YACHT PREPARED FROM BAMBOO WOVEN PREFORM REINFORCED POLYESTER VIA RTM

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SUMMARY: Resin-Transfer Molding (RTM) is a useful process to fill a specific need for improving the productivity of making composite parts, and has been used in many industrial fields, because it is of some advantages. Typical parts would include machine cabinetry, solar collectors, snowmobiles, bathtubs, shower enclosures, airplane wing ribs, hatch covers, car bodies, bus shelters and yacht. The key points of RTM technology can be summarized as the following three aspects: reinforcement for RTM, resin matrix for RTM, and mold design for RTM. In the present research, using bamboo woven preform as reinforcement, a polyester system modified as matrix, designing a suitable mold for RTM, a yacht preparation was carried out and a yacht prepared from bamboo woven preform reinforced polyester via RTM was obtained.

KEYWORDS: bamboo reinforcement, bamboo woven preform, polyester, mold design, RTM, yacht.

INTRODUCTION

In previous years, bamboo, sisal hemp, jute, palm, stalk of cotton and maize plant, bagasse were used as reinforcement for preparing polymer composites reinforced by natural fabrics for replacing wood [1-3]. Especially, among them, bamboo sheet reinforced urea-formaldehyde or phenol-formaldehyde plastics were widely used in many fields, such as mould plate like shuttering, automobile floors, domestic floors, which belong to plane structures. Until now, it has not been reported that non-plane integral structural composite parts prepared from bamboo reinforced plastics are studied and applied.

Bamboo is a kind of natural composite material. On the one hand, either an integral bamboo structure or a bamboo sheet can show some typical composite advantages and behaviors. As a structural material, a natural bamboo sheet is very similar to an artificial unidirectional composite lamina. In fact, although the longitudinal tensile strength (σ_{1T}) and modulus (E_{1T}) of the former are lower than that of the latter, the specific strength and stiffness of bamboo approach those of glass fiber reinforced plastics (GFRP) (see Table 1). On the other hand, bamboo is a kind of short growing period, plentiful and regenerative natural resource. To exploit industrially this sort of natural resource can promote economic development of poverty regions in developing countries. Finally, unlike glass fibers (which is inorganic then difficult to degrade) and carbon fibers (which is high cost and inorganic then difficult to degrade) or Kevlar fibers (which is organic, then can be degraded, but expensive), bamboo is a low cost and organic material. Therefore, a composite prepared from a polymer reinforced by bamboo can be of a low cost and can be easily recycled and degraded, which benefits environmental protection.

Table 1. Comparisons between unidirectional glass fiber/polyester lamina and bamboo sheets

Properties / Materials	σ_{1T} (MPa)	E_{1T} (GPa)	ρ (g/cm^3)	σ_{1T}/ρ (10^3.m^2/s^2)	E_{1T}/ρ (10^5.m^2/s^2)
Unidirectional glass fiber/polyester lamina	450	41.3	1.8	250	229
High quality bamboo sheets	190	20.6	0.9	214	228

Resin-Transfer Molding (RTM) is a useful process to fill a specific need for improving the productivity of making composite parts, and has been used in many industrial fields, because it is of some advantages. Typical parts would include machine cabinetry, solar collectors, snowmobiles, bathtubs, shower enclosures, airplane wing ribs, hatch covers, car bodies, bus shelters and yacht. The key points of RTM technology can be summarized as the following three aspects: reinforcement for RTM, resin matrix for RTM, and mold design for RTM. In the present research, using bamboo woven preform as reinforcement, a polyester system modified as matrix, designing a suitable mold for RTM, a yacht preparation was carried out and a yacht prepared from bamboo woven preform reinforced polyester (BRP) via RTM was obtained.

MATERIALS AND STRUCTURAL DESIGN

Materials

Reinforcements

Long bamboo sheets, having a thickness of 0.8-1.2mm, a width of 15mm, dewaxed from the green covering, heated to reduce its water content for maintaining the strength, and pre-

Table 2. Influences of water content on the properties [4]

Water content (%) / Properties	6	8	12	16	20
Longitudinal tensile strength of bamboo sheets* (MPa)	118	140	155	160	151
Shearing strength between bamboo sheets and polyester resins (MPa)	9.9	7.4	5.8	very low	very low
Shearing strength between bamboo sheets and urea-formaldehyde (MPa)	9.4	8.1	7.2	6.0	4.8

*lower than the values of Table 1 because the sheets consist from bamboo without its green covering

treated with a thin urea-formaldehyde resin coating, were woven to a suitable preform, along GFRP yacht relief mold profile.

The experimental results [4] (see Table 2) showed that the heating and pre-treating of bamboo sheets are quite important, because these treatments can improve significantly the comprehensive properties. From Table 2, one can know that the water content in bamboo sheets influences contrary the longitudinal tensile strength of itself, and the shearing strength between the sheets and the resins. The more the water content, the higher the tensile strength and the lower the shearing strength between the water content from 6% to 16%. It exists a compromise among the water content, the tensile strength and the shearing strength. One can also see that a thin urea-formaldehyde resin coating can obviously enhance bonding properties between the reinforcement and the matrix.

Woven bamboo preforms

A bamboo woven preform possesses the so-called structural stiffness of itself. Therefore, it is of a good shape stability. Long bamboo sheets, having a thickness of 0.8-1.2mm, a width of 15mm, treated with the methods above-mentioned, were woven to a suitable preform, along a GFRP yacht relief mold profile. A preform has a width of about 2mm. It was found that twill weave structure would be suitable the preform, but plain weave structure would be too tight to be flexibly woven and satin weave would be too loose to maintain the preform sharp [5-6]. The plain, twill and satin weaves were illustrated in Fig. 1.

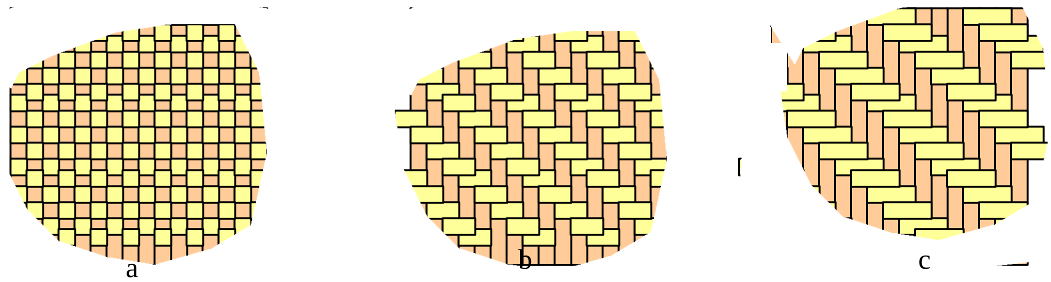

Fig.1 Plain weave (a), twill weave (b), and satin weave (c)

Resin matrix

From property point of view, while choosing or modifying resins as matrix, the following problems should be taken into account: (1) The interface problems between the matrix and bamboo sheets should be considered. (2) The fairly large size yacht hull demands matrix material to have a lower contraction rate during curing reaction and a lower viscosity for keeping fluidity before curing. (3) The curing reaction can be carried out without heating in order to facilitate the processing. From cost point of view, only urea-formaldehyde, phenol-formaldehyde or unsaturated polyester resin can one choose.

General urea-formaldehyde and phenol-formaldehyde resins are not suitable to a closed system in RTM processing because of some water from the condensation reaction. Although general unsaturated polyester resin can be used to a closed system in RTM technology, their bonding properties with bamboo sheets are not desired (see Table 2).

Therefore, first, the bamboo preform was coated with urea-formaldehyde resin. Then, after the coat was cured under air atmosphere, the coating-treated preform was then infiltrated with modified unsaturated polyester resin in the RTM mold space. This procedure can resolve the first problem mentioned above. The reason to modify the unsaturated polyester resin is to resolve the other two problems. The resin systems modified were of a lower contraction rate during curing reaction, a lower viscosity for keeping fluidity before curing, a relatively longer pot life and a capacity to be cured at room temperature with its self-accelerating reaction heat (see Ref.4). So, cooling is necessary to keep the temperature inside from approaching or exceeding 100 , in order to avoid vaporizing the water inside the bamboo [5-6].

Structural Design

Yacht body

The yacht's overall length is 3 m, the width is 0.9 m, the depth is 0.45m, and the displacement is about 800 kg. Taking the yacht stiffness as the objective function for designation, considering an equivalent stiffness in comparison with a conference yacht from GFRP, because stiffness of a plan is proportional to the square of its thickness, the following equation can be written:

$$E_B H_B^2 = E_{GFRP} H_{GFRP}^2 \qquad (1)$$

Where, E_B and H_B stand for Young's modulus and thickness of the bamboo sheets, respectively, and E_{GFRP} and H_{GFRP} stand for Young's modulus and thickness of the glass fiber reinforced polyester resins, respectively.

By taking account into the modulus of GFRP (see Table 1) and the various part thickness of the GFRP reference yacht (see Table 3), the various part thickness results of BRP yacht were calculated with equation (1), which were arranged in the third rank in Table 3 [5-6]. The surface density ratio of yacht parts was also showed in Table 3. The weight of BRP yacht can be reduced by about 5% in comparison with the GFRP conference.

Table 3. Various part thickness of the GFRP reference yacht and the BRP yacht

Location Various yachts	Front skin	Side skin	Back skin (with motor)	Bottom skin	Gunwale
GFRP yacht thickness (mm)	6.0	5.0	8.0	6.0	6.0S
BRP yacht thickness[1] (mm)	8.5	7.0	11.5	8.5	8.5
BRP yacht thickness[2] (mm)	10	9	14	10	10
Surface density ratio (BRP/GFRP, %)	93	100	97	93	93

1. Calculated according to equation (1)
2. Modifying the calculated results by taking account into resin matrix thickness

Lamination of the preforms

Four preform plies can be woven along a same relief mold profile. These four preform plies, as reinforcements, were placed into the space between the intaglio and relief GFRP yacht molds. The outside two preform plies was continuous, and consisted from bamboo sheets with their green covering. However, the inside two preform plies could be discontinuous, and consisted from bamboo sheets with their green covering removed, which makes the yacht cost lower without influencing the properties. Outside the side skin, a ply of glass fiber cloth was laid in order to modify the lay-up processing of bamboo woven preform and to avoid forming a resin-rich area. The size difference of lamination into the space between the intaglio and relief GFRP yacht molds can be neglected. The normal direction (interlaminar direction) of the preforms was not reinforced by any method except the friction forces. As mentioned in Table 3, the back skin has to be slightly thickened because it has to be equipped with the motor.

Design of mold for RTM

The RTM mold was designed into an intaglio mold (lower) and a relief mold (upper). The touching and jointing interface between the intaglio and relief molds was located a position marked with A in Fig.4. The touching and jointing interface arrangement like this not only benefits drawing of patterns, but also can not be harmful to the yacht appearance.

Both of the intaglio and relief molds are made of GFRP. The vertical and the horizontal projective areas of the yacht from BRP were about 2.7m^2 and 1.3 m^2, respectively. Therefore, if the RTM injection pressure was about 0.3 MPa, the vertical and horizontal press forces would be about 80 and 40 tons, respectively. So, in order to maintain the structural stiffness and the sealing and tightening between the two molds, seventeen series of M30 binder bolts with high strength were arranged (see mark A in Fig.2). The intaglio mold was backed up by steel reinforced cements (see mark B in Fig.2). Also, the relief mold was supported by a steel frame (see mark C in Fig.2). A down gate was placed to the center (see mark D in Fig.2). Some rise gates were, symmetrically to the down gate, created on the intersection between the side skin and the gunwale of the relief mold. The whole mold, including the intaglio and relief molds, was weighted about 4 tons.

As mentioned previously, the resin systems modified were of a lower viscosity for keeping fluidity before curing, a relatively longer pot life and a capacity to be cured at room temperature with its self-accelerating reaction heat. So, it was not necessary for the RTM mold to be heated during operation, which facilitated much the processing.

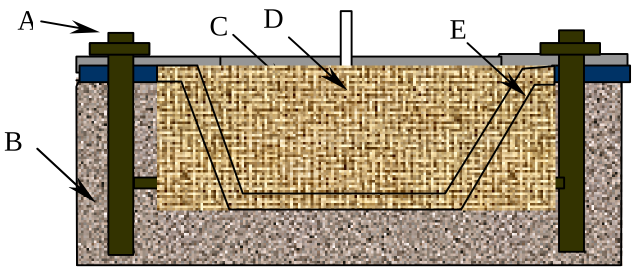

Fig.2 Cross-section of the RTM mold (Mark E stands for the BRP yacht body)

PROCESSING PRECEDURES

The yacht preparation could be carried out according to the following processing procedures:

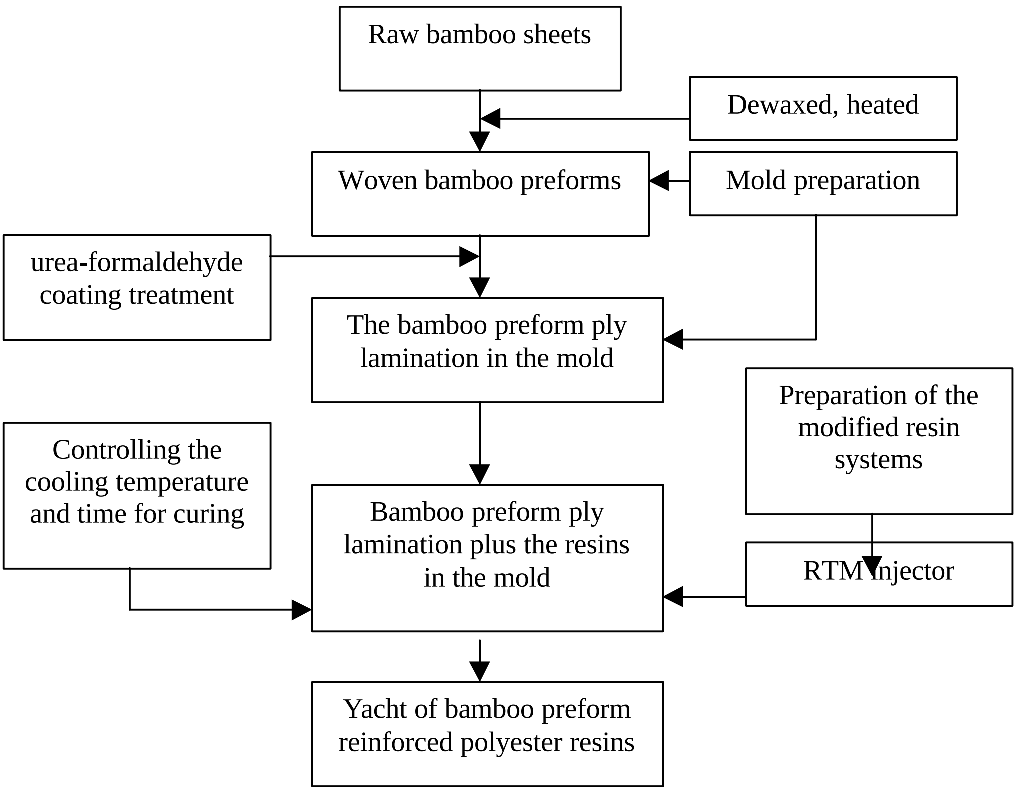

Fig.3. Processing procedures for the yacht preparation

As mentioned by Fig.3, the system of prepared bamboo preform and the RTM molds was assembled. The unsaturated polyester resin matrix system modified was pumped into the system by an injector supplied by GLAS-GLAFT Co. The injection pressure of 0.3 MPa, and the maximum injection speed of 17 times a minute (90g a time) can be given by it. Totally, about 40 kg resins are necessary.

RESULTS AND CONCLUSIONS

Results

The yacht prepared in the present research was shown in Fig.4. When sent to Beijing to attend International Network of Bamboo and Rattan (INBAR) founding exhibition in the end of 1997, the yacht win identical acclaims and was kept as a permanent exhibit product by the organization’s headquarters.

Conclusions

The product exploitation of bamboo woven non-plane preform reinforced polymer can enhance significantly industrial values of bamboo. Some problems existing in the exploitation can be solved by means of polymer matrix composite technology. The processing of bamboo woven preform plus RTM procedure will be of a good prospect.

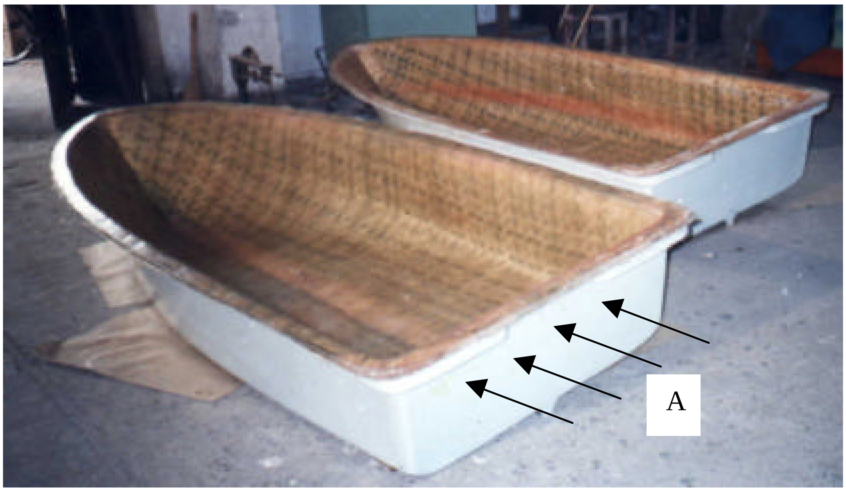

Fig.4. Yacht prepared from bamboo woven preform reinforced polyester via RTM.

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