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Hand Lay-Up GFRP Composite Marine Propeller Blade

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Abstract: Glass Fibre Reinforced Polymer (GFRP) composite material possesses mechanical properties and performances, potential for complex helicoidal marine propeller development. Preliminary investigation of composite marine propeller production using a specific closed-moulding designed for hand lay-up lamination of a single detachable low skew GFRP composite propeller blade was conducted. The GFRP laminate consists of E-glass woven fibre as reinforcement and unsaturated polyester resin (SHP 2719) as matrix material. Complex geometric laminated propeller blade was successfully reproduced after numerous processes of optimization of mould design, lay-up lamination, resin-mixture and curing pressure were carried out to improve the overall quality of the laminated blade.

Key words: Marine propeller blade, glass fibre reinforced polymer composite material, hand lay-up lamination process

INTRODUCTION

Metallic materials had long been the choice of material utilized in conventional marine propeller construction. Composite propeller development started and was successfully developed by the Soviet from the 1960s to 1970s (Mouritz *et al*., 2001). Since then, more advance composite materials had encourages many researchers and manufacturers to give due attention in the marine application development. The advanced composite materials have advantage characteristics such as high in stiffness to weight ratio, resistance to seawater or chemical corrosion and performance tailored, just to name a few.

Marine composite propeller could be developed by open or closed moulding with hand or spray lay-up reinforcement lamination. Molland and Turnock (1991) had successfully produced a hybrid composite (glass-carbon reinforcement) of a four detachable blades propeller type based on Wageningen B4-40 series profile using closed moulding by hand lay-up reinforcement lamination. Wozniak (2005) had also adopted an open mould method for reinforcement materials to lay on to a duplication of an YP677 single propeller blade. The closed moulding type suggested a more controllable of material curing parameters, consistency and quality.

The composite propeller blade being a critical and complex element required a very definitive production handling to meet the nonlinear hydrodynamic forces and pressures during underwater propulsion. Comprehensive study of marine propeller mechanical properties could be traced to Toshio *et al*. (2011) who conducted on the material testing, structure vibration test, evaluation analysis through Finite Element Method (FEM), physical model manufacturing and material loss due cavitation study through erosion test. In addition, propeller blade structure being non-rigid as it deformed during operation speed changes influences the performance. Lin *et al*. (2009), adopted a generic algorithm in the finite element method to optimize graphite reinforcement stacking sequence for handling of blade structure deformation at dedicated operation speed. Molland and Turnock (1991) had also suggested reinforcing the glass fiber by stacking the carbon fibre reinforcement alternately at the root and part of the blade region to improve strength and overcoming the high axial (centrifugal) loadings. In reducing the overall structure density and raw material cost, carbon fiber had the lighter density, but expensive compared to glass fiber. However, the composite material's ability to be evaluated and optimized for ideal performance had heightened its application and replacement of metal for marine propeller.

In this study, a glass fibre reinforced composite propeller development had adopted the Molland and Turnock (1991) approach. A low skew three blade outboard propeller laminate using E-glass reinforced woven fibre and unsaturated polyester resin SHP 2719 was developed. The unsaturated polyester resin SHP 2719 being low cost polyester resin and widely used for composite material application. The exploration involved

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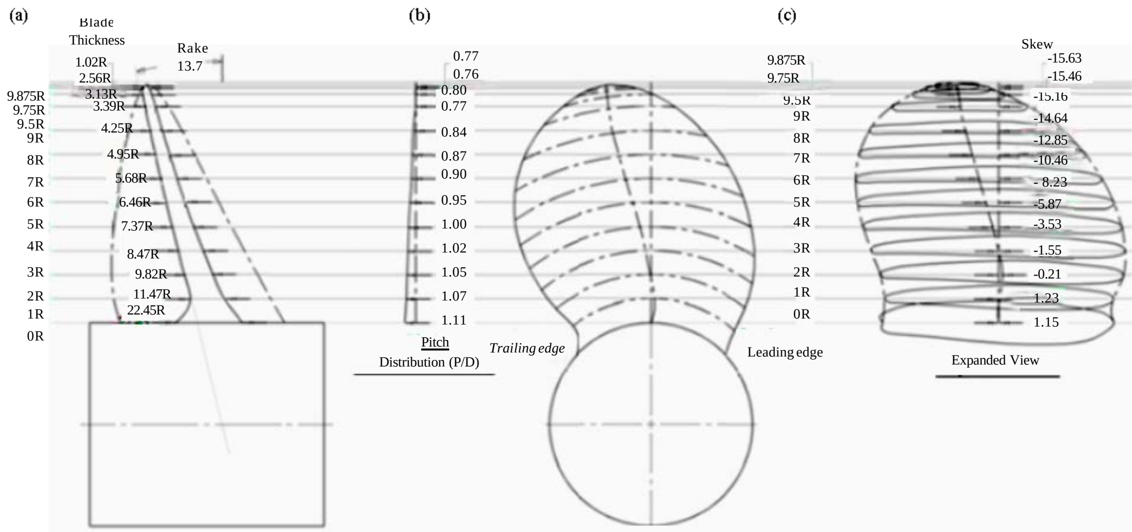


Fig. 1(a-c): Propeller blade design properties, (a) Profile view, (b) Transverse view and (c) Unit (mm)

the blade design, mould design and fabrication, laminate preparation, matrix formulation and lamination process and production result.

BLADE DESIGN

A low skew three blade outboard marine propeller with the diameter of 235 mm, hub diameter of 70 mm and nominal pitch of 203 mm had been adopted in this study. The propeller geometry detail as shown in Fig. 1.

COMPOSITE MARINE PROPELLER DEVELOPMENT

The E-glass woven fibre as the reinforcement material and unsaturated polyester resin (SHP 2719) matrix material had been utilized. The durability and mechanical property study of GFRP composite formulation had been conducted and found to be potential for marine propeller development (Choong *et al*., 2012).

Mould design and fabrication: A two piece mould type was designed to produce the GFRP composite marine propeller detachable blade by a hand lay-up lamination process. The mould design and development was carried out utilizing the computer aided drawing (SolidWorks) and manufacturing (MasterCAM) application tools. The mould was designed to reproduce single propeller blade geometry of low skew as shown in Fig. 2.

The upper mould section was designed to form the propeller blade back (suction) section while the lower mould section as the propeller blade face (pressure) section. The lower mould was also designed with three bleeding paths to ensure that excess resin and air bubbles could be bled out. The mould parting line had been designed along the leading and trailing edges of the propeller blade to eliminate the parting line on the sample. The mould parts were fabricated by computer numerical control CNC machining using Computer Aided Manufacturing (CAM) application tool (MasterCAM) for machining tool path planning and generating.

Woven glass fibre laminar layer preparation: The effort of this exploring aimed to establish a concept of developing a laminate of GFRP single detachable composite propeller blade. The propeller blade geometry being highly complex 3-D hydrofoil varying from the tip to the root was oddly helicoidally deformed. The blade thickness also varied from the root to tip and increasing as the blade radius-section increased. Therefore, the woven-fibre layer geometry (shape and size) for lamination must also vary along with the decrement of propeller thickness from root to tip. The fibre layer lay-up concept for the propeller blade lamination in the X-Z and X-Y cross section view being shown in the Fig. 3.

The E-glass woven fibre cloth was utilized for the lamination without the need to concern with fibre orientation. Based on the lamination concept in Fig. 3, six pairs of different surfaces area fibre cloth were developed and cut out as shown in Fig. 4. The 6th and 7th woven cloth fibre as the mid-layers; the shape and size being similar as the propeller blade expanded area. Subsequent

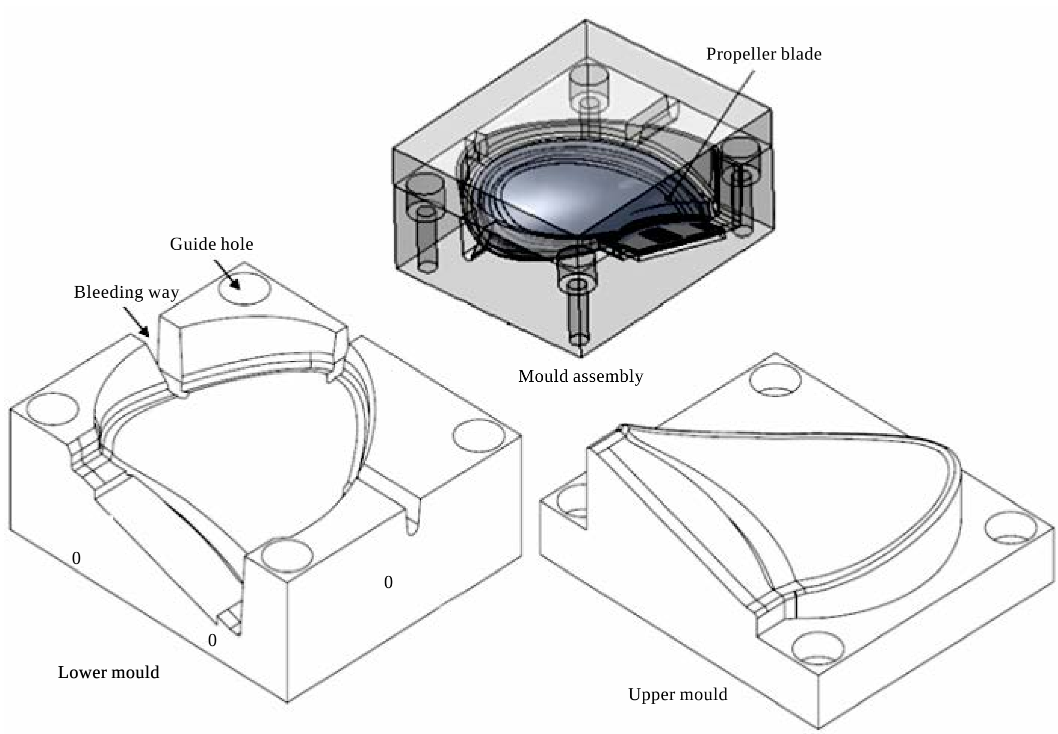


Fig. 2: Mould design

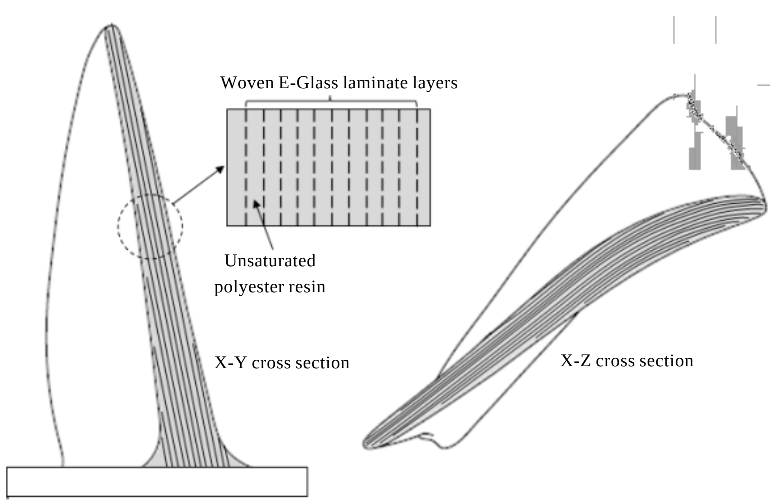


Fig. 3: Propeller blade fibre laminate layers layout

layers of fibre cloth shapes and sizes were reduced by offsetting or scaling down the surface area. The cut out of each layer of woven glass fibre cloths were shown in the Fig. 4.

Matrix preparation and lamination process: For a single laminar layer, a mixture of 190 g of unsaturated polyester resin SHP 2719 with 0.8 mL Butanox M-50 was utilized. In addition, another 10 g of colour primer or pigment was

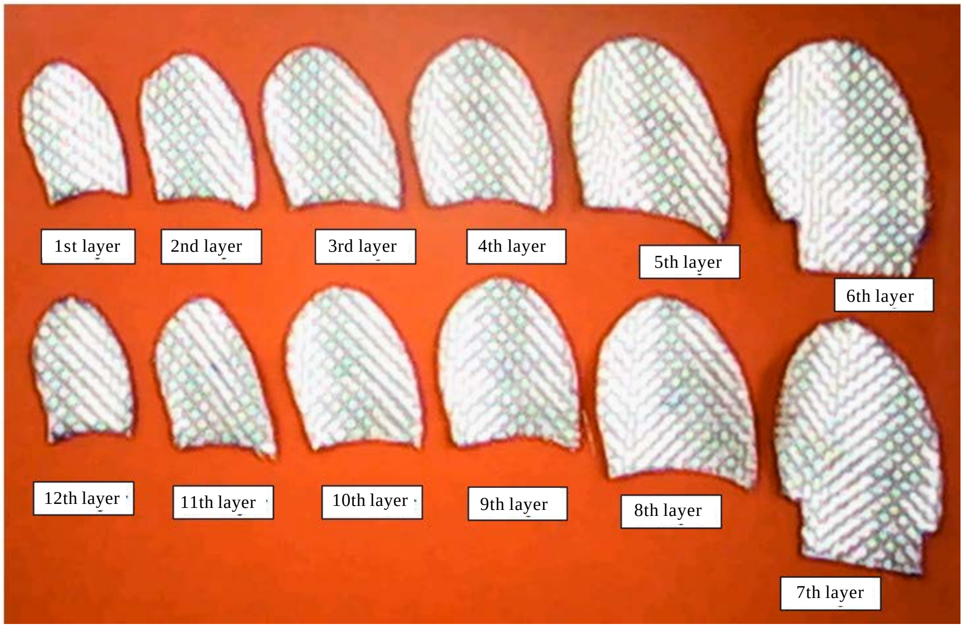


Fig. 4: Lamination layers preparation

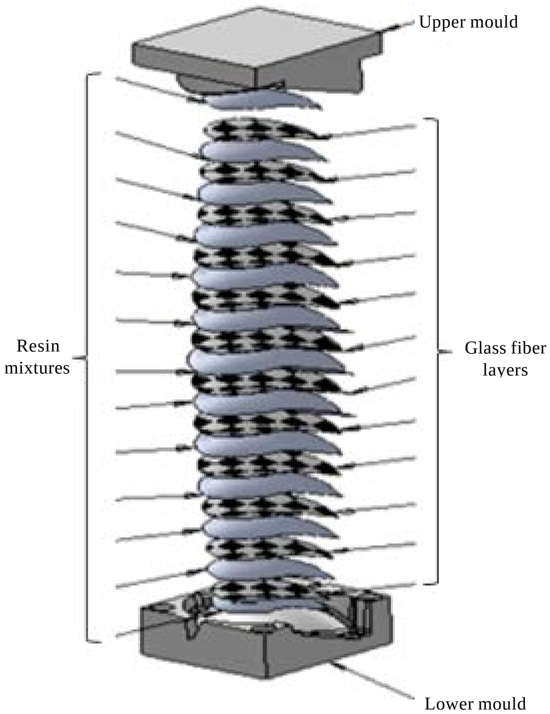


Fig. 5: GFRP propeller blade lamination process

added into the mixture. The lamination process was conducted within the matrix pot life which was less than 10 min. Before the lay-up lamination process, the mould surface was also spray-coated with the release agent. A hand lay-up process of layer by layer of fibre glass and resin was developed to form the GFRP propeller blade laminate. Entrapment of air bubbles were reduced by pressing with a spatula from each laminar layer. The continuous and repeated laying up of all the laminar layers was completed in sequence (Fig. 5).

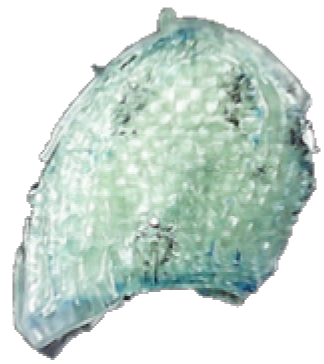
On completing the lamination, the upper mould was gently pressed over the laminar layers and the lower mould together. An external load was applied to the mould, acting as the curing pressure to squeeze out excess resins and air bubbles. The composite propeller blade was left to cure at room temperature for about 24 h before it was removed from the mould. For composite propeller blade mechanical properties studies, the laminate samples were preserved for a further 14 days to ensure the resin was totally cured.

GFRP COMPOSITE PROPELLER BLADE PRODUCTION RESULT

The fabrication process and the production of GFRP composite single detachable propeller blade underwent a continuous development phase elaborated in the Table 1.

The production of composite propeller blade when through four phases of improvement before an acceptable end product was achieved as shown in Table 1. In first

Table 1: Development results of GFRP composite propeller blade

Phase	Face	Back
1st		
2nd		
3rd		
4th		

phase, the composite propeller laminate had pressure and suction surfaces very much depleted due to insufficiency amount of resin applied. Insufficient mould release agent was also realized. Improved phase two production of composite laminate blade was still similarly depleted. Therefore, the third phase development increases further resin amount with additional curing pressure which produces mating texture of woven glass on the suction surface. Finally, the fourth phase production was able to produce repeatable and acceptable composite propeller blade quality. The minimum voids at adequate content of the mixture resin, mould release agent and curing pressure of hand lay-up composite propeller blade was produced.

CONCLUSION

An outline of the hand lay-up and process of GFRP composite propeller blade had been developed for exploring the potential of marine propeller application. The GFRP single detachable composite propeller blade was also successfully reproduced. The potential of utilizing GFRP material in marine propeller development had shown to be encouraging and promising, but shall require further mechanical and durability verification.

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