Mechanical and physical properties of water hyacinth and cogon grass fiber reinforced epoxy resin composites

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Abstract. In this paper, the study investigates the mechanical and physical properties of water hyacinth and cogon grass fiber reinforced epoxy resin hybrid composites**.** Hand lay-up technique was used to fabricate the composites. Water absorption, microstructure, tensile properties, flexural properties, and impact strength tests for total fiber contents, 15 wt %, and different water hyacinth and cogon grass fiber ratios (10/0, 8/2, 6/4, 4/6, 2/8, and 0/10) were used to evaluate the investigation's effects. The addition of water hyacinth and cogon grass fiber into epoxy improves tensile, flexural, and impact properties while decreasing water absorption, according to the findings. Using a scanning electron microscope (SEM), the microstructure of the composites was analyzed, and surface fracture behavior and the void between the fiber and matrix were observed.

1. Introduction

Natural fiber composites are a new material trend in the automotive, construction, and packaging industries. [1]. Furthermore, they are environmentally friendly, renewable, and biodegradable resources [2]. However, a water hyacinth and cogon grass are used to reinforce a polymer matrix in epoxy hybrid composites in this study. Because of its appealing properties, water hyacinth (*Eichornia crassipe* (Mart.) Solms.) is a considered useful natural fiber to use as a reinforcement in composite materials. The cellulose structure is small in diameter but has a high concentration [3]. The water hyacinth possesses a high percentage of holocellulose in comparison to other fibers, which is advantageous in its use as a reinforcing material. Synthetic polymers could thus be reinforced with natural fillers such as water hyacinth to increase their physical and mechanical properties and achieve the desired features in specific applications [4]. Cogon grass (*Imperata cylindrica* (L.) Beauv.) is one of the worlds 's ten most aggressive weeds because of its ability to colonize, spread, and replace valuable plants [5]. This plant is used to make paper, thatch, and weave bags and mats, as well as for traditional medicine [6]. Apart from that, cogon grass is a promising material for use as a reinforcement in the development of polymer composites [5]. As a result, this study examined the physical, mechanical, and microstructure of water hyacinth hybridization with cogon grass composites.

Table 1. Physical and mechanical average values of tests performed.

Sample (Water hyacinth: cogon grass)	Water absorption (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (kJ/mm^2)
Epoxy	3.65±0.07	1.99±0.67	30.83±14.88	32.71±3.38	267.33±0.57	0.35±0.07
10:0	3.36±0.83	20.35±1.88	373.16±2.37	35.49±9.65	1625.88±336.45	4.37±0.015
8:2	2.17±0.95	27.41±1.20	584.33±36.26	52.88±3.61	2053.36±287.12	3.46±0.14
6:4	2.13±0.39	23.55±0.41	382.66±154.39	58.13±6.62	2117.12±318.26	4.60±0.32
4:6	3.13±0.68	22.19±1.70	379.66±148.83	40.77±8.98	1760.85±219.22	4.09±0.46
2:8	2.54±0.41	24.79±0.50	421.33±60.33	50.72±6.34	1784.34±83.38	4.36±0.03
0:10	3.06±0.40	25.54±0.70	433.83±109.61	44.26±2.04	1769.98±425.38	4.95±0.47
p-value	0.08	0.00*	0.00*	0.02*	0.01*	0.00*

Where * indicates a significant difference at $p < 0.05$.

2. Materials and methods

2.1. Raw materials

The raw materials prepared in this research include water hyacinth and cogon grass fiber were collected locally from Kaonoi village Kalasin, Thailand. Both fibers had diameters in the range of 200-300 µm, which were obtained at an average moisture content of 4-13%. The matrix was prepared from epoxy resin and hardener, both of which had a density of 1.18 g/m^3, and were purchased at a local market in Bangkok, Thailand.

2.2. Fabrication of composite

To produce the hybrid composites, epoxy was used to reinforce fabric water hyacinth and cogon grass fibers. Firstly, a penknife was used to extract both fibers from the plants. The fibers are then soaked in water and sundried to eliminate any moisture that could cause poor fiber and matrix bonding. After that, the fibers were immersed in a NaOH solution for 3 hours (NaOH 97 percent Acilabscan Ar 1171-P1 KG, 5% by volume) [7]. Later, the fibers are cleaned with deionized water (DI) until the solution is neutral (pH7) and then dried in an oven for 120 h at 90 ºC [8]. Thereafter, the particles were mixed and sieved until they were between 9 and 10 mesh. Fiber ratios of water hyacinth and cogon grass (10/0, 8/2, 6/4, 4/6, 2/8, and 0/10) were used to produce the fiber contents (15% by weight). Epoxy resin and hardener were mixed in a 10:1 weight ratio to create a matrix [9]. After that, the mixture is put into the acrylic mold. It was carried out in accordance with ASTM standards. (The water absorption, tensile test, flexural and impact test were determined in accordance with ASTM D570, ASTM D680 type 1, ASTM D790 and ASTM D256, respectively). The hand lay-up technique was used to fill the acrylic mold with a suitable amount of water hyacinth, cogon grass, and epoxy resin. The top and bottom of the specimen were then laminated with Mylar films to create a smooth surface. To compress the composite layer, two c-clamps were used to tighten the mold, which produced the compressive force. After 7 days of curing at room temperature, the composite samples were removed from the mold to allow for set-up. After that, scanning electron microscope (SEM) was used to analyze the microstructure of the composite samples, and five samples were prepared for each test to investigate the physical and mechanical properties. Finally, all data are measured standard deviation. The data was analyzed using a one-way ANOVA with a 95 percent confidence level for significant differences. The cut-off for significance is P-value, which is an alpha of 0.05.

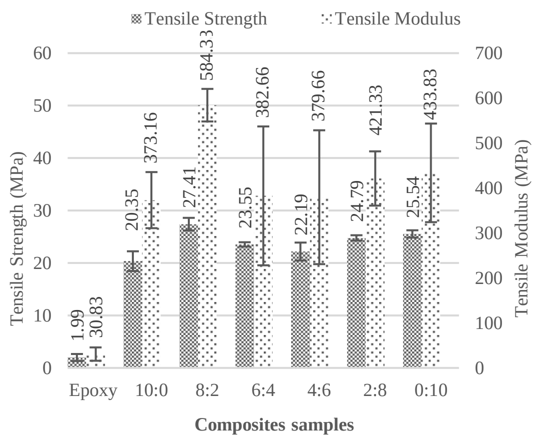

Figure 1. Tensile properties of composites.

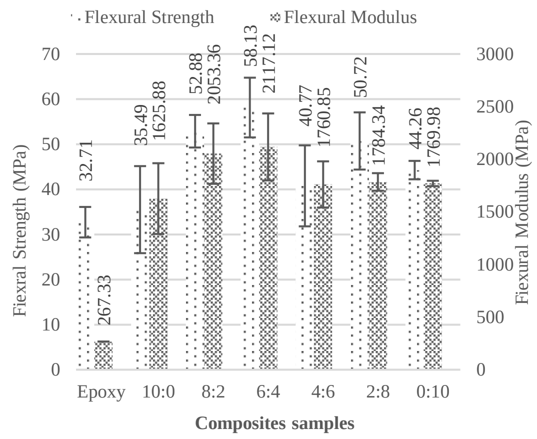

Figure 2. Flexural properties of composites.

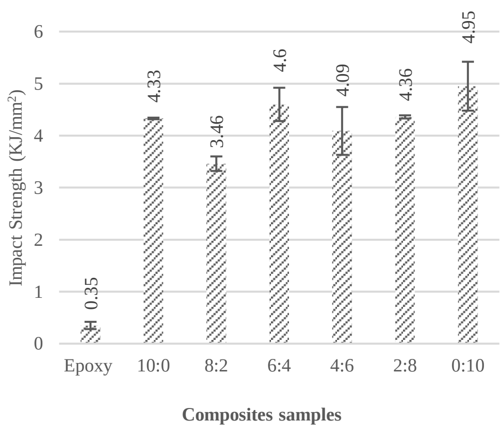

Figure 3. Impact strength of composites

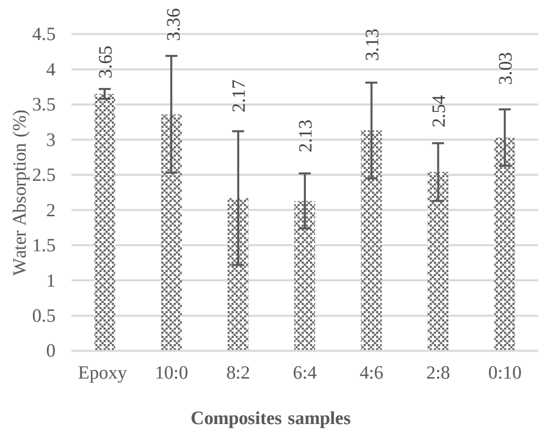

Figure 4. Water absorption of composites.

3. Results and discussion

3.1. Tensile test

Figure 1 illustrates the tensile strength and modulus of composites. In addition, table 1 shows a detailed statistical analysis. Statistically significant differences were found in the mean tensile strength and modulus ratios for both fiber types ($p < 0.05$). All-fiber ratios displayed higher modulus and tensile strength than pure epoxy resin, as shown in figure 1. The composites with 8/2 fiber ratios demonstrate high tensile strength and modulus values than the other fiber ratios, with the highest values of 20.41 MPa and 584.98 MPa, respectively. In addition, the high compatibility between both fibers in variable ratios may contribute to composites improved tensile properties. The strength of a composite can be increased or decreased by adding natural lignocellulose fibers to a polymer matrix. Fibers, such as lignocellulose fibers, can typically improve strength by absorbing stress transferred from the polymer [10]. The natural properties of the fiber and matrix, the adhesion between fiber and matrix, the aspect ratio of fiber and matrix length distribution, volume, and fiber orientation are all factors that Sathiamurthi *et al*. [11] reported influence tensile strength and modulus.

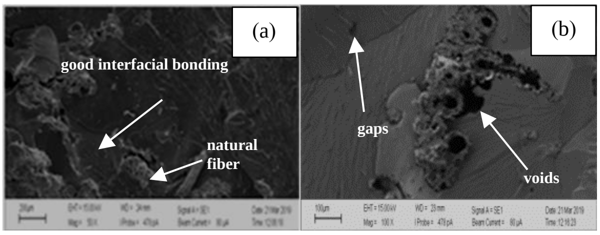

Figure 5. SEM micrographs of composites with fiber ratios of (a) 8/2 and (b) 10/0 after tensile testing.

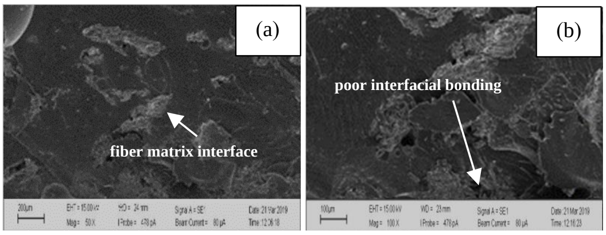

Figure 6. SEM micrographs of composites with fiber ratios of (a) 6/4 and (b) 10/0 after flexural testing.

3.2. Flexural test

Figure 2 illustrates that the flexural strength and modulus of composites are varied by fiber ratios. Table 1 shows the results of an analysis of variance (ANOVA) of the flexural properties. The analysis indicates that varying the hybrid fiber ratios resulted in significant differences ($p < 0.05$) in the composites mean flexural strength and modulus. As the fiber ratios increased from 10/0 to 6/4, the flexural strength and modulus increased, obtaining maximum values of 58.13 MPa and 2117.12 MPa, respectively. The improvement in flexural properties could be attributable to a similar cause as the tensile test results. However, flexural properties decreased at 4/6 fiber ratios, which could be attributed to poor interfacial bonding between the fibers and matrix due to lower fiber wetting. Poor flexural characteristics are caused by weak bonding between fiber and matrix, according to Khalil *et al*. [12]

3.3. Impact test

Figure 3 shows the results of altering the impact strength of the hybrid composites. Simultaneously, the detailed statistical investigation was directed, presented in table 1. Impact strength was not significantly different ($p > 0.05$) when the fiber ratios increased from 6/4 to 0/10 and 10/0. Nonetheless, further 8/2 fiber ratio brought about a significant change ($p < 0.05$) from each other, recording the highest value of 4.95 kJ/m^2 at 0/10 fiber, a ratio which was compared to other ratios. There is also a discontinuous trend in the impact strength from 10/0 to 0/10 fiber ratios, which can be observed. However, there is the lowest strength at 8/2 fiber ratio compared to other ratios except for epoxy resin. The decrease in the impact strength can be described as due to the "overcrowding effect" [13]. From these results, the filler was loaded further an over limit and agglomeration occurs, which affects the load transfer between the matrix and the filler. Inevitably, early failure reduced the mechanical strength [14].

3.4. Water absorption

Figure 4 illustrates the water absorption behavior from several composites after 30 minutes of immersion. Investigation indicated that the water absorption of the samples was not significantly different ($p > 0.05$) for all other fiber ratios as shown in table 1. From these results, it was observed that the 10/0 fiber ratio showed that maximum water uptake with an increase of 3.36%. Water absorption was lowest with 6/4 fiber ratio and increased by 2.13 percent, while epoxy resin has the highest absorption, which is compatible with the mechanical test results. The water absorption ability of the fiber depends on the greater adhesion hydrogen bonding between the network structure [15].

3.5. SEM morphology

The fracture morphology from the tensile and flexural test of samples of the highest and lowest tensile and flexural strength were investigated utilizing SEM a shown in figures 5 and 6. Figure 5 (a) observed good interfacial contact and high strength for 8/2 fiber ratios. At 10/0 fiber ratios, a generally high fiber pulls out and small gaps around the fibers were shown in figure 5 (b). In this micrograph, a fiber was pulled out, and it was observed that the sample had poor internal bonding between fiber and matrix.

Figure 6 (a) shows the image of 6/4 fiber ratios after the flexural test. From this micrograph, it was observed an ability high adhesion between fiber and matrix. As a result, if they have high strength and stiffness, reinforcement is strong adhesion to the matrix [16]. The void in the matrix in figure 6 (b) demonstrated that the porous structures were caused by trapped air bubbles within the matrix composites. The mechanical strength of the composites decreased as the concentration of water hyacinth fiber within the matrix increased. According to Fedulov *et al.* [17] void content was found to minimize the tensile and flexural failure load.

4. Conclusion

The effects of using water hyacinth/cogon grass fiber blends to reinforce epoxy resin composites were investigated. At water hyacinth to cogon grass blend ratio of 8/2, 6/4 and 0/10, epoxy resin hybrid composites produced at a constant fiber weight fraction of 15% achieved maximum tensile, flexural properties and impact strength respectively. The water absorption results showed the composite had a low water uptake rate which improved the mechanical properties. In a composite morphology investigation, fiber pull-out, interfacial characteristics and internal surface structures were all detected. Fiber reinforced epoxy composites could be used to replace synthetic fiber reinforced materials.

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