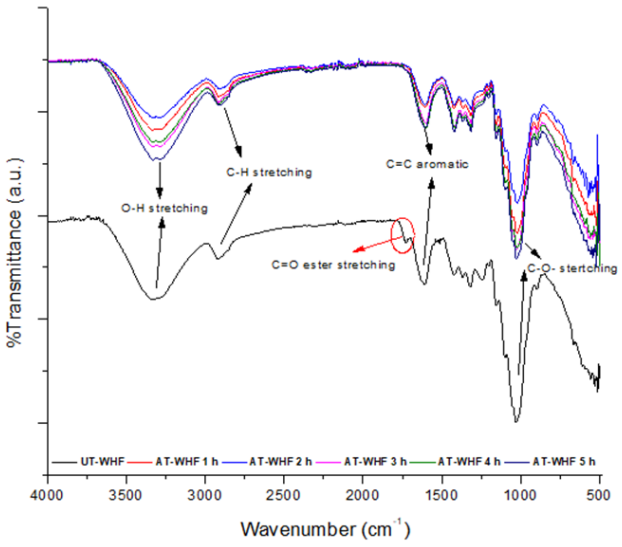

Figure 1. FTIR spectra of UT-WHF and AT-WHF

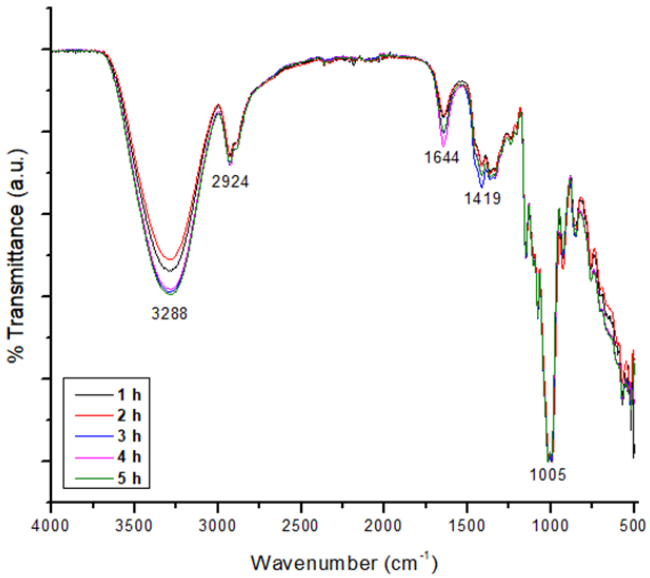

Figure 2. FTIR spectra of bioplastic

The FTIR spectra of starch-based bioplastic reinforced with WHF are presented in Figure 2. This figure reveals a strong-broad absorption band at 3288 cm^{-1} (O-H stretching) and a medium-sharp band at 1419 cm^{-1} (O-H bending). These findings confirm the hydrogen interaction between the hydroxyl groups on the WHF surface and the matrix. [27], [28].

Tensile property. The tensile strength test results of starch-based bioplastic reinforced with WHF are presented in Figure 3. This figure shows that the duration of WHF alkalization directly impacts the tensile strength of the bioplastics. A longer the delignification time leads to greater lignin removal. This increased lignin removal, in turn, results in higher tensile strength, suggesting a stronger adhesion force between the CS matrix and the WHF surface via hydrogen bonding.

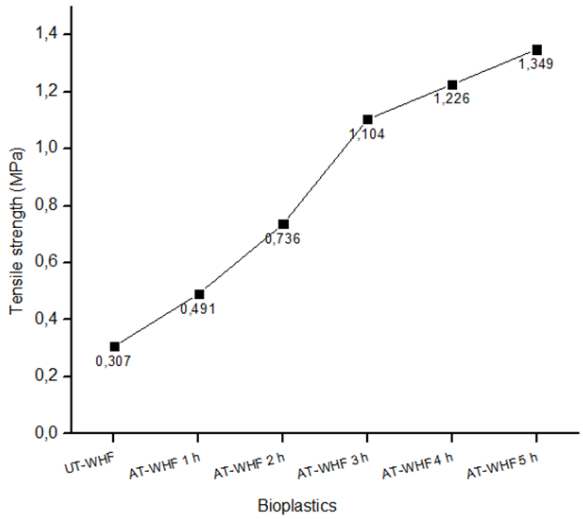

Figure 3. Tensile strength property of bioplastics

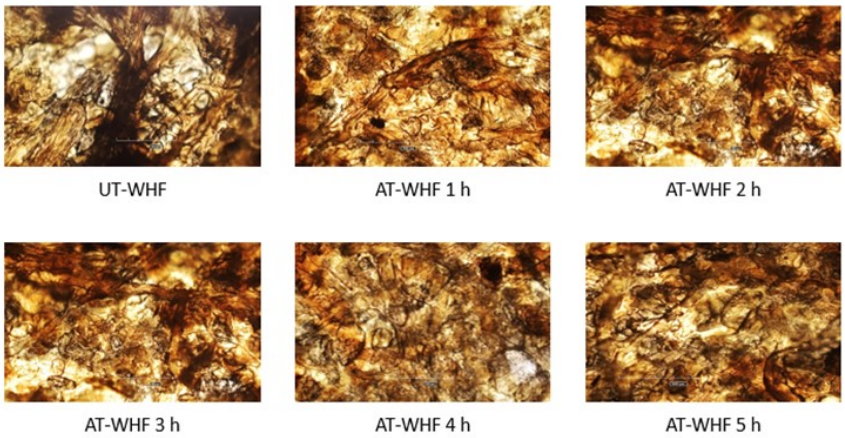

Figure 4. Morphology photography of bioplastics

Notably, AT-WHF bioplastic exhibited higher tensile strength compared to UT-WHF bioplastic. This finding supports the argument by Asrofi et al. [27] that insoluble components in natural fibers such as lignin, pectin, and others encircle cellulose can weaken the adhesion between the matrix and the fiber surface. Weak adhesion caused by lignin, effectively blocks the hydroxyl groups on the fiber from binding with the matrix.

Morphology photography. Figure 4 displays the bioplastics morphology under a Hirox digital microscope with 500x magnification. The UT-WHF bioplastic surface exhibits agglomeration and cavities. This is direct result of the weak interaction of hydroxyl groups on the fiber and the matrix, which consequently led to the low tensile strength. On the other hand, the AT-WHF bioplastics surface show a more evenly dispersed mixture of fiber and matrix, with significantly less agglomeration. This improved dispersion and reduce agglomeration are directly linked to the increased the tensile strength.

Conclusion

The tensile strength of the bioplastics increased with the duration of WHF alkalization. Notably, bioplastics fabricated with WHF delignified for 5 hours exhibited the highest tensile strength, reaching 1.349 MPa. Therefore, the duration of WHF delignification directly impacts the tensile strength of the bioplastics.

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Author Contributions

Tri Astika: Writing – original draft, visualization, investigation, data curation. M. Mahfudz Fauzi Syamsuri: Writing – review, data curation, editing. Dedi Wahyu Ari Setiawan: Writing – original draft, visualization, investigation, data curation. Rusmaniar: Writing – original draft, visualization, investigation, data curation. Hasan Marzuki: Writing – validation, methodology, formal analysis, conceptualization. Deni Agustriawan: Data analysis. Ria Nurwidiyani: Data analysis. Hapin Afriyani: Supervision, Resources.

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