Corn husk Fibers Reinforced Polyester Composites: Tensile Strength Properties, Water Absorption Behavior, and Morphology

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Abstract. The effects of fiber content and immersion time in the water on the tensile, morphology and water absorption properties of composites made from corn husk fiber/polyester have been studied. Composite made with a variety of different fiber contents namely: 20%, 25%, 30%, 40%, 50% and 60% respectively. All composite specimens were immersed in water for 24 h and 72 h. The effects of fiber content and time of immersion of composites in water have been determined by examining the nature of tensile strength, water absorption behavior, morphology. The results demonstrated that after soaked in water for 24 h and 72 h, the water absorption properties of the composites increased with increasing fiber content. The tensile strength and modulus of elasticity of composites tend to increase from 20% to 30% fiber content after immersed for 24 h, and then decrease with increasing fiber and soaking time because the interface between fiber and polyester becomes weak. These results suggest that corn husk fiber composites could have the potential to use as decking, siding, and exterior windows.

1. Introduction

Composites made from natural fibers and thermoset resins are increasingly developing in the polymer industry, specifically as a substitute for wood for outdoor products under wet environments. The advantages of hydrophobic resins have been to protect natural fibers and increase the durability of the final product; therefore they are successfully used in structures such as decking, docks, and exterior windows, etc [1] that are directly in contact with water.

Although natural fiber composites are widely used in many industries, long–term performance and durability are still not comprehensively understood. The fibers and adhesives are inevitable from changes and hostile environmental conditions. Water diffusion in composites and polymer adhesives is considered as one of the main reliability problems for the performance of composites.

Composites made from corn fiber are increasingly interesting to study and their properties still need to be developed. Some researchers have reported the best properties of corn husk fiber composites (CHF) with a polymer matrix. CHF composites with polyester matrices have a sound absorption coefficient of 0.8–0.9 at a frequency of 2 kHz. They also reported the tensile and Young’s moduli of CHF composites around 18.81 MPa–25.73 MPa [2]. The ability to absorb sound from CHF-polypropylene composites is superior to jute–polypropylene [3]. Cornhusk fiber plastic composites had the highest flexural and tensile strengths of 46.10 MPa and 26.58 MPa respectively [4]. 5% CHF
composites showed deformability than 0%–8% CHF with low methoxy pectin (LMP) films [5]. From this previous study, it was agreed that other properties associated with corn husk fiber composites are still very limited.

As materials to be applied to a structure under a wet environment, the absorbed moisture will cause changes in the polymer microstructure, and degradation in their mechanical, thermo-physical, and chemical characteristics [6–8, 2]. The effect of moisture or water exposition on mechanical, morphology, and water absorption of composites is very important to be studied and to explain the performance of composites in wet environments.

Therefore, this study aims to explore the properties of corn husk fiber composites in water immersion. The effects of the CHF content on water absorption behaviour, tensile strength properties, and morphology were investigated.

2. Materials and Methods

2.1. Materials.
Cornhusk has been obtained from the Pagesangan market, Mataram, Indonesia (see in Fig 1a). Corn husk selected on the outside; to maintain uniformity. The average length and width of corn husk is 13.5 cm–15.2 cm. The polyester resin (PE) has a density of 1.2 g/cm³, the tensile strength and a tensile modulus of 8.8 kg/mm² and 500 kg/mm², respectively, and elongation of 2.3%.

2.2. Extraction of fibers
They are immersed in fresh water for 10 days to undergo decay (Fig. 1b). The fibers were taken using a wooden comb with teeth diameter of 0.02 mm; to maintain fiber uniformity, and dried under the sun’s heat (Fig. 1c).

![Figure 1](image_url)

**Figure 1.** Material preparation, a. Corn husk, b. Extraction of CHFs, and c. CHF raw.

2.3. Alkaly treatment of fibers
The prepared CHFs were immersed in NaOH 8% for 2 h (Fig. 2a). They are washed and rinsed with fresh water and repeated three times, and then followed by drying under the sun (Fig. 2b), then dry CHFs (Fig. 2c) are stored in a plastic storage box.
2.4. Preparation of composites

CHF with a fiber length of 4 cm was prepared. A mixture of polyester and catalyst is poured into a mold that filled CHFs with different volume fraction (see in Table 1). Then the mold is closed and pressed at 5MPa for 4 min (temperature 175°C), followed by cooling at ambient temperature. The composite is removed from the mold and ready for testing.

| Code of specimens | Corn husk fibers (% vol) | Polyester (% vol) |
|-------------------|--------------------------|-------------------|
| NC20              | 20                       | 80                |
| NC25              | 25                       | 75                |
| NC30              | 30                       | 70                |
| NC40              | 40                       | 60                |
| NC50              | 50                       | 50                |
| NC60              | 60                       | 40                |

All of the test specimens are given the carrying out by soaking them in water for 24 h and 72 h. They are lifted and wiped using blotting paper. In total there were 54 test specimens with repetition 3 times for each test parameter tests.

2.5. Characterization

2.5.1. Water absorption and Swelling tests. Water absorption tests have been measured according to the international standard ASTMD570 [9]. The water absorption (WA) was calculated using expression 1 [10]:

\[
WA,\% = \left( \frac{N_1 - N_2}{N_1} \right) \times 100
\]  

Where, \(N_1\) and \(N_2\) show the dry weight (g), and the weight after time \(t\) (g).

Measurement of the percentage swellability evaluated using equation 2 [8]:

\[
Swellability,\% = \left( \frac{x - y}{y} \right) \times 100
\]

Where, \(x\) and \(y\) are composite volumes after and before immersion.

2.5.2. Tensile strength test. The specimen prepared was according to ASTMD3039 standard [11] used a Tensilon RTG–1310 that operated at a speed and load cell of of 5 mm/min and 5 kN respectively.
2.5.3. Flexural test. The CHF composites were conducted by the three-point bending method on a UTM and follow ASTMD790 standards [12]

2.5.4. Scanning electronic microscopy, SEM. In this test, the fracture surfaces of the specimen were characterized by SEM Inspect–S50type at 18mA and 10 kV.

3. Results and Discussion

3.1. Water absorption and swelling analysis

The water absorption capacity of composite as display in Fig. 3. The nature of water uptake increases with an increasing amount of fiber content and immersion time of the composite. During 24 h – 72 h period, the polyester resin demonstrated negligible water uptake and the CHF induced significant water uptake. Maximum water uptake is obtained from polyester composites with a volume fraction of 60% CHF (NC60) of 5.62% at 72 h immersion.

![Figure 3. Water absorption of corn husk fiber/polyester composites.](image)

A possible reason for this behavior might be because CHF shows tendency to absorb water higher than polyester (hydrophobic). The presence of lumens, defects, fissures at the interface, hydrogen bonds in fibers, and micro crevices in the matrix can cause the composite to absorb water [13,14]. Hence, the water uptake increases with more CHFs content.

Conversely, composites with low CHF content have better interface adhesion which reduces the interface width between fibers and reduces water uptake through this part to the interior of the composite [15]. It was noted that fiber adhesion/strong interface can help reduce water hygroscopicity, reduce penetration, hence avoiding deterioration in the mechanical performance of composites [16–18]. This also answers the reason why the ability to absorb water from NC20 is lower than other samples. This result has been confirmed by mechanical test results.

Typical swelling data for all composites displayed in Fig. 4, which shows that CHF/polyester swelling increases with increased water absorption, and thus the rate of swelling changes increases with immersion time. The effect of CHF on the polyester ratio on swelling thickness can also be explained by the difference in water uptake between CHF- polyester (see discussion on composite water absorption). Thickness swelling is affected by water uptake and change due to the same mechanism as water uptake.
3.2. Tensile strength analysis

From **Fig. 5a** shows that the strength of composites with a 20 – 30% fo fiber content (NC20, NC25, and NC30) at the 24 h immersion stage tends to increase due to the strong bonding interface between polyester and CHF, and after being soaked in water for 72 h, the strength of the composite tends to decrease with the increasing number of CHFs. This is indicated that the amount of water absorbed in the composite has caused the interface bond between CHF and resin to be quite weak; as a result, the tensile and modulus of elasticity (MOE) of the composite tend to decrease with longer immersion time. A sharp decrease in tensile strength and Young’s modulus values was also seen in composites with 40 – 60% fiber content (see NC40, NC50, and NC60 specimens). This drastic decrease is indicated that when CHFs content was increased, the matrix is no longer evenly distributed and many CHFs overlap one another, resulting in bad bond at the interface, causing the composite strength to be small. The same tendency behaviour is also found in the modulus of elasticity of the composite (**Fig. 5b**). The Young’s moduli demonstrated a gradual increase, its value increased up to 30% CHF content then decreased; it is attributed to the flow of polyester which increased the bond strength and the composite strength.

Furthermore, the NC20, NC25, and NC30 composites have increasing strain values (seen in **Fig. 5c**), this means that there is an opposite response to the large tensile load received, which is indicated by the effect of internal shifts at the atomic level in the composite material so that the composite increases in length thus the strain produced to be high. Conversely, the low strain value is due to the opposite response given by the composite to the small tensile load received.
Figure 5. a. Strength, b. Young’s moduli, and elongation of tensile of corn husk fiber/polyester composite

3.3. Flexural strength analysis

Fig. 6 shows the flexural strength of the composite which tends to be the same as the tensile strength. From Fig. 6 it is known that the average flexural strength value of the composite after immersed in water for 24 h varies from 36.495 MPa to 35.650 MPa, and after immersed for 72 h the flexural strength varies from 30.301 MPa to 32.370 MPa. The flexural strength trend is seen to increase with increasing CHF content from 20% to 25%, and subsequently decreasing. Maximum flexural strength is obtained in the composite after soaking 24 h with 25% fiber content and 75% PE resin of 42.739 MPa. The detected increase in term of tensile and bending behaviour was related to interfacial bonding between the CHF-polyester, and the modification of single corn husk fibers. After 72 h of soaking, the flexural strength of the composite is known to decrease. For example, NC25 with a 25% fiber content have a higher flexural strength value (42.194 MPa) when compared to NC50 specimen which have a flexural strength of only around 36.192 MPa. This decrease was maybe due to the higher level of brittleness of the incorporation of CHF into the PE.
3.4. SEM

Morphology of the fractured surface of specimen composite in tensile is shown in Figs. 7 and 8. After immersed for 24 h (seen in Figs. 7a, 7b, and 7c), it was observed that the composite display the interfacial bonding between the CHFs – PE was high and strong. Localized bunch of CHFs is shown, which indicates the good dispersion of CHFs within the polyester, and the fracture occurred at the CHFs itself. This shows that the stress was well propagated between CHFs–polyester, resulting in enhanced flexural and tensile strength in response to stress. The composite with higher fibers content (seen in Figs. 7d–f) appears to be dominated by fibers breakage. The interfacial fracture accompanied by cross-section damage of the CHFs, resulting in decreased tensile strength.

Figs. 8a, 8b, and 8c shows a crack running through the CHF, and this an indication of the lack of stress–transfer from polyester to CHFs. Figs. 8d, 8e, and 8f, it was found that composite had a damage area interface between CHF and PE is loose. The interfacial fracture is demonstrated by CHF cross-section damage, resulting in decreased tensile, and flexural strength.
Figure 7. SEM photos, (a) NC20, (b) NC25, c. NC 30, d. NC40, e. NC50, and f. NC60 after water immersed for 24 h.
Figure 8. SEM images, (a) NC20, (b). NC 25, c. NC 30, d. NC40, e. NC50, and f. NC60 after water immersed for 72 h.

4. Conclusion
An experimental investigation of the behavior of tensile strength, morphology and water absorption from CHF–based composites under the water environment was carried out. The water uptake and swelling properties of the composites increase with an increasing amount of fiber content and soaking time. Consequently, the tensile and bending strength of the composite to decreased. The maximum tensile strength, and young’s moduly are obtained from composites with 30% fiber content (NC30) after 24 h water immersed, and then decreases. SEM images display the interfacial fracture accompanied by cross–section damage of the CHFs. Composites based CHF are suitable as an alternative material for decking, siding, exterior windows, and doors.
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References
[1] Jiang X, Kolstein H, and Bijlaard F S K 2013 Moisture diffusion in glass–fiber–reinforced polymer composite bridge under hot/wet environment. Composites: Part B 45 407–416. http://dx.doi.org/10.1016/j.compositesb.2012.04.067
[2] Sari N H, Wardana I N G, Irawan Y S, and Siswanto E 2017 Corn Husk Fiber–Polyester Composites as Sound Absorber: Nonacoustical and Acoustical Properties. Advances in Acoustics and Vibration 2017. https://doi.org/10.1155/2017/4319389.
[3] Huda S, and Yang Y 2008 A novel approach of manufacturing light–weight composites with polypropylene web and mechanically split Cornhusk. Industrial Crops and Products 30 17–23. doi:10.1016/j.indcrop.2008.12.007.
[4] Luo Z, Li P, Cai D, Chen Q, Qin P, Tan T, and Cao H 2016 Comparison of performances of corn fiber plastic composites made from different parts of corn stalk. Industrial Crops and Products 95 521–527. http://dx.doi.org/10.1016/j.indcrop.2016.11.005.
[5] Bernhardt D C, Perez C D, Fissore E N, De’Nobili M D, and Rojas A M 2017 Pectin–based composite film: Effect of corn husk fiber concentration on their properties. Carbohydrate Polymers 164 13–22. http://dx.doi.org/10.1016/j.carbpol.2017.01.031.
[6] Levy R L, Fanter D L, and Summers C J 1979 Spectroscopic evidence for mechanochemical effects of moisture in epoxy–resins. Journal Application Polymer Science 24(7)1643–64.
[7] Mikols W J, Seferis J C, Apicella A, and Nicolaïs L 1982 Evaluation of structural–changes in epoxy systems by moisture sorption–desorption and dynamic mechanical studies. Polymer Composite 3(3) 118–24.
[8] Youssef A M, Gendy A E, and Kamel S 2014 Evaluation of corn husk fibers reinforced recycled low density polyethylene composites. Materials Chemistry and Physics 1–8.
[9] ASTM D570–98 2002 Standard test method for water absorption of plastics: Annual book of ASTM Standards. West Conshohocken PA.
[10] Saenghirunwatana P, Noomhorma A, and Rungsardthong V 2014 Mechanical properties of soy protein based “green” composites reinforced with surface modified cornhusk fiber. Industrial Crops and Products, 60 144–150.
[11] Sari N H, Sanjay M R, Arpitha G R, Pruncu C I, and Siengchin S 2019 Synthesis and properties of pandanwangi fiber reinforced polyethylene composites: Evaluation of dicumyl peroxide (DCP) effect. Composites Communications 15 53–57.
[12] ASTM D790 2010 Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. ASTM Standards International.
[13] Stokke D D, and Gardner D J 2003 Fundamental aspects of wood as a component of thermoplastic composites. Journal of Vinyl & Additive Technology 9(2) 96–104.
[14] Sari N H, Wardana I N G, Irawan Y S, and Siswanto E 2018 Characterization of the Chemical, Physical, and Mechanical Properties of NaOH–treated Natural Cellulosic Fibers from Corn Husks. Journal of Natural Fibers 15(4) 545–558. doi: 10.1080/15440478.2017.1349707.
[15] Toro P, Quijada R, Murillo O, and Yazdani–Pedram M 2005 Study of the morphology and mechanical properties of polypropylene composites with silica or rice–husk. Polymer International 54 730–734.
[16] Dobreva T, Benavente R, Perea J M, Perez E, Avella M, Garcia M, and Bogoeva–Gaceva G 2009 Effect of different thermal treatments on the mechanical performance of Poly (l–lactic acid) based eco–composites. Journal of Applied Polymer 116 1088–1098 https://doi.org/10.1002/app.31584
[17] Machado J S, Santos S, Pinho F F S, Luís F, Alves A, Simões R, and Rodrigues J C 2016 Impact of high moisture conditions on the serviceability performance of wood plastic composite decks. Materials & Design 103 122–131.

[18] Kuciel S, Jakubowska P, and Kuzniar P 2014 A study on the mechanical properties and the influence of water uptake and temperature on biocomposites based on polyethylene from renewable sources. Composites: Part B 64 72–77.