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# REVIEW: RESEARCH AND APPLICATION OF BAMBOO AND JUTE FIBERS REINFORCED POLYMER COMPOSITES IN VIETNAM

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ABSTRACT

*In Vietnam, 102 species with 19 geniuses of bamboo families are recorded. But the most popular is Dendrocalamus membranaceus Munro. It has been selected forestation in the provinces from the North Central to Central area of Vietnam. Fabricated bamboo fibers by mechanical and steam exploded techniques consist of short and long fibers. Different methods of bamboo fiber surface treatment have been carried out and alkaline treatment was the best method. Thermoplastic resin (polypropylene -PP) and thermoset resin (unsaturated polyester - UP and epoxy - EP) were used as matrices of composites. Maleic anhydride grafted polypropylene (MAPP) was chosen as coupling agent to improve adhesion between PP and bamboo fiber. Polymer composite materials were reinforced by only bamboo fiber according to skin-core and ply-by-ply structure. Bamboo-PP resin composites with 50 wt. % of bamboo fiber has higher mechanical properties in comparison with pure PP. Bamboo- UP resin composites possess good mechanical and chemical properties, whereas bamboo-EP resin composites show unsatisfied water and chemical resistance. Skin-core structure hybridization of jute with glass fiber in skin increased impact strength significantly (1.8-2.0 times). This hybrid composite was used for making chair, tables, boats, construction panels, etc… Short bamboo fiber-PP composites are going to prepare pall rings using for waste water treatment in the present of micro-organism.*

**Keywords:** *Bamboo fibers, bamboo extraction, fiber treatment, natural fibers.*

## I - INTRODUCTION

Vietnam locates in the area where climate is suitable for the prolific cultivation of bamboo. At present, about 800,000 hectares of pure bamboo forest and 700,000 hectares of bamboo-wood mixed forest have been surveyed [1]. In Vietnam, up to 2003 year, bamboo has been known as raw materials for handicraft manufacturing, paper industry and construction [2].

After the Japan - Vietnam Joint Symposium on Bamboo and Composite Materials organized at November 25-26, 2003 in Hanoi and thanks to devoted support of Prof. T. Fujii - director of Research and Development Center on Bamboo Resources, Doshisha University, the research on bamboo fibers as reinforcement for polymer composites was began in Polymer Centre, Hanoi University of Technology (HUT).

This paper presents main research and application result of bamboo and jute polymer composites in period 2004-2007 in Vietnam.

## II - EXPERIMENTAL

## 1. Materials

- Polypropylene (PP Hoplen CY 130 was received from Honam Petrochemical Corporation, Korea).

- Maleic anhydride grafted PP (MAPP) can be effectively modified by maleic anhydride because maleic anhydride provides polar interactions and cocalantly link PP to hydroxyl groups on the cellulose fiber [3]. In this study MAPP was received from Aldrich (USA) with maleic anhydride (MA) content of 0.6% and from Polymer Centre, HUT with MA content of 0.5 % in weight. These above MAPP were used as coupling agent which mixed with pure PP at a ratio 8:92 in weight.

- Unsaturated polyester resin (Oxnopol - 2112, Norpol Polymer, Malaysia)

- Cycloaliphatic epoxy resin EPR 760, hardener EPH 860 and catalyst EPC100 (dimethylbenzylamine-DMBA) were supplied by Bakelite GmBH, Germany.

- Glass fiber (mat 300 $g/m^2$ and roving 300 $g/m^2$ were imported from Korea.

- Plain wear jute fabrics (280 $g/m^2$) were supplied by Hanoi Jute Factory.

Bamboo fiber (BF) was prepared at Polymer Centre, HUT.

## 2. Grafting of MA onto PP by reactive processing

The grafting reactions of MA onto PP by reactive processing were carried out in Leistriz twin-screw extruder. The reactive extruder process was performed using the following conditions: temperature profiles 165, 170, 180, 180, 180, 180, 180 and 170ºC; screw speed at 50 rpm. The following ratio ware used 100/1.2/0.5 phr for PP/MA/dicumin peroxide, respectively. All components of the reaction were simultaneously introduced in the main feeder of the extruder. The rods from the extruder were cut into granules about 4mm long after cooling in the water batch.

## 3. Methods for extracting bamboo fibers

*a) Mechanical method*

Short BF was mechanically extracted by a rolling and cutting machine. At first, bamboo slabs were rolled into bamboo chips by two rolls machine. Short BD was obtained from bamboo chips using the cutting machine.

*b) Chemical - mechanical method [4]*

Long BF was extracted by sodium hydroxide treatment. Firstly, thin bamboo strips were put into sodium hydroxide solution 1.5 N for 10 h at 70ºC. Then, treated bamboo strips were separated into long BF by scratching through steel nails. The average diameter of long BF was 147 μm.

*c) Steam explosion method [3]*

The steam explosion technique was applied to extract fiber from bamboo tree. The conditions of the steam explosion show in table 1.

*Table 1*: Conditions of the steam explosion method

| Content | Time, min | Temperature, ºC | Pressure, MPa | Number of cycles |
|---|---|---|---|---|
| Bamboo | 110 | 170-180 | 0.12-0.18 | 11 |

The bamboo bubbles were not effectively separated into single fibers; therefore this kind of bamboo fiber was used mainly for preparing bamboo mat.

## 4. Micro-droplet tests

Micro-droplet test (see Fig. 1) were carried out by using material testing machine Lloyd 0.5 KN [5]. Test was conducted under the laboratory condition: 25□3ºC and 70% RH. The crosshead speed was 5 mm/min. The interfacial shear strength (IFSS) is calculated by the following equation [6]:

$$IFSS = Fp(L1.L2)$$

Here, Fp is the maximum load to pull out the fiber from the matrix. $L_1$ is the embedded length of fiber. $L_2$ is the circumference of the fiber.

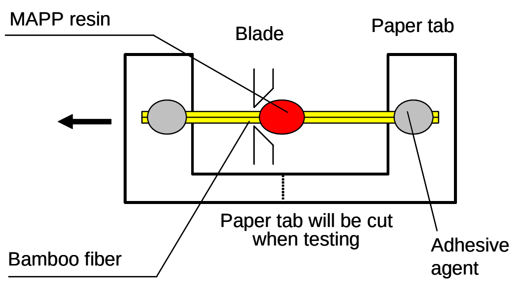


*Fig. 1*: Schematic drawing of micro-droplet testing

**5. Tensile test of bamboo fiber bundle**

First of all, the basic components of bamboo fiber bundles were investigated in order to determine its specific properties. The average diameters of fiber bundles were measured in microscope (the number of observations were about 30). Fig. 2 shows the dimensions of the fiber bundle specimen.

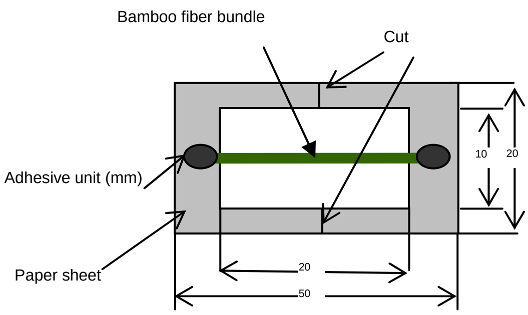


*Fig. 2*: Dimensions of specimen for fiber bundles tensile test

Before the test, fiber bundles were dried for 2 hours at 120ºC. Then one of bamboo fiber bundle was glued on a sheet of paper. The paper works as an attachment for the specimen. Then, the gage positions of the paper were cut after chucking it on the testing machine to apply the tensile load. Tensile test were conducted using a small-capacity testing machine Lloyd 0.5 KN at 5mm/min of crosshead speed. The reaction force and displacement of the chuck were monitored with connected PC, and nominal stress and strain were determined while the tensile was being loaded to the specimen at laboratory condition. Their moduli were also estimated by the responses of nominal stress and strain.

**6. Composite testing methods**

- The tensile tests were carried out with the universal testing machine (Instron 100kN, Model 5582 and Lloyd 0.5 kN, LRX Plus) according to ISO 527-1993E at a cross head speed of 5 mm/min, while bending test were conducted according to ISO-178-1993 at the same cross head speed.

- Impact strength was performed with the testing machine (Tinius Olsen, Model 92T) according to ASTM D256.

- Bucker Tensor 27 FT-IR spectrophotometer was used to obtain the IR spectra of fibers at a resolution of 4 $cm^{-1}$.

- Dynamic contact angle analyses were performed on a Thermo Cahn, series 300 at 22ºC in an air-conditioned room.

- Morphology of polymer composite material and fiber surfaces were investigated by Jeol JSM-6360LV scanning electron microscope operating at a Voltage of 20KV.

## III - RESULTS AND DISCUSSION

**1. Surface treatment of bamboo fibers**

Methods of surface modification of natural fiber were presented by A.K. Bledzki, J. Gassan [7]. Recently, different studies on surface treatment of bamboo fibers were carried out at Polymer Centre, HUT [8-11] such as: acetic anhydride, acrylonitrile, air-plasma and alkaline treatment. However, alkaline treatment is the most suitable method [12]. According to this method, the bamboo strips were soaked in 0.1N NaOH solution for 72h.

**2. Characterization of bamboo fiber surface by dynamic contact angle method [13]**

Wetting parameters, e.g., contact angles, work of adhesion, fiber surface energy and interfacial energy of the untreated and the alkaline-treated bamboo fiber extracted by a steam explosion method have been determined using a dynamic contact angle technique (Wilhelmy technique). In this technique, the contact angle θ, at the solid/liquid/vapor boundary interface was calculated by the following equation:

$$F.g=\gamma.p.\cos\theta$$

Where F is the interaction force between fiber and liquid; g is the gravitational constant; p is the wetted perimeter of the bamboo fibers; γ is the surface tension of the liquid. Surface free energy of bamboo fiber and PP films were indirectly determined by Geometric mean method in which surface free energy of the solid (γ) was consisted of two components, polar ($\gamma^p$) and dispersive ($\gamma^d$), and expressed as: $\gamma = (\gamma^p) + (\gamma^d)$. When the bamboo fibers were partially immersed in the liquid, the relationship between the contact angle and the surface free energy of the bamboo fiber was:

$$\gamma_{LV}\,(1+\cos\theta)=2\left(\sqrt{\gamma_{SV}^{d}\gamma_{LS}^{d}}+\sqrt{\gamma_{SV}^{p}\gamma_{LV}^{p}}\right)$$

Where $\gamma_{LV}$, $\gamma_{SV}$ are the surface tension of the liquid and bamboo fibers, respectively.

The surface of fibers was also analyzed with scanning electron microscopy. The treatment effects on the fibers have been characterized by infrared spectroscopy. It was found that the bamboo fibers were partially wetted out by polar solvents. A baseline shift hysteretic was observed, possibly due to the hydration of the bamboo surface. This study shows that the alkaline treatment does lead to an increase of hydrophobic of bamboo fibers, due to the decrease of roughness and hydroxyl groups on the surface of fibers.

In the case of PP, adding 8 wt% of MAPP causes polymer surface free energy and polarity to significantly increase. By comparing the wet ability of fiber and polypropylene, the alkaline treated bamboo fibers could be expected to have better adhesion with modified PP than untreated bamboo fibers.

## 3. Mechanical properties of bamboo fiber bundles

- Diameter distribution of bamboo fiber bundles

Diameter of untreated and treated bamboo fiber bundles were measured by optical microscopy with 50 samples for each fiber type. The distribution of bamboo fiber bundle's diameters is shown in figure 3. This figure indicated that the diameter of treated fiber is much smaller than that of untreated fiber. The average diameter of treated and untreated fiber was 136.6 μm and 216.3 μm respectively. It might be caused by the removal of lignin and hemicelluloses in fiber surface.

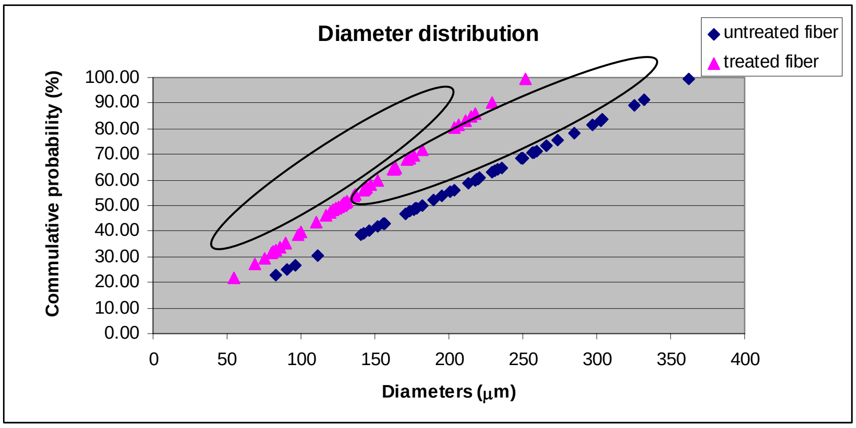


*Fig. 3*: Diameter distribution of bamboo fiber bundles

- Mechanical properties of bamboo fiber bundles

Mechanical property of bamboo fiber bundles was investigated via fiber's tensile strength. 50 samples of each treated and untreated fiber type were tested by LLoyd 0.5 KN machine. Tensile strength distribution of bamboo fiber bundles is shown in figure 4 as below. Those distributions of fiber's tensile strengths show that tensile strength of treated fiber is much higher than that of untreated with 393.78 MPa and 301.2 MPa in average respectively.

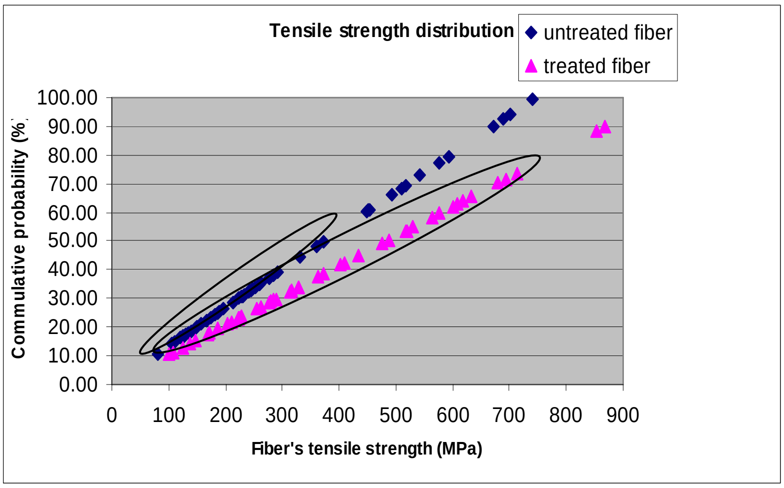


*Fig. 4*: Tensile strength distribution of bamboo fiber bundles

- Effect of alkaline treatment on IFSS of bamboo fiber bundles with MAPP resin

IFSS of treated and untreated bamboo fiber bundles with MAPP resin was tested with 45 samples each type by LLOYD 0.5 KN machine. The distribution of those properties is described in figure 5 below. This figure shows that IFSS of treated fiber was much higher than that of untreated fiber with 4.21 MPa and 3.17 MPa in average respectively.

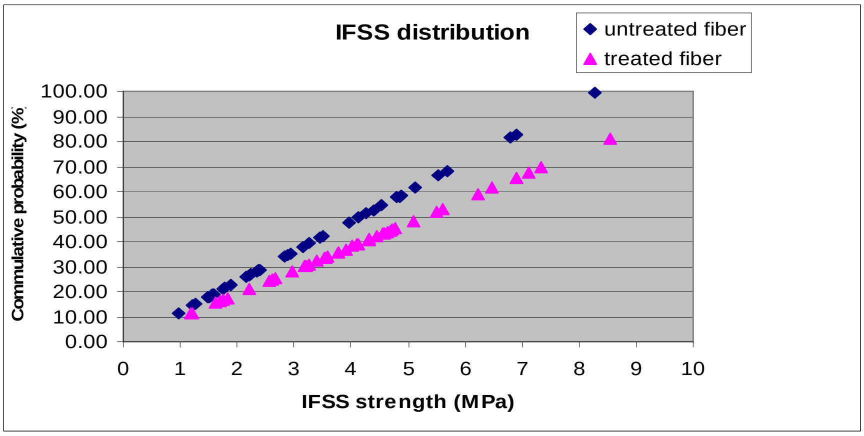


*Fig. 5*: IFSS distribution of bamboo fiber bundles with MAPP

**4. The effect of position along bamboo trunk on properties of fibers and composites [14]**

- The distribution of bamboo fibers

Fig. 6 showed the distribution of bamboo fibers extracted from different part of raw bamboo trunk

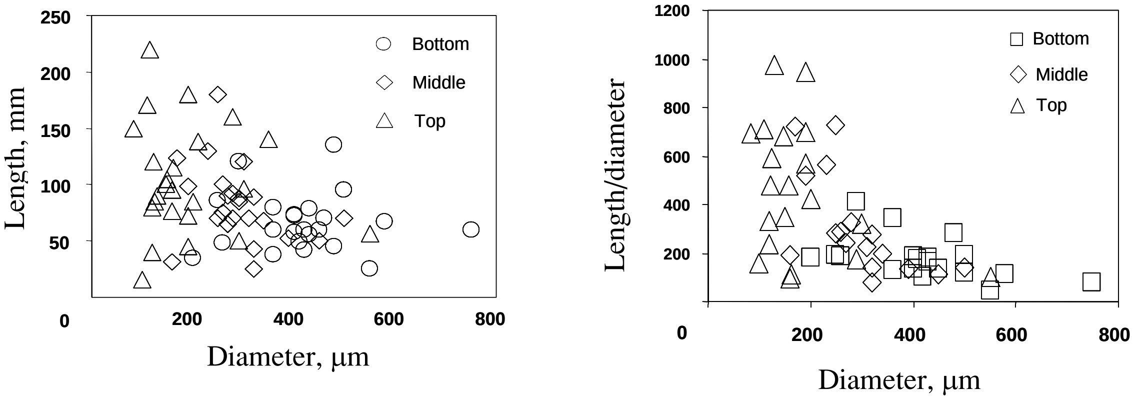


*Fig. 6*: The distribution of bamboo fibers

It is clear that the bamboo fiber from the top and the bottom have wide rank distribution. The diameter is from 150 to 800 µm while the bamboo fibers from middle of trunk gave the steadier on diameter (200 - 450 µm). However, the aspect ratio of bamboo fibers from the top is better than that of bamboo from other part of bamboo trunk.

- Bamboo fiber strength.

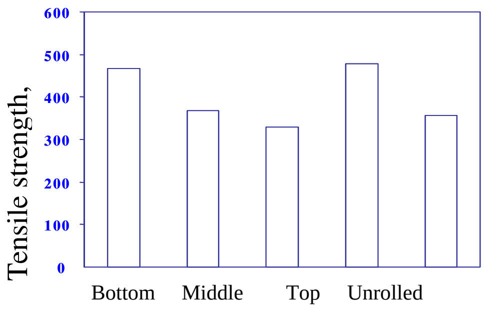


*Fig. 7*: Tensile strength of bamboo fibers

In the Fig. 7, tensile strength of bamboo fibers decreased from bottom to the top of bamboo fibers. This can be explained that in the bottom, the cellulose content is higher than other part and it decreased along the tree from the bottom to the top. Therefore, the tensile strength of bamboo fibers increased from the top to the bottom. The extracting method was also affected on the tensile strength of fibers. The fibers extracted using roll machine was have lower tensile strength. The SEM image (Fig. 8) of bamboo fibers was proved the explanation above. It is clear that the soft cell on the fibers surface increased from the bottom to the top of bamboo trunk. It means that the bamboo fibers of the bottom are hardest and it reduced along the height of trunk. With the unrolled bamboo fibers, the surface was flat and covered by a soft layer. Thus, during the rolling process, the structure of bamboo slat was destroyed and it was soften. Therefore, the bamboo fibers were extracted more easily and the surface was rough.

Practically, the mixed bamboo fiber composite reinforced both PP and UP resin have high strength (10% lower than middle bamboo fiber). Therefore, the whole bamboo trunk can be applied for making bamboo fiber but not scarifying much strength of composite.

## 5. Preparation of polymer composite based on PP reinforced by short bamboo fibers and their product [15]

This study presents the results of the effect of short bamboo fiber prepared by mechanical method and alkaline treatment on mechanical properties of composites based on PP. With content of 50 wt.% in composition, the tensile, the flexural and impact strengths have been increased as 24%, 23% and 40%, respectively compared with pure PP. Using the prepared bamboo fiber by steam explosion method in stead of mechanical one, the tensile strength of composite increased 16%, meanwhile the flexural and impact strength have the equivalent value. The composite reinforced by 50 wt.% of short bamboo fiber inside washing and absorption scrubber using for waste water treatment in the present of micro-organism (see Fig. 9).

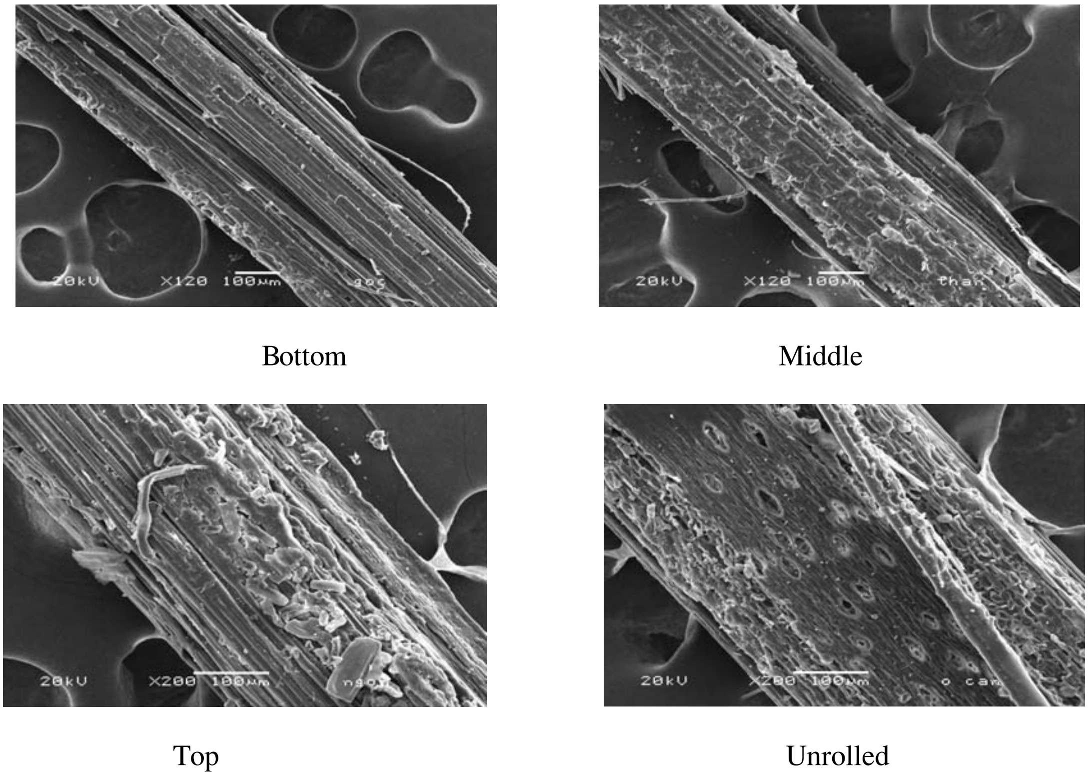


*Fig. 8*: SEM image of bamboo fiber surface

*Fig. 9*: Short bamboo fiber - PP pall rings

## 6. Properties of composite based on hybrid jute-glass fiber reinforced PP by ply-by-ply and skin-core structures [16]

In order to improve the mechanical properties of composite based on PP reinforced by jute fibers as well as to enhance the resistance to chemicals and to reduce the moisture absorption of composite, hybrid jute/glass fiber composite was developed with ply-by-ply (alternative lay-up) and skin-core (glass fiber mats for skin layer and jute fiber for core layer) structures. Their mechanical properties are given in table 2.

*Table 2*: Mechanical properties of hybrid composites

| No | Reinforced system | Jute/glass fiber ratio | Tensile strength, MPa | Flexural strength, MPa | Impact strength, MPa |
|---|---|---|---|---|---|
| 1 | Jute cloth 280 g/m$^2$ | 100/0 | 76.4 | 105.1 | 13.2 |
| 2 | Glass mat 300 g/m$^2$ | 0/100 | 120.6 | 140.5 | 182 |
| 3 | Jute/glass mat (ply-by-ply) | 60/40 | 83.2 | 133.6 | 32.8 |
| 4 | Jute/glass mat (skin-core) | 70/30 | 78.4 | 148.2 | 26.4 |
| 5 | Jute/glass mat (skin-core) | 60/40 | 83.6 | 162.6 | 38.9 |
| 6 | Jute/glass mat (skin-core) | 50/50 | 86.1 | 152.4 | 35.6 |
| 7 | Jute/glass mat (skin-core) | 40/60 | 100.8 | 148.0 | 31.1 |

A composite using hybrid jute/glass fiber layer has higher tensile and flexural strengths than composite reinforced by only jute fabrics. The test results also indicate that composite with skin-core structure has more superior mechanical properties than those of composite hybridized by ply-by-ply stacking sequence when the hybrid ratio between jute/glass fiber is constant (60/40).

It is understand that the tensile strength of hybridized composite significantly increases with increasing the glass fiber content. However, an increase of glass fiber scarifies weight saving as well as damages the environment. The hybridized composite has the best flexural strength of 162.6 MPa which is 1.2 times higher than that of composite reinforced by glass fiber mats only (140.5 MPa).

In particular, hybridization of jute/glass fibers remarkably increases the impact strength of composites which have either ply-by-ply lay up sequence or skin-core structure. For the skin-core composites, the impact strength increases 190% compared not only to jute fiber composite but also the glass fiber composite. These hybridized composites can be used for high impact resistant structures. An appropriate fiber fraction and combination of reinforcements increase the mechanical properties of hybrid composites and bring considerable benefits to the economy and the environment.

## 7. Water absorption and diffusion coefficient of short bamboo fiber reinforced hot curing epoxy resin composite [17]

The influence of short bamboo fiber on water absorption was shown in Fig. 5.

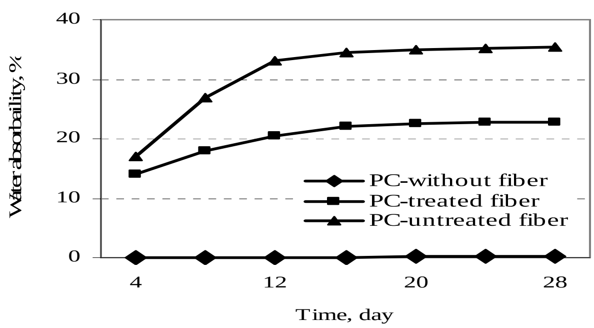


*Fig. 8*: Water absorption of materials

Fig. 8 showed that water absorption increased remarkably due to the presence of bamboo fiber. Water absorption of materials reinforced by treated fiber was much smaller than that of materials with untreated fiber. Also, this high water absorption weakened mechanical properties of materials after 42 days water soaking. The mechanical property decrease was shown in table 3.

From water absorption of different times and using the Fick law combined with the T.S. Postovskaia's extrapolation method [18] the diffusion coefficient materials was calculated. The results were presented in table 4.

*Table 3*: The mechanical properties decrease of materials after 42 days water soaking

| Properties | Non-soaking | Soaking | Decreases, % |
|---|---|---|---|
| Tensile strength, MPa | 66.7 | 17.8 | 73.3 |
| Flexural strength, MPa | 89.2 | 22.6 | 74.7 |

*Table 4*: Diffusion coefficient of materials

| Sample | $\sum_{i=1}^{n} \tau_i^2$ | **$Q_{max}$** | $\sum_{i=1}^{n}\left(-\ln\frac{Q_{max}-Q_i}{Q_{max}}\right)\times\tau_i$ | **λ** | **$D.10^9 cm^2/s$** |
|---|---|---|---|---|---|
| PC-untreated fiber | 31104 | 29.4 | 682.6 | 0.022 | 22.38 |
| PC-treated fiber | 838656 | 24.1 | 4793.5 | 0.0057 | 7.77 |
| Without fiber | 1880064 | 1.1 | 5157.4 | 0.0027 | 4.75 |

$\tau_i$ Time, hour; $Q_i$ % weight gain after $\tau_i$ hours; $Q_{max}$ the % balance weight gain after $\tau_i$ hours (determined by T.S. Postovskaia's extrapolation method)

The diffusion coefficient of materials increased because of short bamboo fiber present. The diffusion coefficient of materials reinforced by unsaturated fiber was 20.38. $10^{-9}$ $cm^2/s$ and 13 times higher than that of materials with treated fiber. This indicated that the water resistance of materials reinforced by treated fiber was smaller than that if materials without fiber but still much higher than that of materials with untreated fiber. This confirmed that the alkaline treatment increases adhesion between fiber and matrix.

## 8. Short bamboo fiber PP-composite using to prepare waste water treatment pall rings in the present of micro-organism

- General requirements for micro-organism attached-growth media material.

Due to important role in waste treatment, material for micro-organism attached-growth media (MAGM) has to meet some special requirements:

- Having suitable strength
- Resistance in media of waste water
- Easy for attachment by micro-organism.

The obtained short bamboo fiber PP composite was satisfied all mentioned above requirements.

- Manufacturing of MAGM

After analyzing some type of MAGM, the spherical form of MAGM was designed. The main characteristics of these MAGM are presented in table 5.

Spherical MAGM were manufactured from short bamboo fiber PP-composite by common injection machine. Then they were used to fill in two waste water treatment columns at Institute for Environmental Science and Engineering, Hanoi University of Civil Engineering. The first column run in down-flow regime under aerobic condition as trickling filter. The second column was run in up-flow regime under anaerobic condition as anaerobic filter.

The effectiveness of MAGM was calculated after 16 months treatment (from 8/2004-11/2005). The main results are presented in tables 6 and 7.

*Table 5*: Main characteristics of spherical MAGM

| Diameter, mm | Quantity, piece/$m^3$ | Surface area, $m^2/m^3$ | Wall thickness, mm | Hollowness, % |
|---|---|---|---|---|
| 60 | 5600-5700 | 210-218 | 1-1.5 | 88-89 |

*Table 6*: Aerobic treatment process with MAGM trickling filter model

| No | Parameters | Water in, mg/l | Water out, mg/l | Removal efficiency, % |
|---|---|---|---|---|
| 1 | Suspended solods | | | |
| | Max | 258.7 | 142.7 | 92 |
| | Min | 36.7 | 15.3 | 11 |
| | Average | 123.8 | 48.1 | 56.5 |
| | Standard deviation | 64.4 | 32.4 | 21.1 |
| 2 | Chemical oxygen demand | | | |
| | Max | 295 | 82.1 | 89.5 |
| | Min | 75 | 23.4 | 30.8 |
| | Average | 196.2 | 54.2 | 63.4 |
| | Standard deviation | 72.9 | 17.1 | 17.6 |

*Table 7*: Anaerobic treatment process with MAGM in up-flow anaerobic filter model

| No | Parameters | Water in, mg/l | Water out, mg/l | Removal efficiency, % |
|---|---|---|---|---|
| 1 | Suspended solods | | | |
| | Max | 398.1 | 139.6 | 96.9 |
| | Min | 75.4 | 32.5 | 34.8 |
| | Average | 175.5 | 43.4 | 74.0 |
| | Standard deviation | 59.2 | 6.6 | 16.5 |
| 2 | Chemical oxygen demand | | | |
| | Max | 416.0 | 156.4 | 87.4 |
| | Min | 193.3 | 42.7 | 45.2 |
| | Average | 301.1 | 96.9 | 67.4 |
| | Standard deviation | 53.4 | 27.8 | 9.3 |

The results shows that the treated waste water after MAGM made from short bamboo fiber PP-composite can satisfy the class A-B of Vietnamese standard for waste water.

## IV - CONCLUSIONS

Due to cooperation with Research and Development Center on Bamboo Resources, Doshisha University, Japan, the different topics of research and application bamboo fibers for polymer composites have been carried out successfully at Polymer Centre, HUT, Vietnam.

The obtained results were stimulated the reaction and perception of the industrial people about the role of bamboo in the sustainable economic development. We are sure bamboo can compensate the lack of other natural plants.

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