

Water Uptake and Tensile Properties of Plasma Treated Abaca Fiber Reinforced Epoxy Composite

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ABSTRACT: This work presents the tensile properties and water uptake behavior of plasma treated abaca fibers reinforced epoxy composites. The composites were prepared by vacuum assisted resin transfer molding. The effects of treatment on tensile properties and sorption characteristics of abaca fiber composites in distilled water and salt solution at room temperature were investigated. The tensile strength of the composites increased with plasma treatment. With plasma treatment, an improvement of 92.9% was obtained in 2.5 min exposure time in plasma. This is attributed to high fiber-matrix compatibility. Less improvement on tensile properties of hybrid treatment of sodium hydroxide and plasma was obtained. However, both treatments reduced overall water uptake in distilled water and salt solution. Hydrophilicity of the fibers decreased upon plasma and sodium hydroxide treatment, which decreases water uptake.

Key Words: water uptake, plasma treatment, abaca fiber, composite

1. INTRODUCTION

The increasing interest in environmentally-friendly green composite has stimulated the use of degradable, renewable and inexpensive reinforcing materials. Among the natural fibers that have potential for reinforcement of composite is abaca. It is widely known as “Manila Hemp”, which is obtained from the pseudo-stem of banana family (*Musa Textilis Nee*) with relatively good mechanical properties. The Philippines is the worldwide leader in the production of abaca fibers with 85% of the market share [1]. Abaca offers great potential for different applications due to high tensile strength, specific flexural strength, rot and salt resistance [2-6]. Abaca fiber reinforced composites are becoming one of the recent interests in the composite industry due to the innovative application in under-floor protection of passenger cars by Daimler Chrysler [4-7]. The main drawback of natural fiber as reinforcement for composite is the poor compatibility of the fibers and the matrix and the degrading behavior of the composites when exposed to environmental conditions such as sunlight, humidity and microorganism. The hydrophilic nature of natural fibers is the main disadvantage of fibers as reinforcement for composites

which leads to incompatibility and poor wettability with hydrophobic polymers, and thus poor bonding at fibers/matrix interfaces [8-11]. The poor resistance of the fibers to moisture has unfavorable effect on the long term properties of the composite and this can only be reduced if there is good fiber-matrix interaction. Several chemical modifications on the surface of fibers were done. To our knowledge, there is no information on the effect of plasma treatment on the water uptake of abaca/epoxy composites manufactured by vacuum assisted resin transfer molding. A detailed investigation on the effect of abaca treated with plasma on the water uptake and tensile properties of abaca reinforced epoxy composites were carried out. The results were compared with untreated and with hybrid treatment. The interfacial adhesion between the fiber and the matrix was determined from the fractured surface morphology of abaca fiber/epoxy composite.

2. EXPERIMENTAL

2.1 Materials

The abaca fibers used in this study were selected from the variety of S-1 and S-2 from the Bicol region of the Philippines

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[1]. The fibers were weaved into fabrics consisting of 3-ply in weft and 1 ply in warp direction. The YD 128 standard liquid resin (EEW: 184-190, room temperature viscosity: 11,500-13,500 cps) a diglycidyl ether of bisphenol A (DGEBA) as the matrix and KBH 1089 anhydride type as curing agent were used and purchased from Kukdo Chemicals. Other chemical such as sodium hydroxide and acrylic acid were used without further purification.

2.2 Processing

Plasma treatment was generated in a glow discharge manner which was operated in closed and semi-automatic systems. The sample was placed on the ground electrode in the middle of the reactor. The abaca fabric was placed between the electrode plates where the plasma polymerization is being done. Helium was used as a carrier gas and acrylic acid was used as a monomer to modify the surface property by plasma polymerization. Acrylic acid was used as precursors to create a hydrophobic fabric surface [12]. The frequency and voltage were 20 KHz and 3 KV respectively. The fabric was exposed to plasma for 1, 2 and 2.5 minutes. Another set of fabric which was previously treated with 2% NaOH for 60 minutes was then exposed to plasma for 1, 2 and 2.5 min.

2.3 Preparation of composite

Five layers of abaca fabric were stacked up in the fabrication of composite using vacuum assisted resin transfer molding. Epoxy resin which previously mixed with curing was used as the matrix. After filling up the surfaces of the fabric, the composites were cured at 120°C for 120 minutes. The fabric weight contents for plasma treated specimens were 30.5%, 31%, 30.8% for 1, 2 and 2.5 min, respectively. Those for hybrid treatment of 2% NaOH were 28.5%, 28% and 27.8% for 1, 2 and 2.5 min plasma treatment, respectively.

2.4 Characterization

Tensile tests were carried out on universal testing machine model Instron 5882 equipped with a 5 kg load cell in accordance with ASTM standard D3029 with crosshead speed of 5 mm/min. All the samples were cut in weft direction. The average values of the mechanical properties were obtained from 6 specimens. The water uptake was determined in accordance with ASTM D5229. Prior to absorption experiments, five specimens were first dried in an oven for 24 hrs at $102 \pm 3^\circ\text{C}$. The specimens were immersed in distilled water and in a salt solution (35 ppm sodium chloride) at room temperature and the weight change was monitored as a function of time. The values of water absorption in percentage were calculated as follows:

$$\text{WA} (\%)_t = (\text{Mc} - \text{Mo})/\text{Mo} \times 100 \quad (1)$$

where WA (t) is the water absorption at time t, Mo is the mass of the dried specimen and Mc is the mass of the specimen as a

function of immersion time. The photomicrographs were recorded using SEM with a JEOL model # JSM-J310 to study the changes in the surface morphology after immersion in distilled water.

3. RESULTS AND DISCUSSION

To determine the effectiveness of surface treatment, the tensile properties were determined. The tensile strength and Young's modulus as a function of plasma exposure time are shown in Fig. 1 and Table 1. The tensile strength of untreated abaca composite is about 85 MPa while that of the plasma treated one is about 96 MPa, showing an improvement of 12.9%. A tensile strength value of 164 MPa was obtained with 2.5 min plasma exposure time, which represents an improvement of 92.9%. This increase in tensile strength was due to the plasma treatment of the fiber resulting in a better compatibility of the fiber and the matrix. No further improvement was seen in the hybrid treatment of abaca. It is clearly seen that the hybrid treatment resulted in lower tensile strength compared to those with plasma treatment. In Table 1, the Young's modulus of both plasma and hybrid treatment were almost the same.

Water is one of the major concerns of natural polymer composite for industrial application since natural fibers absorb moisture when immersed in water or in humid environment. For this particular experiment, the water immersion test was done to evaluate the effect of plasma treatment on water uptake of abaca fiber reinforced epoxy composite. Fig. 2 shows the percentage water uptake as a function of square root of time for plasma treated fiber composites at different deposi-

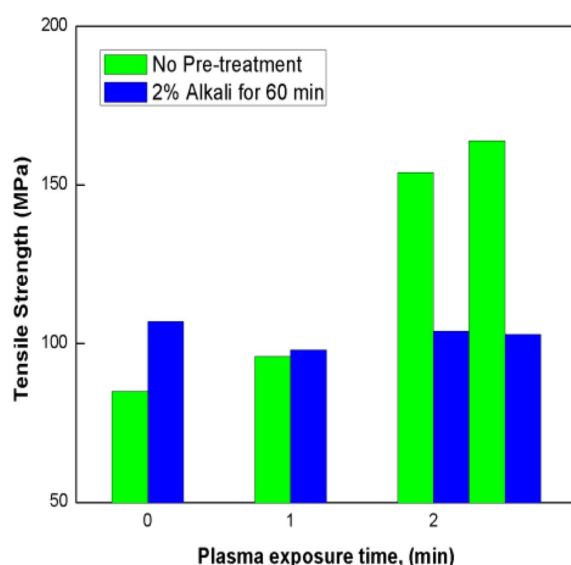


Fig. 1. Tensile strength of abaca fiber reinforced epoxy composite as a function of plasma exposure time Note: no treatment prior to plasma and 2%NaOH was first done before plasma treatment.

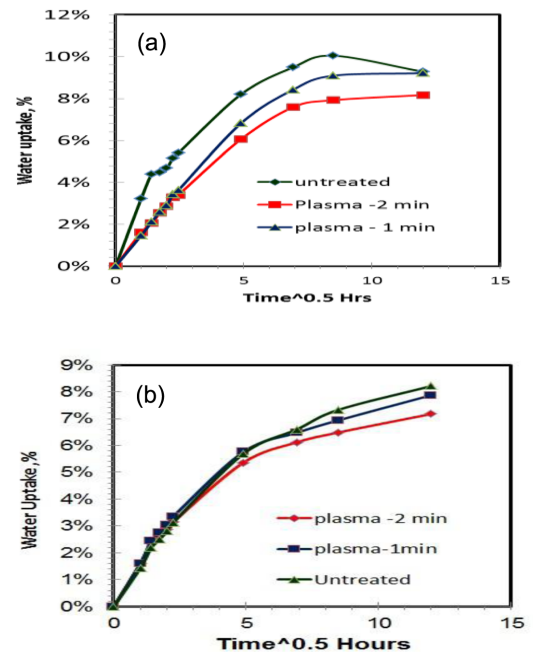
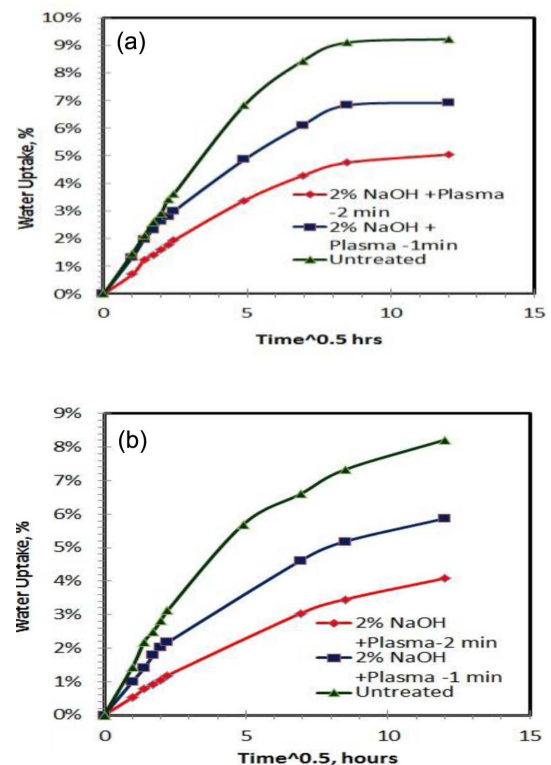
Table 1. Young's modulus of abaca fiber reinforced epoxy composite

Plasma exposure time, min	Young's Modulus, GPa	
	No pretreatment	2% NaOH
0	2.59	2.67
1	2.82	2.75
2	2.76	2.77
2.5	2.64	2.72

tion times. The moisture uptake increased with time indicating that the water molecules penetrate into the composites thus gaining weight. At early time, the weight abruptly increased showing the rapid water penetration into the composites. It was observed that the behavior of water uptake of plasma treated abaca composite was dependent on the type of medium. The curves in Fig. 2(a) in which the composites were immersed in distilled water have reached their saturation state after prolonged time with maximum moisture while the composites immersed in salt solution (Fig. 2b) showed continuous increasing of weight. Increasing the plasma exposure time showed lower water uptake in distilled water whereas very slight difference in salt solution. However, it is interesting to note the water uptake of composite in salt solution is lower than in distilled water. Fig. 3 shows the water uptake behavior of composite made up of abaca fiber which undergone pretreatment of 2% NaOH prior to plasma treatment. Similar to plasma treated abaca composite at initial time, the weight sharply increased both in distilled water and salt solution. However, saturation stage was observed in distilled water compared to a continuous weight increase in the salt solution. It is clearly seen that the treated fibers resulted in much lower water uptake than with no treatment.

The comparison of water uptake of hybrid treatment and plasma treated for 2 min and treated and hybrid treatment is shown in Fig. 4. It can be seen that the water uptake both in distilled and salt solution of hybrid treatment is lower water uptake than treated only with plasma. This is attributed to the removal of lignin and hemicelluloses after alkali treatment, thus increasing the fiber roughness in which mechanical interlocking, and also the amount of cellulose exposed. However, all the composites immersed in salt solution did not reach saturation after prolonged time suggesting non-Fickian behavior compared in distilled water almost plateau value after 100 hrs.

SEM micrographs in Fig. 5 show the effect of water uptake on the surfaces of untreated, plasma treated for 1 and 2 min. It is clear from Fig. 5 (a and b) that microcracks were formed on the surface of the matrix. The abaca is hydrophilic and readily absorbs water that developed internal stresses between the fiber and the matrix. The effect of water absorption resulted to fiber debonding, as shown in the arrow (Fig. 5b). No microcracking and debonding was observed in Fig. 5(c). Matrix

**Fig. 2.** Water uptake of plasma-treated abaca fiber reinforced epoxy composite in (a) distilled water (b) salt solution.**Fig. 3.** Water uptake of hybrid treatment of 2%NaOH and plasma abaca fiber reinforced epoxy composite in (a) distilled water (b) salt solution.

microcracking, poor interfacial between the fibers and the matrix and anatomical characteristics of abaca fibers, as shown

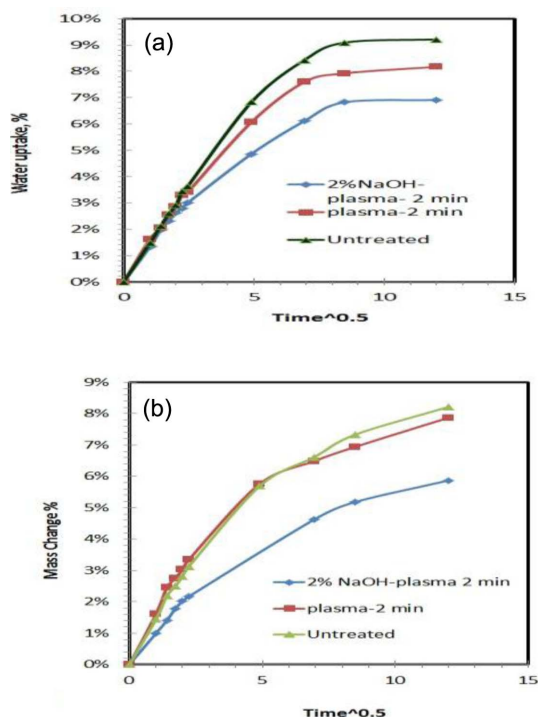


Fig. 4. Comparison in water uptake of plasma treated and hybrid treatment in (a) distilled water (b) salt solution.

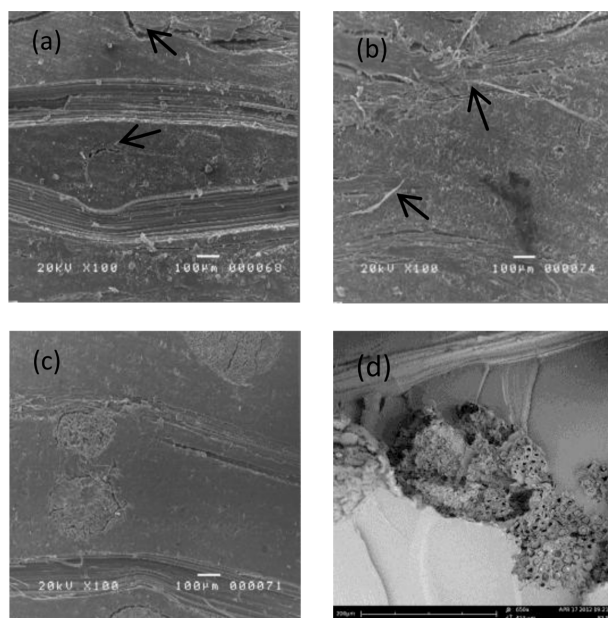


Fig. 5. SEM micrographs of (a) untreated (b) plasma treated for 1 min (c) plasma treated for 2 min after water uptake experiment (d) plasma treated for 2 min before immersion in distilled water. Magnification of a-c : 100 µm and d: 650 µm.

in Fig. 5(d), are the factors that responsible in poor composites properties in humid conditions.

4. CONCLUSION

The following conclusions could be drawn from the results:

The tensile properties of the abaca/epoxy composites were improved by treating the abaca fibers with plasma.

The tensile strength of the composites treated with plasma was significantly superior to those with hybrid treatment and no treatment.

The amount of water uptake was clearly dependent on the medium of solution.

The water absorption of the composite was reduced with increasing plasma exposure time and further reduced with hybrid treatment of NaOH and plasma.

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REFERENCES

1. http://fida.da.gov.ph/Templates/abaca_production_and_market_scenario.htm. 2011. Fiber Industry Development Authority. Abaca Production and Market.
2. Bledzki, A.K., Mamun, A.A., and Faruk, O., "Abaca Fibre Reinforced PP Composites and Comparison with Jute and Flax Fibre PP Composites," *eXPRESS Polymer Letters*, Vol. 1, 2007, pp. 755-762.
3. Huang, G., "Tensile Behaviours of the Coir Fibre and Related Composites after NaOH Treatment," *Materials and Design*, Vol. 30, 2005, pp. 3931-3934.
4. Bledzki, A.K., Faruk, O., and Sperber, V.E., "Cars from Bio-fibres," *Macromolecular Materials and Engineering*, Vol. 291, 2005, pp. 449-457.
5. Scherubi, B., "An Innovative Composite Solution in the New Mercedes a Class-a Successful Story about the Natural Fibre ABACA," In: *Proceedings of Sixth Global Wood and Natural Fibre Composites Symposium*, Kassel, A 12, April 2006.
6. Eichholzer, W., *Natural Fibre Applications in Automotive Manufacturing* In: *Proceeding of Sixth Global Wood and Natural Fiber Composites Symposium Kassel A11*, April 2006.
7. Hintermann, W., *Automotive Exterior Parts from Natural Fibers*. RIKO 2005. Hannover, Germany 2005.
8. Li, X., Tabil, L.G., and Panigrahi, S., "Chemical Treatments of Natural Fiber for Use in Natural Fiber-reinforced Composites: A Review," *Journal of Environmental Polymer Degradation*, Vol. 15, 2007, pp. 25-33.
9. Corrales, F., Vilaseca, F., Llop, Girones, M., Mendez, J.A., and Mutje, P., "Chemical Modification of Jute Fibers for the Production of Green Composites," *Journal of Hazardous Materials*,

- Vol. 144, 2007, pp. 730-735.
10. Rana, A.K., Manda, A., Mitra, B.C., Jacobson, R., Rowell, R., and Banerjee, A.N., "Short Jute Fiber-reinforced Polypropylene Composites: Effect of Compatibilizer," *Journal of Applied Polymer Science*, Vol. 69, 1997, 329-338.
 11. Seki, Y., Sever, S., Sarikanat, M., Gulec, H.A., and Tavman, I.H., "The Influence of Oxygen Plasma Treatment of Jute Fibers on Mechanical Properties of Jute Fiber Reinforced Thermoplastic Composites", 5th International Advanced Technologies Symposium (IATS'09), Karabuk, Turkey. May 13-15, 2009.
 12. Yasuda, H., Plasma Polymerization, Academic Press, Orlando, Florida, 1985.