DEVELOPMENT OF A PLEASURE BOAT USING BAMBOO FIBER REINFORCED PLASTICS

Ryusuke TANAKA*, Kazuya OKUBO*, Toru FUJII*, Masao ONO, Akio SAKURAI****
***Doshisha University, Department of Engineering & Systems,**
****Osaka Branch, National Maritime Research Institute**

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Abstract

Pleasure boats for three persons were fabricated by using the Va-RTM with Bamboo FRP (BFRP). The lacks of BFRP strength and moisture absorption of bamboo fiber during fabrication are the most important problems which should be conquered in the case of BFRP application. Non-woven mats using relatively short and curled bamboo fibers are convenient as reinforcement because it is technically difficult and expensive to extract fine, long and straight bamboo fibers. The carding process is necessary to get fine bamboo fibers. As a result, the observed Young's modulus of BFRP is more inferior than that of GFRP. Therefore, the specific rigidity must be improved due to sandwich structure. Consequently, the rigidity of BFRP-sandwich boats can be as high as that of GFRP boats. However, the impact strength of BFRP-sandwich structure is still lower than the strength enough to survive the boat-dropping test. Partial patches, namely, adding straight bamboo fibers onto the bamboo mats is one of idea to increase the impact strength of the boat. Moisture absorption of bamboo fibers during fabrication causes delamination of gel coat. This delamination occurs due to vapor caused by heat of the thermoset resin during the curing stage .If bamboo mats are well dried before the Va-RTM process, no significant water vapor is emitted. As a result, little delamination occurs.

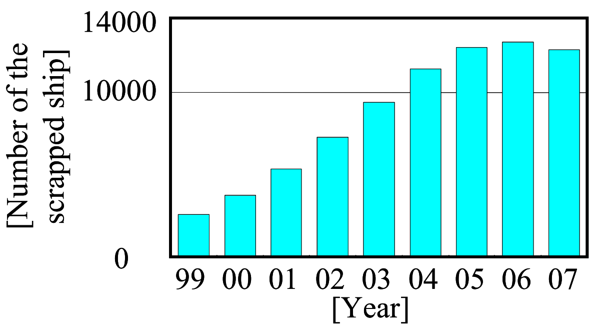

Fig.1 Variation of the number of scrapped FRP ships with respect to year

1 Introduction

Glass Fiber Reinforced Plastics (GFRP) have superior mechanical characteristics such as high specific strength, high endurance and high impact strength. Therefore, GFRP have used for various fields such as bathtubs, building materials, cars or ships. Above all, a lot of GFRP small boats such as pleasure boats were manufactured from 1970's. The life of GFRP pleasure boats is about 30 years from 50 years. And, the number of ships scrapped has been increasing rapidly in Japan. It is estimated more than 10,000 every year as can be seen in Fig.1 [1]. Presently we need additional energy for scrapping waste GFRP ships since noninflammable glass fibers are contained in GFRP. We cannot ignore the impact to the environment due to scrapping, and it becomes the serious social issue [2]. The primary disposal method for scrapped ships is the landfill disposal method since GFRP is not burnable. In addition, the cost of landfill disposal is expensive and about 10,000$ per a ship. The expensive disposal cost is one of reasons for illegal ship dumping. These problems can be solved if scrapped ships could easily be burned and the thermal energy would be obtained. Namely, FRP ships are made with burnable reinforcement, natural plant fibers such as jute and kenaf. We may greatly reduce the disposal cost due to easy burning. We may have a chance to obtain some energy when natural plant fiber FRP ships and incineration are enabled when the natural fiber. The use of natural plant fibers also contributes to reduce CO_2 emitted into the atmosphere since energy consuming glass fibers are replaced by a CO_2 neutral material [3].

Natural plant fibers are now booming as one of biomass. Usage of jute and kenaf are now increasing,

Fig.2 Photograph of a BFRP pleasure boat

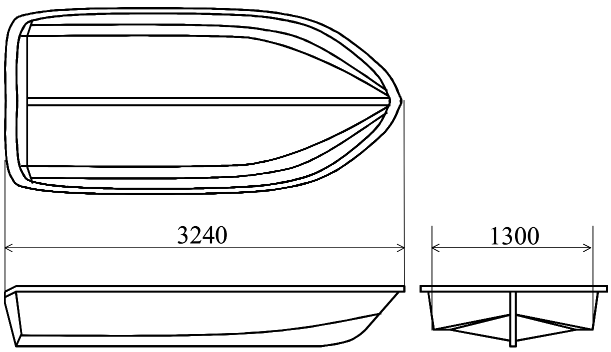

Fig.3 Drawing of a BFRP pleasure boat

and consequently a new environmental problem may occur. Some wood forests are cut and the new flat lands are cultivated, changing their flora. On the other hand, bamboo is quite abundant natural and sustainable resource, but not industrially used. They usually grow in rivers, hills and mountains where people do not positively utilize. Therefore, we try to use bamboo fibers instead of other conventional plant fibers as reinforcement for FRP.

Bamboo fiber has relatively high specific strength and high specific stiffness among natural fibers. The purpose of this paper is to reveal whether bamboo fibers are applicable as reinforcement of FRP used for pleasure boats instead of glass fibers.

Fig.4 Non-woven bamboo fiber mat

2. Fabrication of BFRP pleasure boats

Figure 2, 3 shows the BFRP boat and a drawing of one. In order to examine the applicability of bamboo fiber reinforced plastics (BFRP) to pleasure boats carrying three person are fabricated.

2.1 How to fabricate a small pleasure boat using bamboo fiber reinforcement

There are several methods to fabricate relatively large structures; Hand-Lay-Up method, Spray-Up method, Resin Transfer Molding Method (RTM). The RTM is desirable from a viewpoint of quality control. However, the cost is expensive for trial since both male and female molds must be prepared. Therefore, we chose Va-RTM (Vacuum assisted-RTM) method. No male mold is necessary for Va-RTM and high reinforcement fraction can be achieved in the case of thick and irregular reinforcement. This method has been introduced to fabricate small boats by two of the authors at National Maritime Research Institute.

2.2 Materials

Bamboo fibers extracted by NaOH treatment were imported from Indonesia, of which conditions and procedure had been given by R&D Center of Bamboo Resource at Doshisha University. It is necessary to use reinforcement of a mat form when using the VA-RTM method. However, long and fine bamboo fibers cannot be extracted. Therefore, a non-woven mat (BF mat) was processed using a carding, drafter and needle punch machines as shown in Fig.4. An epoxy acrylate resin (8250L:Japan U-PiCA Co., Ltd.) was used as matrix.

2.3 Processing

How to fabricate a small pleasure boat is given below.

(1) BF mats are precut to fit the female boat mold (see Fig.5).
(2) They are placed onto the mold (Fig.6).
(3) A bagging film is set onto the mats after a mesh cloth is put on the mats to assure good resin flow (Fig.7).
(4) Then, the gap between the bagging film and the mold surface is sealed with sealant (Fig.8).

Fig.5 Precut BF mats

Fig.6 Place onto the mold

Fig.7 Set mesh film

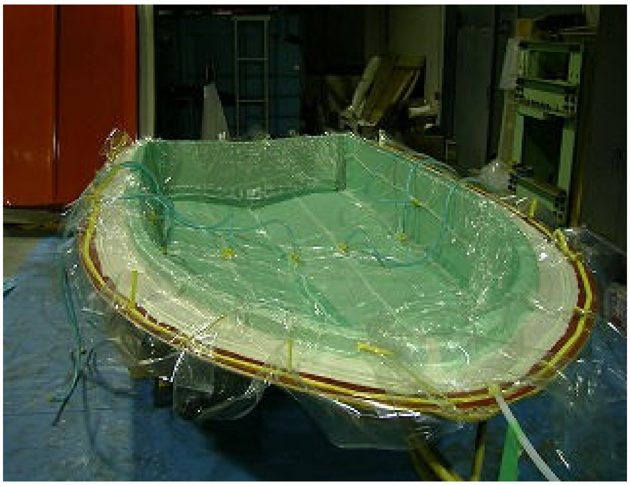

Fig.8 Sealed with sealant

(5) After some mouthpieces are attached to the film , resin is supplied into the mold while the air inside is vacuumed.

Three persons were necessary. The total time for completing one boat was about 25 hours.

2. 4 Problems for fabrication

Some pinholes occurred in the bagging film during vacuuming process, and a lot of air came into the mold through those pinholes. They caused voids while BFRP was consolidating. Some bamboo fibers were vertically directed due to needle punching. Those fibers are enough sharp and stiff to penetrate the bagging film. This problem can be solved by hammering the mats in advance.

There occurred delamination between gel coat and BFRP as can be seen in Fig.9. Delamination occurred at resin-rich regions. Temperature there was recorded beyond 100 ℃ during curing. Such high temperature must have caused the delamination. Fibers were dried in an oven before fabrication. It took about two hours to complete the processes of (2), (3) and (4). Bamboo fiber absorbs a great amount of moisture in only two hours as can be seen in Fig.10. High curing temperature caused vapor emitted from bamboo fibers because they absorbed moisture during fabrication. As a result, delamination occurred due to such vapor [4]. This delamination might cause water seeping into the boat during operation.

We introduce some steps to prevent such delamination as follows. Firstly we increase the bamboo fiber content. We expected that a large amount of fibers might reduce the temperature during the curing period.

3. Performance of pleasure boats using bamboo fibers

3.1 Pleasure boats

Three pleasure boats were fabricated. These were fabricated by using BFRP, GFRP and sandwich panels, respectively.

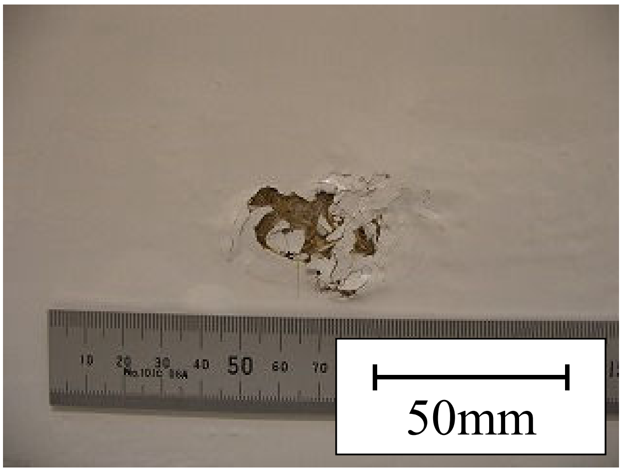

Fig.9 Delamination of gel coat

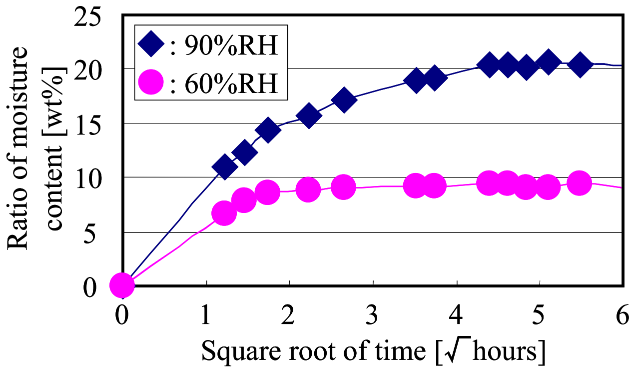

Fig.10 Moisture absorption curves of bamboo fiber

Materials of the BFRP boat were the same materials as those in Chapter.2. The conventional GFRP pleasure boat was fabricated as a control. The material system of GFRP laminates was E-glass/UP. The stacking sequences were [0/90/Random orientation mats (R_c)]. The pleasure boat using sandwich panels was fabricated in order to improve the specific rigidity. KLEGECELL (PVC form GREDO55 KANEKA CO.) was used as the core material of the sandwich structure. Table 1 shows the performance of each boat.

3.2 Experiments

3.1.1 Three-point bending tests

Three-point bending tests carried out in order

Table 1 Performance of each boat

	Material	Weight [kg]	V_f [-]	Board thickness [mm]
1	BFRP	52	13.5±0.5	5.5±0.5
2	BPP-FRP-sw	70	15.3±0.5	14.6±0.6
3	GFRP	38	42.1±0.5	3.2±0.2

Fig.11 Photograph of a drop impact test

to examine the flexural properties of the boat materials according to JIS (Japan Industrial Standard) K-7171. The strain rate was 1.0 %/min.

3.1.2 Boat-dropping test

Boat-dropping tests were carried out at the Osaka branch of National Maritime Research Institute as can be seen Fig.11, according to the standard provided by JCI (Japan Craft Inspection organization). Sandbags instead of three persons were loaded onto the boats. The specifications given in the standard are satisfied when a boat survives the dropping test. The drop height was set 1.72m in this report. The impact force due to dropping from this height is equivalent to the impact, which a boat undergoes when sailing at the speed of 15 knot. The acceleration was measured at the center of gravity of the boat in order to evaluate the rigidity of the boat.

3.2 Results and discussion

3.2.1 Three-point bending tests

Table 2 shows the bending test result. The bending modulus of BFRP was much inferior to that of GFRP. Therefore, the specific rigidity must be improved due to sandwich structure. Figure 12 shows the stacking sequences of BFRP sandwich panel (BFRP-sw). However, the fracture behavior of

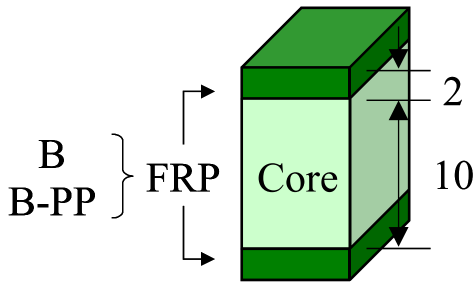

Fig.12 Material design of sandwich panels

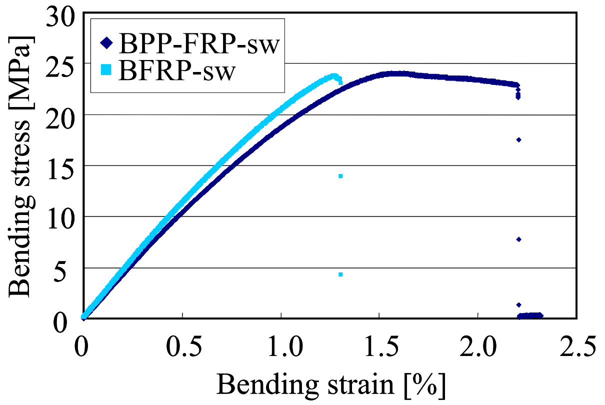

Fig.13 Stress-strain curves of each specimen

Table 2 Result of bending tests

	BFRP	BPP-FRP	BFRP-sw	BPP-FRP-sw	GFRP
Bending rigidity [GPa]	4.35	3.54	2.64	2.19	21.11
Bending strength [MPa]	67.7	62.5	24.4	24.0	433.7
Specific bending rigidity [GPa]	3.97	3.25	4.45	3.95	11.85
Specific bending strength [MPa]	61.8	57.5	41.6	43.1	243.4
Strain at maximum stress [%]	2.10	2.43	1.20	1.46	3.43

BFRP-sw was brittle, as can be seen Fig.13. In general, brittle material is not expected to use as a structural material. Therefore, the fracture behavior of BFRP-sw must be improved. Polypropylene (PP) fiber was mixed with bamboo fibers in the weight ratio of PP:BF=1:4. Then, the fracture behavior was significantly improved, as can be seen Fig.13.

3.2.2 Boat-dropping test

Table 3 shows the boat dropping-test results. The BFRP and GFRP boats satisfied the JCI standard because no visible damage was found after the tests. Therefore, the BFRP and GFRP boats have an enough performance to sail at the speed of 15 knot. However, passengers must not feel safe due to appreciable deformation of the BFRP boat. In order to increase the rigidity of BFRP boats, we may put more bamboo fibers, resultantly the thickness of the boat hull increases. However, it is not a good idea since the commercial value of BFRP boats decreases due to the increase in weight.

Alternatively we may introduce sandwich structure. The rigidity of BFRP-sandwich boats is as

Table 3 Result of boat dropping-tests

Drop height [m]	1.72	2.50
Corresponding speed [knot]	15	30
BFRP	○	×
BPP-FRP-sw	×	—
GFRP	○	○

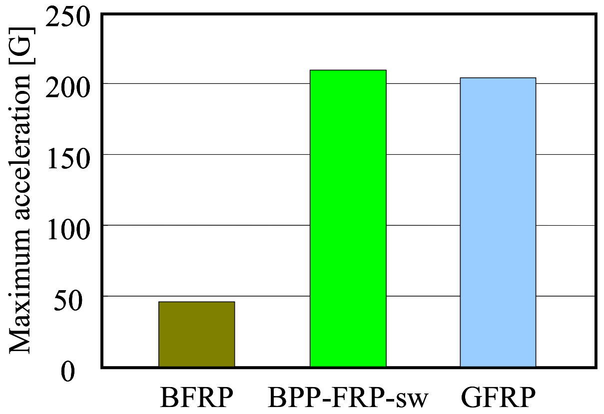

Fig.14 Maximum drop impact acceleration of each boat

high as that of GFRP boats as can be seen in Fig.14. Figure 14 shows the maximum drop impact acceleration for each boat. The rigidity of the boat is high when the maximum drop impact acceleration is high. However, the BPP-FRP-sw boat did not satisfy the JCI standard. There occurred visible cracks and delamination between BPP-FRP and the core as can be seen in Fig.15. This result indicates the lack of BPP-FRP strength. The BF mat cannot effectively reinforce the matrix because curled fibers cannot effectively carry and transfer the load [5]. The tensile strength of BFRP was inferior to that of the matrix as can be seen in Fig.16. Therefore, curled fibers could be defects in FRP. This problem may be solved by using non-woven mats using relatively short but straight fibers.

4. Conclusion

Small pleasure boats were successfully fabricated by using bamboo fibers as primary reinforcement. However, the lack of BFRP strengths and moisture absorption of bamboo fibers during

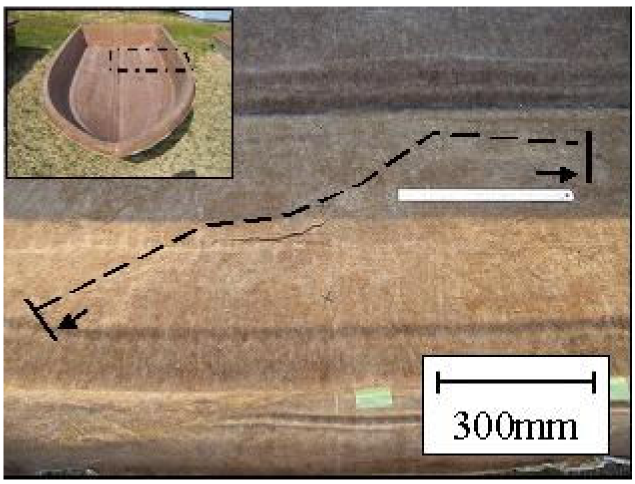

Fig.15 Crack occurred at the ship bottom

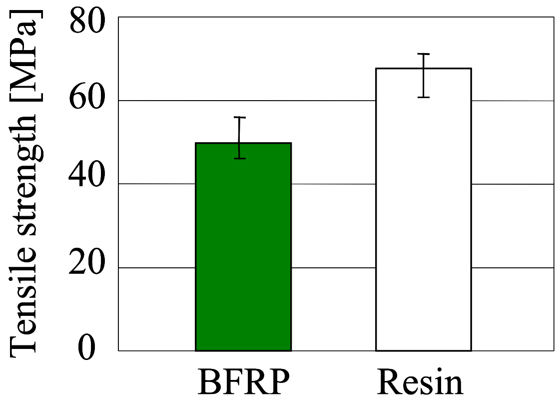

Fig.16 Tensile strength of BFRP and Resin

fabrication are the most important problems which should be conquered in the case of BFRP applications. Non-woven bamboo fiber mats cannot effectively reinforce the matrix because the BFRP used relatively short and curled bamboo fibers as reinforcement.

Moisture absorption during fabrication caused delamination between gel coat and BFRP. This indicates that the bamboo fibers must be well dried and the boat should be fabricated in a dry environment.

Acknowledgements

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References

[1] Japan Boating Industry Association

[2] Tsuchiya T. “Journal of the Japan Society for Composite Materials”. Vol.29, No.4, Page129-135 2003

[3] Fujii T. “Journal of Reinforced plastics”. Vol.5l. No. 8, Page 358-362, 2006

[4] Kubo Y. “Journal of Reinforced plastics”. Vol.2l. No. 11, Page 481-488, 1975

[5] Iguchi M.”Journal of High Performance Paper Society”.No.28, Page 19-26,1989