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Mechanical properties of natural fiber reinforced polymer (NFRP) composites using anahaw (*Saribus rotundifolius*) fibers treated with sodium alginate

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Natural fiber reinforced polymer (NFRP) composites have been a focus of various research projects because of their advantages compared to traditional fiber reinforced plastics. In this study, Anahaw (*Saribus rotundifolius*) was used as fiber source because it is abundant in the Philippines. The fibers were treated by immersing in a sodium alginate solution and then in a calcium chloride solution. The treated fibers were used to reinforce the orthophthalic unsaturated polyester. Mechanical properties were tested using a universal testing machine (UTM) and the fracture surfaces were characterized using a scanning electron microscope (SEM). Sodium alginate treatment resulted in higher tensile and flexural strengths of the composites as compared to those reinforced with untreated fibers. On the other hand, the sodium alginate treatment was not able to show any improvement on the wet mechanical properties of the material. The increase in fiber load was also found to increase the stiffness of the composites. The measured stiffness and modulus of the treated Anahaw fiber-reinforced composite was found to be comparable to those of commercially available particle boards and fiber boards.

Key words: Natural fiber reinforced polymer (NFRP), composite, sodium alginate, anahaw, polymer.

INTRODUCTION

Fiber-reinforced polymer (FRP) composites have emerged as one of the most common and widely used engineering materials. They have a diverse range of applications as construction material for aircraft, space-craft, ships, automobiles, chemical equipment, sporting goods and infrastructure (Tong, Mouritz and Bannister, 2002). Traditionally, these fiber-reinforced composites are made using carbon, glass, and aramid fibers. However, because these fibers are not environment-friendly and require energy intensive processes to manufacture, many research projects today are geared towards using natural fibers as alternative reinforcement material. Natural fibers have already established their place in the infrastructure and commercial products market, and currently many types of fibers derived from either wood and agricultural fibrous plants (such as flax, hemp, jute, and kenaf) or vegetable wastes (such as bagasse, rice husk, and grass) have already been used for plastics (John and Thomas, 2008).

Natural fiber-reinforced polymer (NFRP) composites

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Figure 1. Dried and milled anahaw fibers.

are green composites that utilize bio-based materials that can reduce disposable solid wastes through natural or accelerated biodegradation (in some cases). NFRPs can also provide a solution for mitigating industry-driven CO_2 emission through fixation of organic carbon, with the extent of carbon storage which has been quantitatively determined using life cycle analytical tools and thermogravimetric analysis (Tumolva et al., 2011). The Philippines, as a largely agricultural country, has many plant fiber sources such as abaca, pineapple, agave and sisal, as well as about 13,500 species of plants which might provide new fiber sources (DENR, 2010). This abundance of plant fiber resources provides many opportunities for research on developing novel NFRP composites using untapped plant fibers, such as the study on the use of water hyacinth fibers (*Eichhornia crassipes*) to reinforce unsaturated polyester resins (Ortenero et al., 2012). One potential natural fiber reinforcement is *anahaw* (*Saribus rotundifolius*). Anahaw is a tree that is widely-distributed throughout the Philippine archipelago, and its broad leaves are used in making various types of handicrafts and as roofing for huts.

The objective of this study is to investigate the potential of anahaw as raw material for producing NFRPs. In order to improve composite properties, the natural fiber reinforcement is often treated using chemicals such as sodium hydroxide or organic coupling agents, which can be hazardous and even toxic; hence, it is desired to use an eco-friendlier fiber treatment. In this study, the anahaw fibers are treated with sodium alginate, which is a biocompatible gum derived from seaweed. However, the effects of using sodium alginate on the performance of anahaw NFRP is still unknown and must therefore be determined to establish commercial viability of the composite.

MATERIALS AND METHODS

The anahaw stalks used were obtained from the Bicol Region, Philippines. These stalks were dried and milled into short fibers (Figure 1). The fibers were extracted through decortication from the petiole and their chemical composition was analyzed at the Fiber Industry Development Authority (FIDA). The matrix used was orthophthalic unsaturated polyester (R10-103), which was purchased together with a methylethyl ketone peroxide (MEKP)

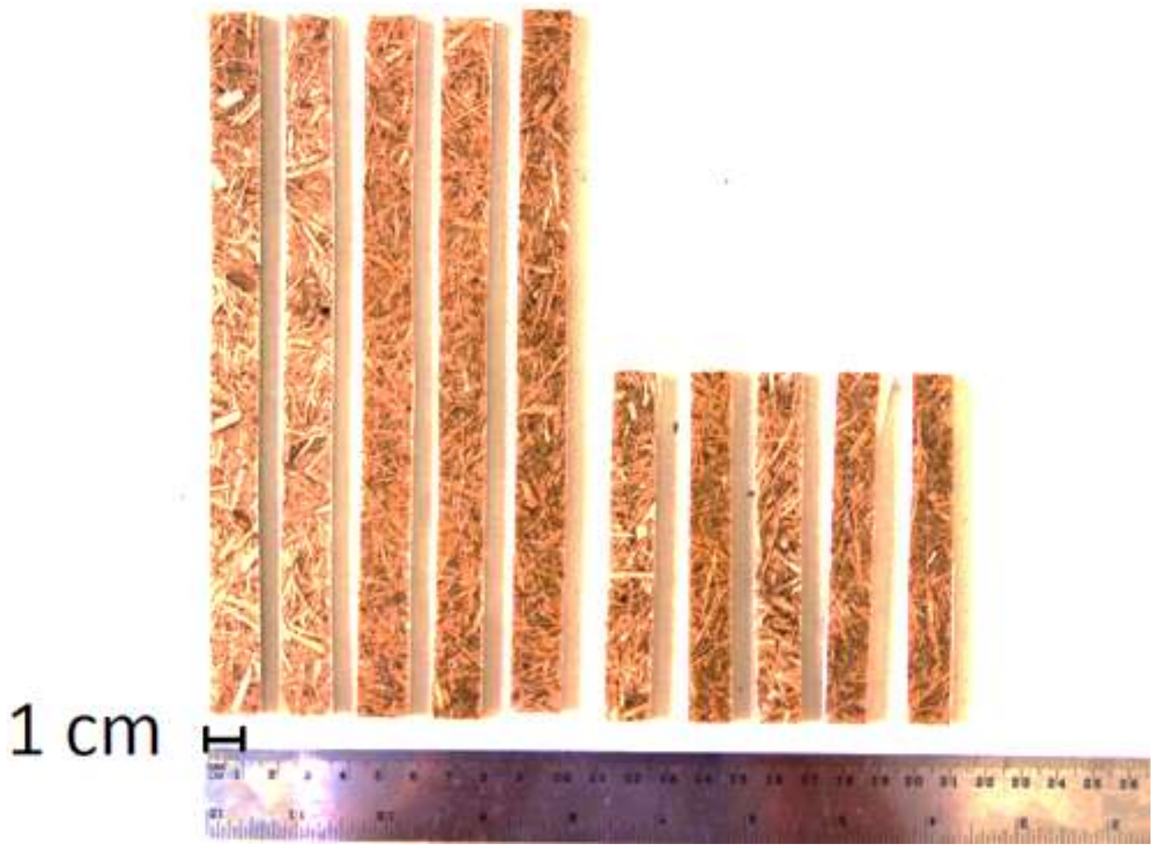

Figure 2. Specimens for tensile strength test and for flexural strength test.

hardener and liquid released wax from Polymer Products Philippines, Inc. The sodium alginate used was purchased from Mega Polygums and the calcium chloride was purchased from Belman Laboratories.

Fiber sheet preparation

The anahaw fibers were immersed in a 2-L sodium alginate solution at varying concentrations (0, 0.25, 0.5, 0.75 and 1%) for 30 min, then lightly squeezed to remove excess sodium alginate. They were then immersed in a 1% calcium chloride solution for 90 min. After the treatment, the fibers were shaped in fiber mat form on aluminum molds. The fiber mats were placed in a thermal press at 85°C for 2 h and were then placed in an oven for 3 h to remove excess moisture.

NFRP preparation and testing

The NFRP composites were prepared at varying fiber weight (0, 17, 20, 22, and 24%) by hand lay-up method using aluminum steel molds. Orthophthalic unsaturated polyester resin was used as matrix, with the MEKP hardener mixed with the pre-polymer at 1.5:100 weight ratios. The laminated fiber mats were then cured in a thermal press at 55°C for 4 h. The cured samples were cut into test specimens following ASTM D3039 and ASTM D790 (Figure 2), which are the standards for tensile strength test and for flexural strength test for polymeric materials, respectively. The tensile and flexural properties of the NFRP specimen were determined using the Universal Testing Machine (UTM); after which, the resulting fracture surfaces of the specimen were observed using a scanning electron microscope (SEM). Water-immersion was also performed to measure the wet mechanical properties of the anahaw/NFRP. This analysis is essential since natural fibers are inherently hydrophilic, thus making NFRPs susceptible to degradation under wet environment (Kubouchi et al., 2013). In this study, the specimens prepared at varying sodium alginate concentration were immersed in water for 96 h; afterwards, the tensile and flexural strengths were measured using the UTM.

RESULTS

Fiber composition analysis

The composition of the anahaw fiber has been determined in order to provide insights on how the fiber will act as reinforcing material. As a reinforcing material, it is desired for the fiber to have a relatively high amount of cellulose, since it is the backbone that absorbs the applied stress in the material and is the primary means of carbon storage of the fiber (Tumolva, 2011). As shown in Table 1, results of the performed fiber analysis prove that anahaw fiber has a composition that is comparable to those of other natural fibers (Nguong et al., 2013; Kabir et al., 2012) that are already commercially used as reinforcements.

Table 1. Composition of various plant fibers compared to anahaw.

Plant fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Hemp	70.2-74.4	17.9-22.4	3.7-5.7
Banana	64	10	5
Abaca	59	-	12.5
Sisal	67-78	10-14.2	8.0-11.0
Jute	61.0-71.5	13.6-20.4	12.0-13.0
Kenaf	51	21.5	10.5
Pineapple	76	-	8.85
Anahaw (FIDA)	67.96	22.77	15.54

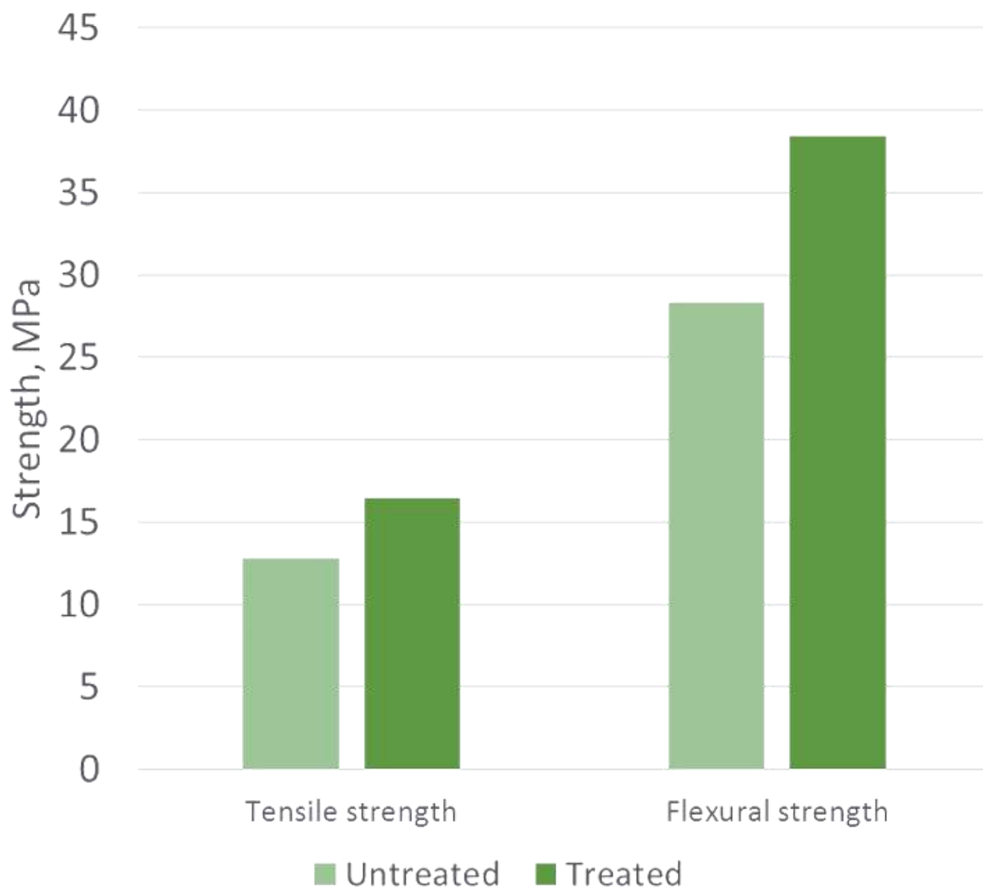

Figure 3. Tensile and flexural strength of anahaw fiber-reinforced NFRP.

Tensile and flexural strength

Tensile and flexural tests showed that sodium alginate treatment results in a significant increase to the tensile and flexural strength over those of the NFRP samples with untreated fibers, as shown in Figure 3. The improvement brought by sodium alginate can possibly be attributed to bonds formed between the fiber and the alginate chains. The structure of sodium alginate allows for the formation of hydrogen bonds with the cellulose backbone. The addition of calcium chloride displaces sodium in sodium alginate to form calcium alginate, and the divalent calcium ions allow the formation of crosslinks in between alginate chains (Kashima and Imai, 2012). The formed calcium alginate layer acts as a coupling agent to the composite, with the polar parts binding to the hydroxyl groups of the cellulosic fibers while the non-polar parts are the ones expected to bind with the ortho-

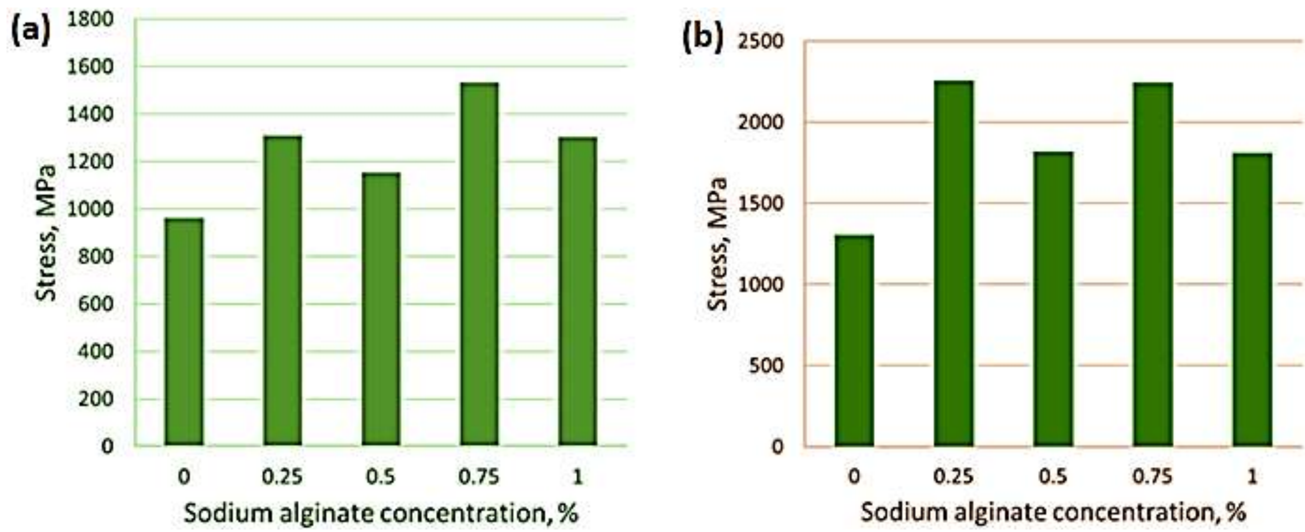

Figure 4. Tensile (a) and flexural (b) moduli of anahaw NFRP at different sodium alginate concentration.

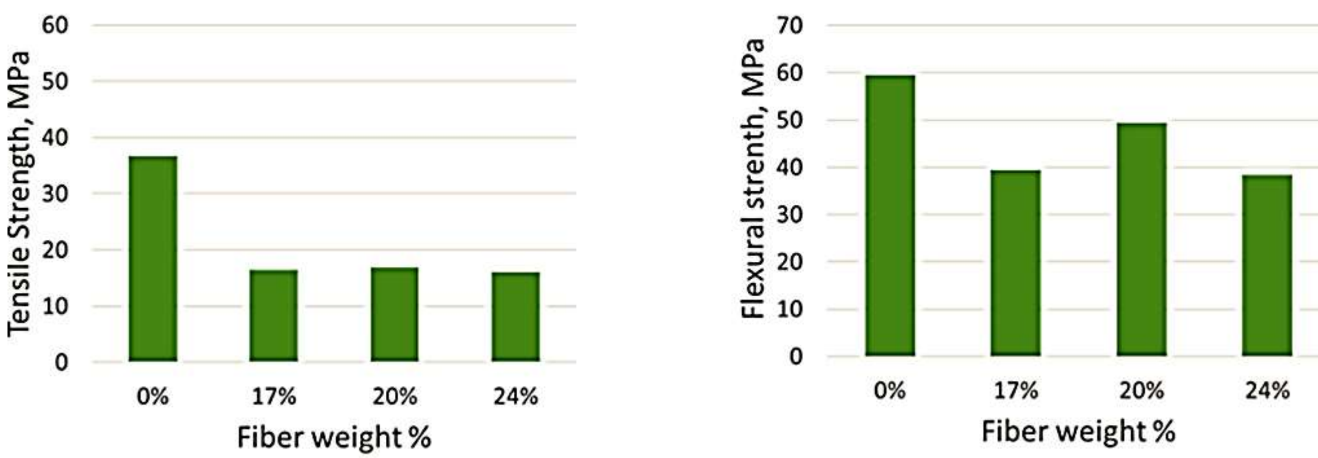

Figure 5. Tensile and flexural strengths of anahaw NFRP at varying fiber loading.

UP resin.

Effect of sodium alginate concentration

Similar to what had been observed by John and Anandjiwala (2009) from using the protein zein (which has both hydrophilic ends and a hydrophobic body), it is expected that sodium alginate would act as an adhesive coating for the hydrophilic anahaw fiber to make it bond with the hydrophobic ortho-UP resin. From the results of this study, there is an observable increase in the tensile and flexural moduli, which indicates that the composite becomes stiffer and is able to absorb higher loads before undergoing deformation. Based on the results shown in Figure 4, there is an evident increase in modulus at higher sodium alginate concentrations, with the best condition observed at 0.75%. The slight decrease at exceedingly high concentrations may possibly be attributed to the formed alginate coating that is too thick.

Effect of fiber loading

As shown in Figure 5, there is an observed decrease in the tensile and flexural strengths of the NFRP with increasing fiber load, which may limit its applicability. This decrease may be due to the competing effects brought by the introduction of fibers in the polymer. The addition of fibers causes heterogeneity that result in weak points

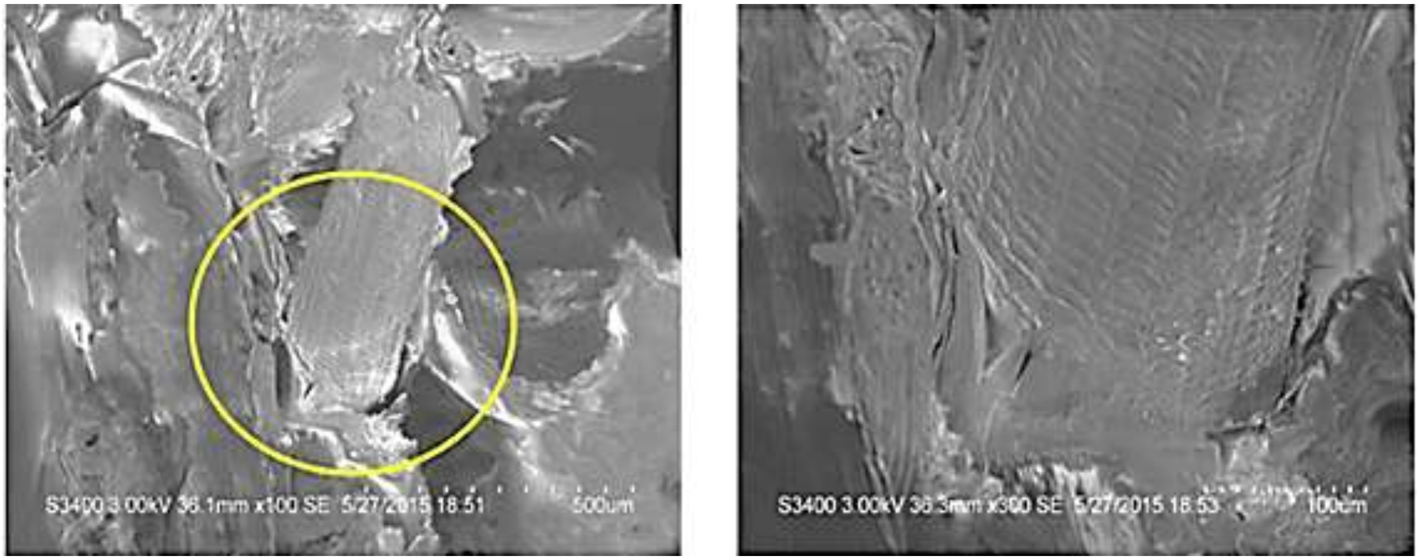

Figure 6. SEM images of fiber pullout at the fracture surface of the anahaw NFRP at 100× magnification (left) and of the fiber pullout at 300× magnification (right).

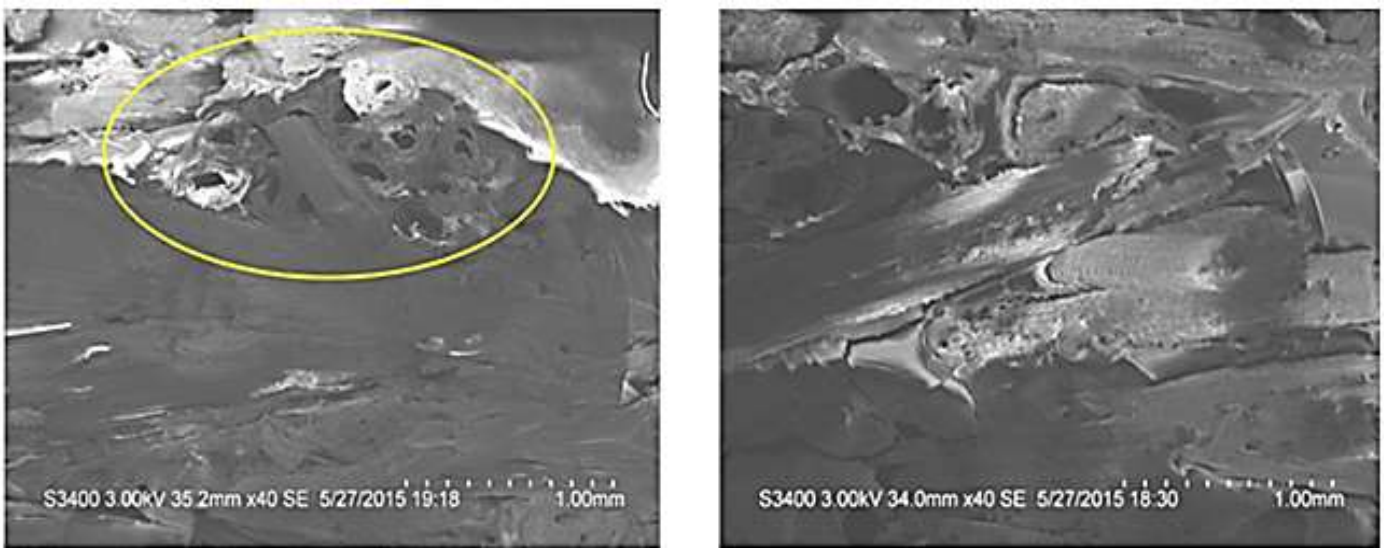

Figure 7. SEM images showing the anahaw fiber lumen at 40× magnification.

within the material (Tumolva, 2011). However, since the fibers are stronger than the matrix and as such can therefore support most of the applied stress during mechanical testing, it is expected that the addition of these fibers will overcome this competing effect and overall strengthen the composite material. Comparing these results with those on the moduli, it can therefore be concluded that the addition of the anahaw fibers can decrease the ultimate strength of the composite but can increase the amount of stress it can absorb before failure occurs.

Fracture surface characterization

SEM images shown in Figure 6 indicate that the interphase between the ortho-UP matrix and the anahaw fiber is very small, which suggests that the adhesion between the fiber and the matrix is good. Good adhesion between the fiber and matrix ensures that stresses are effectively transferred from the matrix to the reinforcing material. SEM analysis in Figure 7 also shows that there is the presence of a large lumen in the middle of the fiber cell bundle, with sizes ranging from about 99 to 120 µm.

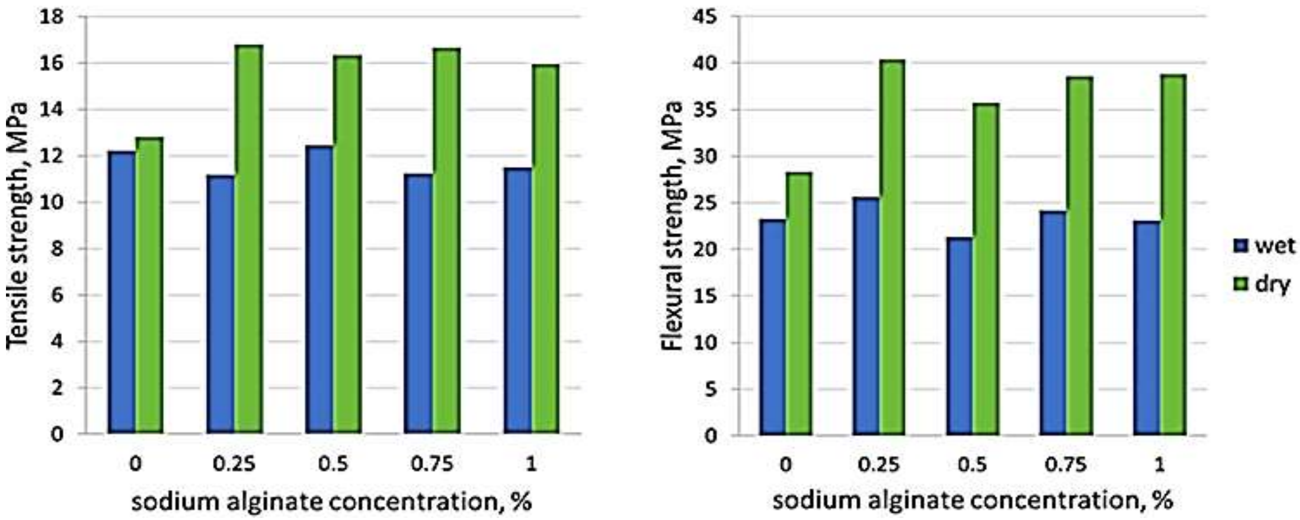

Figure 8. Comparison of wet and dry tensile mechanical strength of anahaw NFRP.

These hollow voids present an additional contribution to the decrease in strength of the reinforcement the anahaw fibers can provide for the ensuing composite. The presence of the voids may be due to the absence of a treatment that will alter the morphology of the fiber itself; as previously stated, the sodium alginate acts only as an adhesive coating for the surface of the fiber to be more compatible to the resin.

Wet mechanical strength

Water sorption is one of the most crucial aspects in the evaluation of NFRPs. Because the lignocellulosic fibers are intrinsically hydrophilic, their use as reinforcement significantly increases the composites' water sorption properties, which consequently alters the mechanical strength and dimensional stability (Dhakal et al., 2007).
The results in both tensile and flexural strength tests are shown in Figure 8. The significant decrease in tensile and flexural strength is expected since the water weakens the fiber-matrix interface (Sreekala et al., 2002). Water can significantly affect the polymer network and then interact with the polar groups of the fiber and the alginate, thereby resulting into a plasticizing effect and a reduction in strength. The results also show that an increase in sodium alginate concentration does not have any effect on the tensile and flexural strength of the wet composites even if sodium alginate concentration is increased. This may be because the hydrophilic alginate does not prevent the entry of water into the material.

CONCLUSIONS AND RECOMMENDATIONS

Anahaw fibers are a viable reinforcement for polymer composites. Fiber treatment using sodium alginate can significantly increase the tensile and flexural properties of the composite compared to those reinforced with untreated fibers; however, sodium alginate treatment does not significantly affect the strength after water immersion even if concentration is increased. The resulting NFRP composites are comparable to commercial fiberboards and particleboards used in various applications such as furniture.

The range of flexural modulus observed in the analysis is from 1.31 to 2.70 GPa. Comparing these values with the ones reported by Youngquist (1999), it can be concluded that the flexural modulus is comparable to different grades of particleboards and fiberboards. This means that the fabricated NFRPs can be used as alternative to particleboards and fiberboards, both of which are commonly used as structural materials for flooring and furniture. Also, the flexural modulus of the fabricated composite is comparable to that of a medium-density fiberboard which is frequently used as an alternative to plywood.

For future studies, it is recommended to investigate the use of long anahaw fibers, since continuous fibers tend to provide better reinforcement than short fibers, as well as to study the effect of varying the concentration of the calcium chloride coagulating medium.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Department of Environment and Natural Resources (DENR) (2010).

Some Familiar Philippine Palms that Produce High Food Value and Tikog. Research Information Series on Ecosystems. Ecosystems Research and Development Bureau. 22(1).
John MJ, Anandjiwala RD (2009). Chemical modification of flax reinforced polypropylene composites. Composites: Part A, 40:442-448.
John MJ, Thomas S (2008). Biofibres and biocomposites. Carbohydr. Polym. 71:343-364.
Kabir MM, Wang H, Lau KT, Cardona F (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. Composites: Part B. 43:2883-2892.
Kashima K, Imai M (2012). Advanced Membrane Material from Marine Biological Polymer and Sensitive Molecular-Size Recognition for Promising Separation Technology. Advancing Desalination, Prof. Robert Y. Ning (Ed.).
Kubouchi M, Tumolva TP, Shimamura Y (2013). Biofiber-reinforced thermoset composites, in Polymer Composites (eds Thomas S, Joseph K, Malhotra SK, Goda K, Sreekala MS), Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany. doi: 10.1002/9783527674220.ch6.
Nguong CW, Lee SNB, Sujan D (2013). A Review on Natural Fibre Reinforced Polymer Composites. Int. J. Chem. Nucl. Metallogr. Mater. Eng. 7(1):33-40.
Ortenero J, Tumolva T, Kubouchi M (2012). Water hyacinth fiber-reinforced green composites. Proceedings of the 7th International Workshop on Green Composites (IWGC-7). 28-30 August 2012, Hamamatsu City, Japan.
Tong L, Mouritz AP, Bannister MK (2002). 3D Fibre Reinforced Polymer Composites. Oxford, UK: Elsevier Science, Ltd.
Tumolva TP (2011). Development and evaluation of natural fiber-reinforced thermoset-based composites for long-term carbon fixation. A doctoral dissertation. Tokyo Institute of Technology, Japan.
Dhakal HN, Zhang ZY, Richardson MOW, (2007). Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. Composite Science and Technology 67:1674-1683.
Sreekala MS, Kumaran MG, Thomas S (2002). Water sorption in oil palm fiber reinforced phenol formaldehyde composites. Composites: Part A, 33:763-777.
Tumolva T, Kubouchi M, Aoki S, Sakai T (2011). Evaluating the carbon storage potential of furan resin-based green composites. Proceedings of the 18th International Conference on Composites Materials. 21-26 August 2011, Jeju Island, South Korea.
Tumolva T, Takiya N, Kubouchi M, Sakai T (2008). Mechanical properties of bagasse fiber-reinforced polyester composites. Proceedings of the Fifth International Workshop on Green Composites. Fukushima, Japan.
Youngquist JA (1999). Wood-based composites and panel products. In: Wood Handbook: Wood as an Engineering Material. Gen. Tech. Rept. FPL-GRT-113. USDA Forest Serv., Forest Prod. Lab., Madison, WI. pp. 1-31.