



the CNC machine and the multi-articulated robots.

Hence, the existing wooden mold-making method and the mold-making method using the CNC machine and the multi-articulated robots have the defects in that the material costs, the personnel costs, the installation costs are raised.

In this work, we have proposed and demonstrated a new technique to solve these problems, and it is an object of this study to provide a mold structure for constructing a ship formed of composite materials.

## 2. Materials and Manufacturing Process

### 2.1 Materials

In this study, reinforcement is used thermal contracting fabrics and films, and matrix is used epoxy paint that specific gravity is 1.28 and thickness is 40 $\mu$ m.

### 2.2 Manufacturing process for hovercraft hull

Hand lay-up is one of the most common forms of fabrication methods for FRP as shown in Fig. 2. Hand lay-up is the simplest and oldest open molding method of the composite fabrication processes. It is a low volume, labor intensive method suited especially for large components, such as boat hulls. Glass or other reinforcing mat or woven fabric or roving is positioned manually in the open mold, and resin is poured, brushed, or sprayed over and into the glass plies. Entrapped air is removed manually with squeegees or rollers to complete the laminates structure. Curing is initiated by a catalyst in the resin system, which hardens the fiber reinforced resin composite without external heat. For a high quality part surface, a pigmented gel coat is first applied to the mold surface.

The ideal resin ratios and curing temperature could be found from various manufacturing investigations. After finishing all of the manufacturing processes of new material mold system, material characteristics were analyzed. Fig. 3 shows lay-up process of mold structure with new material system.

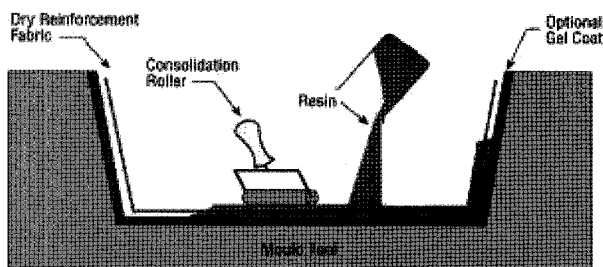


Fig. 2 Schematic of hand lay-up process

### 2.3 Comparison of process for wooden mold and new materials mold

The process in the conventional method for manufacturing the mold for constructing the ship formed of FRP comprises the steps of making the wooden mold made of plywood, veneer sheets, square lumber, nails, FRP sheets or other hard materials in a manual manufacture. The manufacturing process for FRP boats divided drawing, lofting, manufacturing frame, inner mold treatment, surface grinding process and mold release process.

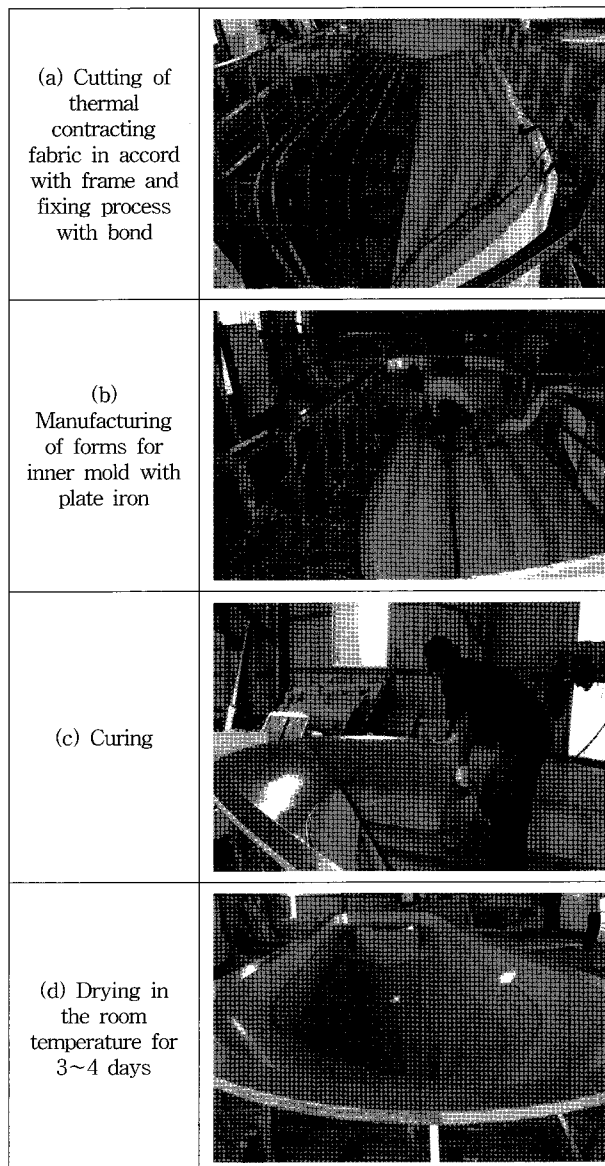


Fig. 3 Lay-up process of high functional mold structure with new material system

#### 1) Drawing for manufacturing boat

The drawing of FRP boats drawn on a scale of 1 to 20. Fig. 4 shows drawing for manufacturing boat.

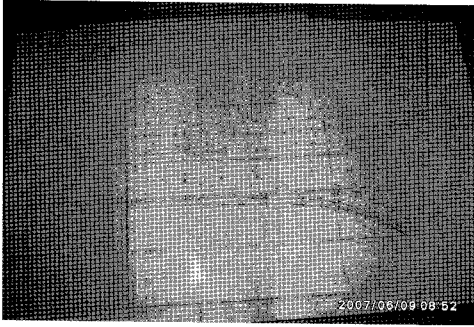


Fig. 4 Drawing for manufacturing boat (1/20 size)

2) Lofting for manufacturing boat

The lofting is used plywood based on drawing prepared. Fig. 5 shows lofting for manufacturing boat.

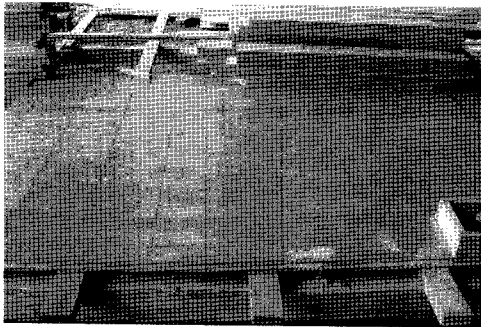


Fig. 5 Lofting for manufacturing boat

3) Manufacturing for frame

On the other hand, in the manufacturing process of frame for wooden mold, the hard wood sheets having restricted sizes are formed to be flat or curved by fixing the outer edge structures(pipes) of the wooden mold by means of screw nails, rivets and bolts, and in this case, so as to support the stress of the wood sheets, the fixing parts should be strong and needed in large numbers.

In the composite mold, the frame are formed of the thermal contracting fabrics or films, such that as they have appropriate flexibility to provide free curved surfaces. After the contour of the ship has been made by using the square or round steel pipes, the plurality of frames are fixed by means of welding and bolts so as to take the solid contour of the ship.

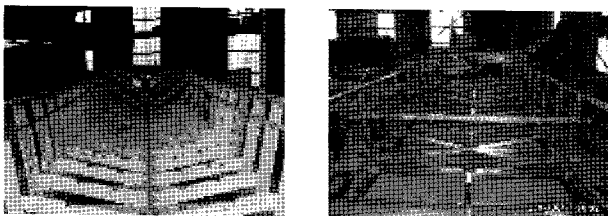


Fig. 6 Frame for wooden(left) and new material mold(right)

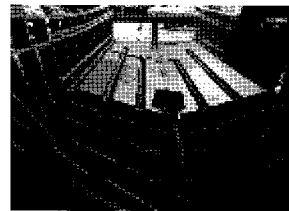
Fig. 6 shows manufacturing process of wooden mold frame and new materials mold using thermal contracting fabrics or films and square or round steel pipes.

4) Manufacturing process of inner mold

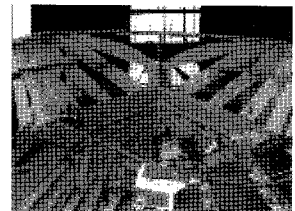
A new material process was able to know that a wooden process was more concise.

At a step of bonding the flexible materials, the female and male flexible materials formed of the thermal contracting fabrics or films are bonded by means of an adhesive to the frames, constituting the contour of the ship formed by the step of installing the pipes.

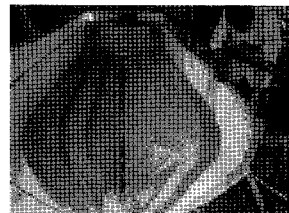
At a step of heating the flexible materials, the flexible materials bonded at the step of bonding the flexible materials are heated so that they are contracted according to the features of the thermal contracting fabrics or films to provide tension adequate to construct the ship formed of composite materials.



(a) Manufacturing process of strake lines



(b) Manufacturing process of bow parts

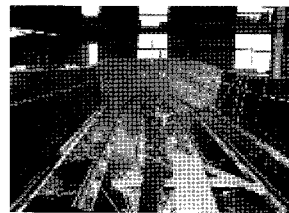


(c) Connecting process between strake lines and bow parts

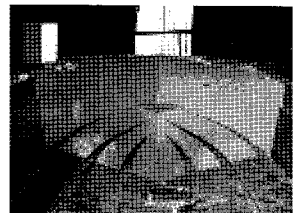


(d) Reinforcing process of bow parts

Fig. 7 Inner mold manufacturing process for wooden mold



(a) Lay-up process



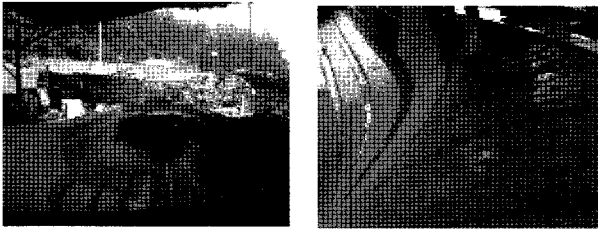
(b) Fabric coating process

Fig. 8 Inner mold manufacturing process for new material mold

5) Surface grinding process

The surface grinding process is filling a filler(putty) in gaps, curves and concave/convex portions formed on the connection portions between the materials, and smoothly

polishing the entire surfaces of the wooden mold, but it is not necessary process in the new material mold.



(a) Surface grinding with reinforcing solvent (b) Surface grinding hand-grinding machine

Fig. 9 Surface grinding process for new material mold

6) Mold release process

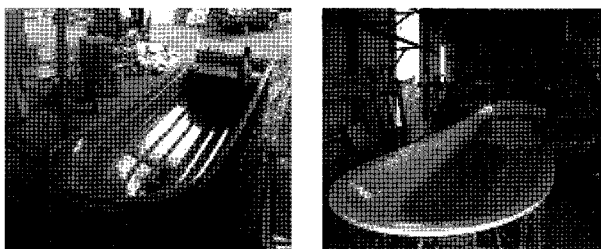
At a step of releasing the mold, an epoxy and urethane-based paint and glazing agent are applied on the female and male flexible materials expanded at the step of heating flexible materials, the mold is released to prepare the mold for constructing the ship formed of composite materials. The mold releasing is the same as in existing wooden molds, and if compressed air and water are put between the product and the mold at the time of mold releasing, the mold can be reused two or three times. The gel coat process were carried out in order to prevent stick and damage



(a) Mold-release coating process (b) Gel coating process

Fig. 10 Mold release coating and gel coating process

Fig. 11 shows completed wooden mold and composites mold



(a) Wooden mold type (b) Composites mold type

Fig. 11 Manufactured boat mold structure

### 3. Evaluation of Efficiency for Characteristics and Manufacturing Process

#### 3.1 Comparison of characteristics for wooden mold and new composite materials mold

The total weight was lighter in new materials than those in wooden mold. It is concluded that material characteristics of new mold system were more superior than that of wooden mold system in specific strengths, specific stiffness and thermal characteristics.

Table 1 Comparison of characteristics between wooden mold and new composite materials mold

Work process	Mold type	
	Wooden mold	Composite mold
Weight	100%	40%
Anti corrosion	Bad	Good
Specific strength	Low	High
Specific stiffness	Low	High
Thermal resistance	Bad	Good
Water resistance	Bad	Good
Number of parts	Many	One
Maintenance	Bad	Good
Recycling	Bad	70% (Steel frame is available)

#### 3.2 Comparison of process efficiency for wooden mold and composites mold

The process efficiency of composites mold system were more superior than that of wooden mold system

Table 2 Comparison of process efficiency between wooden mold and composites mold

Work process	Mold type	
	Wooden mold	Composite mold
Drawing process	100%	100%
Real sized drawing process	100%	100%
Manufacturing frame	100%	60%
Inner mold manufacturing process	100%	30%
Surface grinding process	100%	10%
Mold release process	100%	100%

#### 4. Conclusion

The obtained results are summarized as follows.

- (1) The material characteristics of new mold system were more superior than that of wooden mold system in specific strengths, specific stiffness and thermal characteristics.
- (2) 40% of frame manufacturing process, 70% of inner mold manufacturing processes and 90% of surface grinding process were reduced in efficiencies of manufacturing processes.

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