FABRICATION OF BIO-COMPOSITES MATERIAL FROM WATER HYACINTH (*EICHHORNIA CRASSIPES*) AND POLYESTER RESIN

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ABSTRACT

Natural fiber-reinforced polymer-based composites are proposed as attractive candidates to replace or reduce the use of synthetic fibers because of their many advantages. Water hyacinth fiber (WHF) is a cellulosic material with high absorption and great potential for composite materials used. The WHF is derived from water hyacinth (*Eichhornia crassipes*), a free-floating plant widely distributed in Southeast Asia and Vietnam. With a fast growth rate, it can withstand many different environmental conditions. It has become an environmental problem as a result of the rapid depletion of minerals and oxygen from water. However, the porous interior structure of the fiber results in a low density, and it has a good prospect of enhancing the characteristics of composite materials. In this work, we have developed a composite material by combining unsaturated polyester (UPE) with WHF. Thermal, tensile, flexural, and morphological properties of the WHF/UPE composite samples are determined. Additionally, SEM observation confirms good adhesion between the WHF and UPE matrix with a WHF/UPE percentage ratio of 38:62 (wt%). Furthermore, the mechanical properties of the research sample compared to those of reference material (medium density fiberboard-polyester (MDF-PE), medium density fiberboard-polypropylene (MDF-PP)) showed outstanding results, highlighting the roles of WHF. Therefore, this study suggests the potential of WHF in place of synthetic fibers in the production of composite materials.

1. INTRODUCTION

The water hyacinth *Eichhornia crassipes* is a species of aquatic herbaceous floating in the water, belonging to the genus Eichhornia of the family Pontederiaceae (Gichuki et al., 2012). The water hyacinth plant is about 30 cm tall with round, green, glossy, and smooth leaves. The leaves roll together like flower petals. The leaf stalks swell like spongy bubbles, helping them to float on the water. The water hyacinth roots look like black feathers hanging in the water, up to 1 meter long. Water hyacinth fibers originate from nature, so water hyacinth fibers also have the same chemical composition and physical properties as natural fibers. In particular, water hyacinth contains a large amount of 60% cellulose, 8% hemicellulose, and 17% lignin (Asrofi, Abral, Kasim, & Pratoto, 2017), (Motaleb, Abakevičienė, & Milašius, 2023). Therefore, water hyacinth has excellent potential to reinforcing composite materials.

As per the findings of (Kalia, Kaith, & Kaur, 2009), the application of NaOH solution to water hyacinth fiber (WHF) will increase the surface roughness of the water hyacinth fiber compared to untreated fiber. Furthermore, this treatment is expected to result in the fracturing of some WHF, leading to the formation of more porous fibers due to the elimination of lignin and other components. According to (Punyamurthy, Sampathkumar, Srinivasa, & Bennehalli, 2012), increasing the roughness on the surface of the water hyacinth fiber leads to increased bonding between the resin and the water hyacinth fiber in the composite. (Thang & Huyen, 2020) assert that the mechanical characteristics, such as flexural and compressive strength, of the composite specimens reinforced with water hyacinth fibers exhibited a significant enhancement following treatment of the fibers derived from water hyacinth.

Therefore, this experimental work aims to manufacture composite materials based on WHF and unsaturated polyester (UPE). Samples were analyzed using a scanning electron microscope (SEM) to investigate the fiber surface. The physical and mechanical properties of the material, for example, flexural strength, compressive strength, and tensile strength were studied for all synthesized samples before and after treatment.

2. MATERIALS AND METHODS

2.1. Materials

The WHF stems were collected from water hyacinth trees growing on a branch of the Saigon River, then they were prewashed with tap water to remove dirt on the stem; we took the obtained stem and pressed it thinly, then dry in the sun for about a week, and then cut the water hyacinth stem short to an average length of about 10mm. We dry it in a dryer at 105°C within 24 hours.

UPE 8022 originates from Malaysia, with a 30-35% styrene content, a 0.5% cobalt octoate accelerator and a viscosity of 450-600 cPs. The curing agent Methyl Ethyl Ketone Peroxide (MEKP) produced in Taiwan, China, and initiates the curing reaction of UPE plastic. Wax 8, originating from the United States, is an anti-stick agent of the wax family that is used in the mold release process in the production of composite materials.

2.2. Methods

2.2.1. Water Hyacinth Fiber Treatment

The dried WHFs were soaked in a NaOH solution at 1% (w/v), for 2 hours and the corresponding investigation temperature was 80°C. Then, the fibers soaked of concentration ofNaOH 1% for 24 hours at room temperature based on literature (Flores Ramirez et al., 2015). After 24 hours, the fibers removed and washed with clean water to remove all NaOH adhering to the fiber surface and then rinsed with distilled water at pH 7. The fibers dried at 105□C for within 24 hours. We obtain preprocessed fiber. The purpose is to remove the ligin content to reduce the fiber's ability to absorb water and make the fiber surface rougher, so it bonds better with the base resin.

2.2.2. Composite fabrication

The modeling mold is a three-piece mold with the surface cleaned and applied with an anti-stick agent. After using the anti-stick agent, we leave it for about 15 minutes for the anti-stick agent to dry because when the anti-stick agent is still wet, it will react with the resin we add into the mold. Water hyacinth fibers are mixed evenly with resin according to the survey ratio and with a MEKP content of about 1% compared to the amount of resin. After mixing well, the fibers were placed in the mold, spread the fibers evenly, and then placed in the press; we press the sample, paying attention to releasing air to reduce foaming in the sample. After 30 minutes, we remove the sample. The composite sample has dimensions (200 x 200 x 5.4 mm), density 1.2 g/cm^3, mass m = 259.2g (Figure 1).

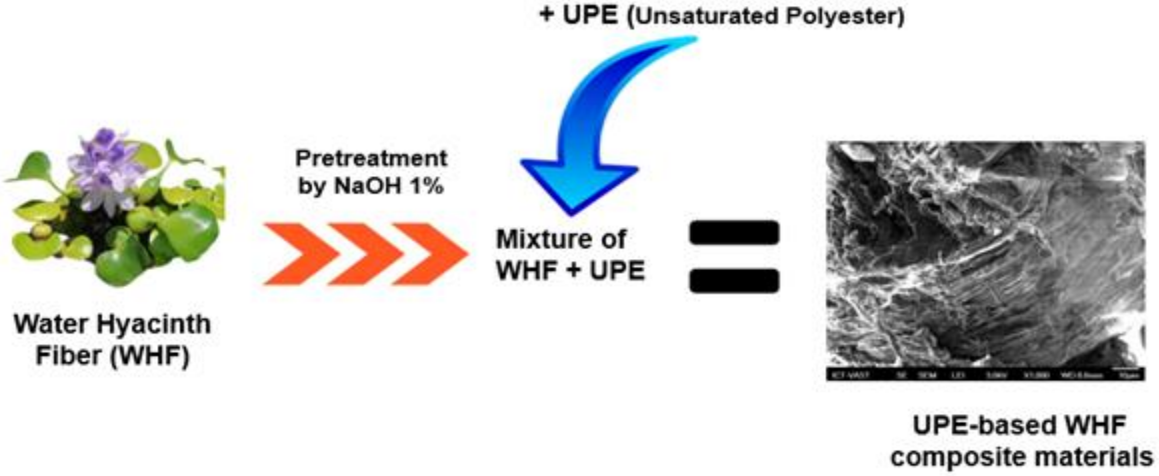

Figure 1. Schematic synthesis procedure of UPE-based WHF composite materials

2.2.3. Characterization of Composites

The flexural strength of the material is determined according to the ASTM D790 standard with a bending speed of 3mm/min (D790 ASTM, 2014). Tensile strength is determined according to the ASTM D638 standard with a tensile speed of 2 mm/min (D638 ASTM, 2014). The compressive strength is determined according to the ASTM D695 standard with a compression speed of 1.3 mm/min (D695 ASTM, 2014). Three samples representing three measurements were used for each experiment and the average value was taken as the result. Temperature measured at room temperature (□30□C), sample humidity 50%. All properties were measured on an LLOYD LR 30K mechanical measuring machine, Polymer Materials Center, University of Technology, Vietnam National University Ho Chi Minh City High Technology Center. The morphological structure of the material was captured on a scanning electron microscope (SEM), on a Hitachi FESEM S-4800 device at the Ho Chi Minh City High Technology Center.

3. RESULTS AND DISCUSSION

3.1. Characteristics of materials before and after alkaline treatment

The process of treating water hyacinth fibers with 1% NaOH is carried out in a small stirring tank and heated to 80□C for 2 hours, then we soak the fibers for another 24 hours. During the process of washing the fibers to remove the remaining NaOH, we see that the fibers are separated into smaller and clearer fibers. Fibers turn brown when they dry in the sun and then in the dryer. After drying, we see that the fibers are stiffer and smaller and stick together. This is explained by the fact that NaOH dissolved part of the lignin and nonorganic parts, causing the cellulose content in the fiber to increase and making the fiber surface cleaner to remove impurities. The experimental results are consistent with previous research (Thang & Huyen, 2020). The SEM results in Figure 2 show that the fiber surface treated with NaOH is much cleaner than the untreated fiber surface, removing impurities and making the fiber surface more uniform, helping to improve the mechanical properties of the composite products based on resin and fiber. Additionally, fiber samples were also subjected to XRD imaging. The XRD image (Figure 3a) shows that the untreated fiber has peaks at 22°, 28□ và 40□ related to its crystalline structure (Setyaningsih et al., 2019), (Chaiwarit, Chanabodeechalermrung, Kantrong, Chittasupho, & Jantrawut, 2022). Meanwhile, alkaline-treated fibers (Figure 3b) no longer appear at these peaks (28□ và 40□). This shows that the impurities have been separated from the fiber.

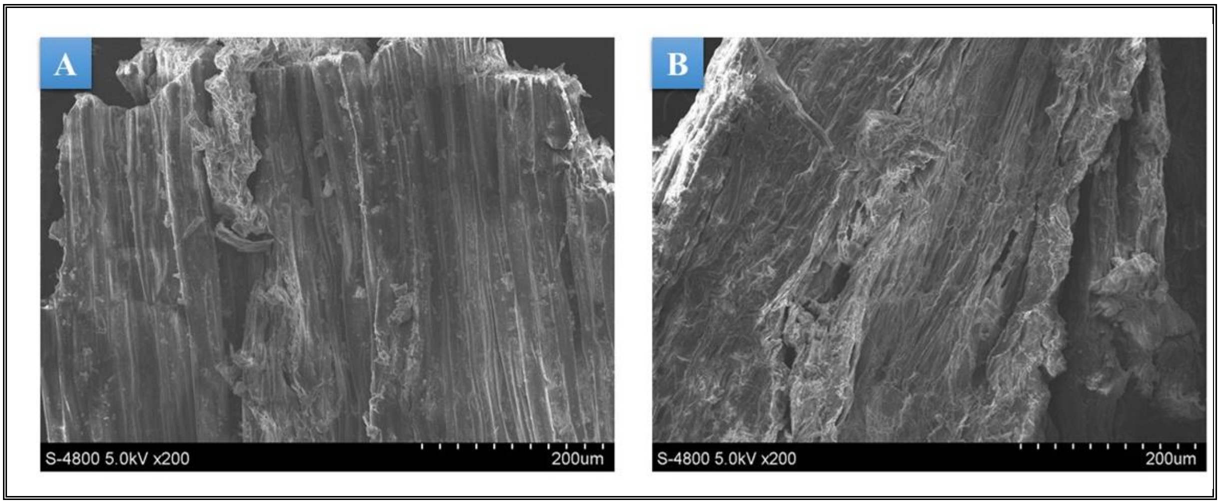

Figure 2. SEM photos of water hyacinth fibers (a) untreated and (b) treated with 1% NaOH

The fibers of untreated water hyacinth and those treated with NaOH were analyzed for fiber composition using a gravimetric method: AOAC official method 973.18 (AOAC, 2006). The results of the fiber composition analysis are shown in Table 1. The cellulose content increased significantly from 38.4% for untreated fibers to 67.7% for fibers treated with 1% NaOH. The increase in cellulose content improves the mechanical properties of the fiber, improving the mechanical properties of the composite product. Additionally, the lignin content decreased from 5.63% to 3.69%, improving the interface between the base resin and the fibers and increasing the bonding force between the base resin and the fibers.

Table 1. Results of the analysis of the composition of the water hyacinth fiber sample

Parameter	Untreated	Treated with NaOH 1%
Cellulose % (w/w)	38.40	67.70
Hemicellulose % (w/w)	18.44	4.39
Lignin % (w/w)	5.63	3.69

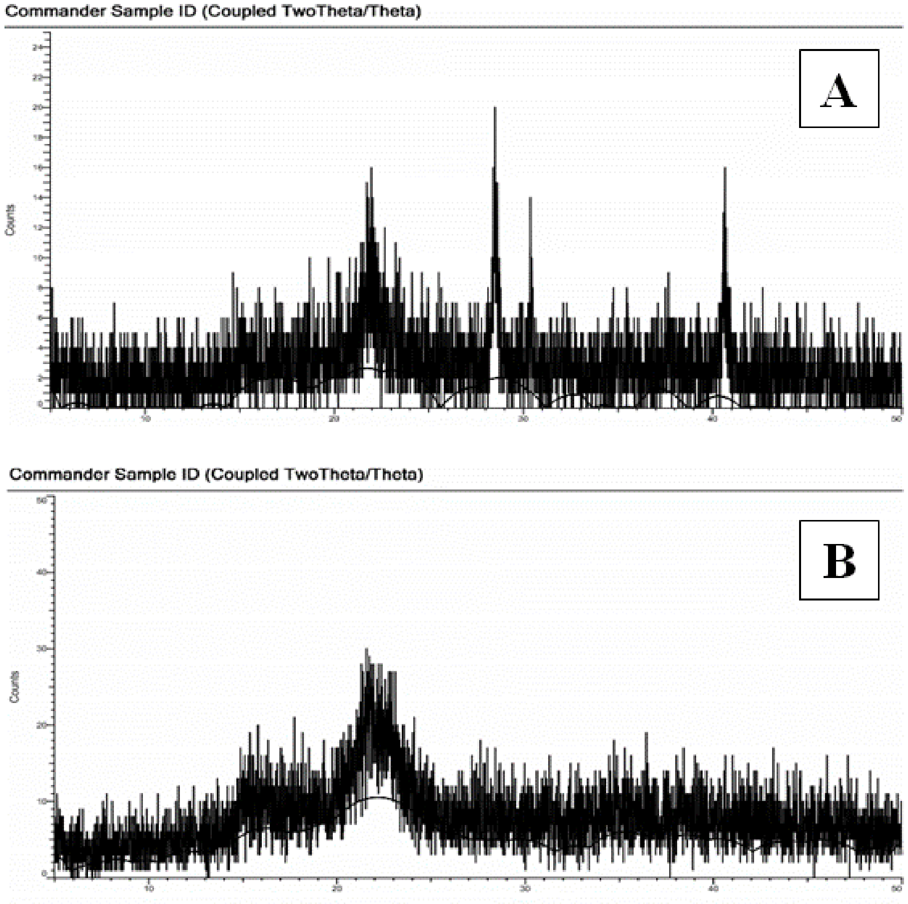

Figure 3. XRD patternsof (a) untreated fiber samples and (b) 1% NaOH treated fiber samples

3.2. Research on the process of manufacturing composite materials based on UPE resin and water hyacinth fibers

3.2.1. Flexural Strength and Flexural Modulus

The influence of sample treatment on the mechanical properties of the material is described in Table 2. The results of Table 2 show that the flexural strength of the sample with the same WHF/UPE ratio but treated with 1% NaOH is higher. Flexural strength is better than untreated. This proves that the fiber processing process has improved the bond with the resin, and the mechanical properties of the fibers have also increased, thus providing better reinforcement for the sample. With processed water hyacinth fibers, we proceed to create composite samples and change the pressing temperature. Table 3 shows that composite samples cured at normal temperatures give better results than samples cured with mold heating at 80^0 C. The purpose of heating is to create more uniform curing to avoid shrinkage. Still, during the heating process, the temperature of the mold is higher than what we set, which results in the curing process occurring faster and the air bubbles generated during the curing process not completely escaping from the sample.

As a result, the composite sample contains many air bubbles, which reduces its mechanical properties and flexural strength. When the content of water hyacinth fiber increases in the composite sample, the flexural modulus increases. When the fiber type in the composite composition is changed, we see that the composite sample reinforced with treated water hyacinth fibers has a much higher flexural modulus than the composite sample reinforced with untreated water hyacinth fibers with the same fiber content. With a WHF/UPE ratio of 26/74, we see that when replacing untreated water hyacinth fibers with treated water hyacinth fibers, the flexural modulus increases but is not equal to the composite sample with a WHF/UPE ratio of 38/62. This shows that fibers treated with NaOH have partially removed lignin, making the surface rougher and better able to bond to the base resin. When changing the sample press temperature, we see that for composite samples with the same WHF/UPE ratio, when the sample is heated to 80^0 At C, the modulus decreases, proving that foaming occurs, reducing the mechanical properties of the sample. When the fiber content in the composite sample increases, the modulus increases, demonstrating that the water hyacinth fiber has good load transfer and reinforcement for the composite sample (Table 3).

3.2.2. Compressive Strength and Compression Modulus

Compressive strength represents the highest compression resistance of a material. As the fiber content increases, the compressive strength increases and reaches the highest value with a fiber content of 32% for treated fibers (Table 2). In terms of compressive strength, treated fiber has better compressive strength than untreated fiber, because the mechanical properties of treated fiber are better than those of untreated fiber and the cellulose content in treated fiber is higher. The interface between fiber and resin has a better combination. Strength changes with the WHF/UPE ratio: like the flexural strength, when the fiber content increases, the fiber plays a load-bearing role, and the resin matrix transmits the load to the fiber. Therefore, the compressive strength of the composite samples increases with resin content. Compressive strength changes with temperature: heat the mold to 80□C when creating composite samples. Because the curing reaction of UPE resin is an exothermic reaction, if the mold's heat is also close to the radiated temperature, we will avoid thermal stress, avoid creating cracks in the sample, and make the sample give better compressive strength.

The compression modulus changes as the WHF/UPE content changes: for untreated fibers, the composite sample has the highest compression modulus with a fiber content of 26%, which is well distributed in the sample (Table 2). The sample had the highest compression modulus for treated fibers with a content of 38% (Table 2). The compression modulus varies with the fiber type: treated fibers provide better reinforcement for composite samples by creating a better bond with the matrix resin. The compression modulus of the composite sample does not change significantly when it cures at room temperature or when heating at 80^0 C. As the fiber content increases, the compression modulus increases.

3.2.3. Tensile Strength and Tensile Modulus

Tensile strength represents the ability of a material to withstand maximum tensile force. Tensile strength changes with the changing fiber content, but not much. In general, composite samples with treated fibers have better tensile strength than untreated fibers, and the bond between resin and fiber is stronger. The tensile strength increases as the fiber content of the sample increases, and curing at 80□C results in higher tensile strength because the curing reaction occurs more smoothly and eliminates the thermal stress that occurs during the curing process.

The tensile modulus of the composite sample changes with the content: the higher the fiber content of the composite sample, the lower the tensile modulus (Table 3). Cracks may appear between the fiber and the substrate during the modeling process. The tensile modulus of the composite sample changes when the fiber type changes: The treated fiber has a rougher surface because of the removal of part of the lignin, so the mechanical properties of the fiber increase. Therefore, the composite sample also has a higher tensile modulus.

Table 2. Results of the mechanical properties of composite materials based on UPE resin and water hyacinth fibers (WHF).

Ratio of WHF:UPE (%)	Flexural strength (MPa)	Compressive strength (MPa)	Tensile strenth (MPa)	Flexural modulus (MPa)	Compression modulus (MPa)	Tensile modulus (MPa)
Untreated fiber with NaOH 1%						
26:74	28.26	34.68	13.11	1734.42	660.89	839.23
32:68	24.88	17.68	12.73	1417.23	308.48	772.76
38:62	29.58	24.94	14.46	1570.56	433.64	764.65
Treated fiber with NaOH 1%						
26:74	32.39	35.76	15.61	2065.95	653.74	1369.97.0
32:68	34.27	42.03	15.83	2341.04	729.01	1262.06
38:62	33.68	40.02	16.70	2668.03	826.63	1308.03

Table 3. Mechanical properties of materials at different temperatures

The ratio of WHF:UPE (%)	Flexural strength (MPa)	Compressive strength (MPa)	Tensile strength (MPa)	Flexural modulus (MPa)	Compression modulus (MPa)	Tensile modulus (MPa)
At a temperature of 30□C						
26:74	32.39	35.76	15.61	2064.95	653.74	839.23
32:68	34.27	42.03	15.83	2341.04	729.01	772.76
38:62	33.69	40.02	16.70	2668.03	826.63	764.65
At a temperature of 80□C						
26:74	35.45	43.15	13.68	2109.96	706.93	1369.97
32:68	29.90	36.50	17.40	2137.04	646.05	1262.06
38:62	33.15	44.86	19.40	2375.02	799.96	1308.03

Table 4. Comparison of mechanical properties between materials

Mechanical properties	UPE+ Water Hyacinth Fiber	Pressed paper	MDF-PF	MDF-PP
Flexural strength (Mpa)	29.58	37.54	14.07	12.24
Flexural modulus (Mpa)	1570	2400.13	1400.34	617.52

3.3. Comparison of Mechanical Properties between Materials

Table 4 shows that the properties of composite samples based on WHF/UPE fiber (fiber content 38%) are not equal to pressed paper materials. However, the mechanical properties are better than those of the MPF wood types on the PF and PP resin substrates. Therefore, it is possible to replace these materials entirely.

4. CONCLUSIONS

Changing the fiber content affects the mechanical properties and permeability of the water of the material. Specifically, the higher the fiber content, the greater the mechanical properties and the greater the tolerance to deformation. However, a higher fiber content increases water permeability according to the resin content (62%)/fiber (38%) for good mechanical properties. Composite samples based on UPE resin and treated fibers have better mechanical properties than untreated fibers. This is explained by the fact that the treated fiber has a rougher surface as a result of the partial dissolution of lignin and nonorganic substances. Fibers are smaller and stiffer than untreated fibers. Composite products made from UPE resin and water hyacinth fibers have durability that meets civil applications, so they can replace standard plywood products in life.

DECLARATION OF COMPETENCE INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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