

Data Descriptor

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Data Descriptor

Production Reliability Technology Based on Vacuum Infusion Process Convergence to Design Strengthen Boat Safety

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Abstract: In this paper, to reinforce the safety of boats, we develop a technology to improve the stability and quality of boat equipment manufacturing through vacuum infusion process fusion. Safe mold design and manufacture are performed to determine the resin flow rate and water surface flow of the boat, and the performance of vacuum maintenance work is guaranteed through the tensile and compressive strength of the manufactured hull and deck. When manufacturing a boat air mechanism (Aerostat), the adhesive strength between the materials of the equipment and the deformation of the joints are very important factors for safety. Process fusion to minimize a number of manual work processes due to the nature of the equipment manufacturing, minimizes deformation after manufacturing through an accurate manufacturing ratio. Accordingly, the mixing ratio of the resin and curing agent is accurately controlled as an optimal condition for drying and securing safety of the boat, and durability and quality are improved by analyzing working conditions such as resin flow and flowchart by time and converting optimal information into a database. This enables efficient production process management with a small number of workers in multiple workplaces, which is expected to increase production efficiency and safety.

Keywords: strengthening safety; vacuum infusion; convergence process; quality improvement; boat design

1. Introduction

With the development of the water leisure sector around the world, the demand for boats such as charitable, leisure, torrential riding, skin scuba, lifesaving, and fishing dragons on the mother ship is gradually increasing. In particular, consumer patterns are diversifying as the market expands from inland leisure boats to marine sports and leisure equipment. The high-speed sliding posture of these small boats is created by ship speed in addition to hull weight and buoyancy, and in the process of balancing dynamic hydrodynamics and the power of forces with each other, it appears in the form of trim and sinkage, and resistance changes significantly as the port posture changes [1,2].

As there are many processes of manual production of underwater boats, it is necessary to use a standardized production system in relation to safety. Therefore, in the production of the water surface attachment device, it is possible to manufacture a safe boat through the integration of the production process with the vacuum infusion technology required for the uniform mixing ratio injection of resin and epoxy [3]. Figure 1 shows the production flow of the boat manufacturing process.

Due to the nature of boat work, various types of small-scale production dominate, and the work efficiency of workers and product quality are determined as all processes are carried out manually. In particular, the resin and the curing agent are mixed depending on the manufacturing experience of the worker, and the manually painted paint also affects the worker's health. Therefore, it is difficult to systematically manage quality, and it is difficult to actively cope with defects [4].

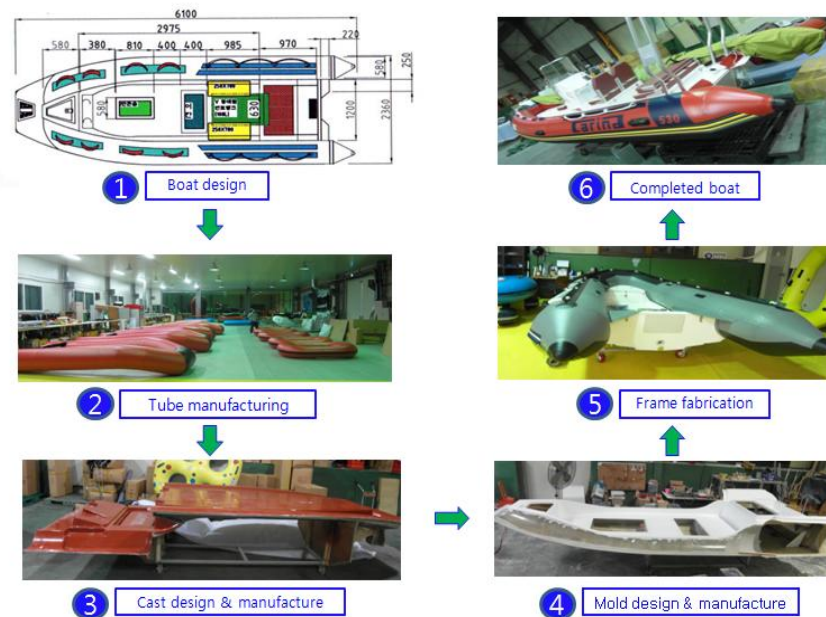


Figure 1. Production flow of boat.

In addition, in the production of boats that produce small amounts of various types, optimal working arrangement is essential for each workplace, and it affects not only production efficiency but also boat performance. Therefore, it is necessary to design a back-room infusion process automation technology to improve the productivity of hull molds and molds [4].

In fact, boats operating at sea level can be used in very poor environments. The worst environment should be considered for the role of boats in mobilizing wind and rain due to severe swells, high flow rates, or rapid environmental changes. Moreover, when a boat is used for special activities such as a coast guard or firefighter operating in the offshore coast, the weight of equipment possessed by divers or related personnel cannot be ignored. Therefore, even if it is designed and developed for a certain number of people on board, it can cause capsized due to the weight of equipment in possession [5]. Figure 2 shows the boarding status of various active boats, such as coast guards and divers.

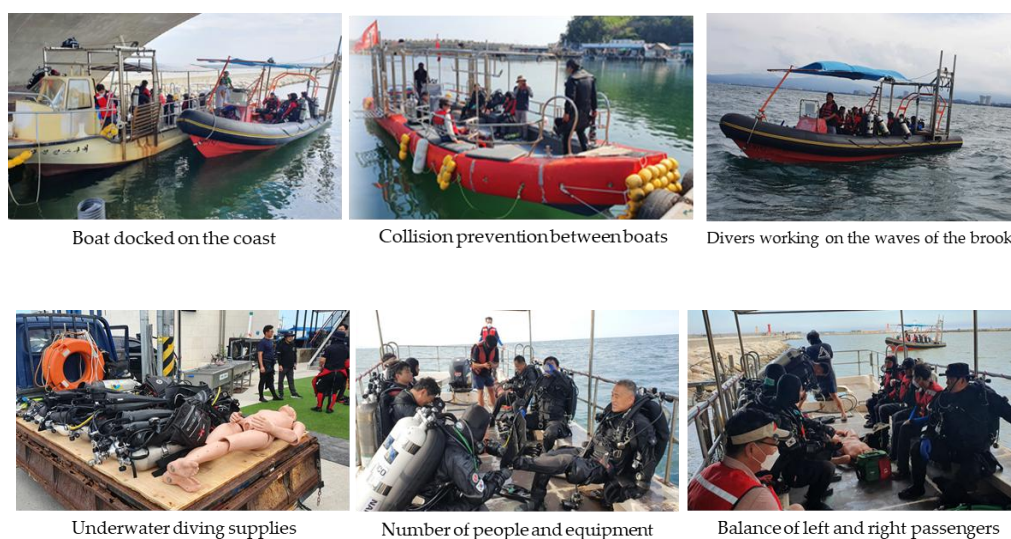


Figure 2. Boarding status of various active boats.

In this paper, we develop a vacuum infusion automation technology and process fusion technology to improve boat stability and quality. Using a potential flow algorithm, we can use the

potential flow algorithm to determine the amount of flotation generated on the hull. Calculate it and consider it as an additional buoyancy and assess it with hull weight and estimate the constant posture using the form. Resin and hardener are adsorbed inside the hull and deck in a very short time by vacuum at a standardized mixing ratio, and problems such as strength increase and post-deformation are solved.

At this time, by accurately controlling conditions such as the mixing ratio of the resin and curing agent to find optimal conditions for drying and securing rigidity of the boat, model-specific information analysis and optimization information on working conditions such as resin flow rates and resin flowcharts by time is converted into a DB to improve quality such as durability.

2. Vacuum infusion method and molding design

The streamlined design of the waterfront contact, the injection of the balance of the mixture inside the instrument, and the balance of the left and right weights must be constant to be safe during high-speed driving. In high-speed driving, the imbalance mechanism is linked to a direct accident in case of a scratch or collision by an underwater obstacle.

2.1. Analysis of 3D liquidity of boats

The key to the development of built-in extended mold design and molding technology is to secure durability through reinforcement of the lattice at the back of the mold. Automatic bonding using a coupling device, high gloss maintenance through vinyl ester gel coating, and boat design optimization based on 3D flow analysis play an important role in standardization and stable production of the system by reducing multiple work processes [6–9].

Figure 3 shows design examples of the total length, total width, tube thickness 500 m/m, compartment water 4 ea, loading load 1150 kg, 8 people on board, propulsion engine 50-70 HP, and weight 185 kg [4].

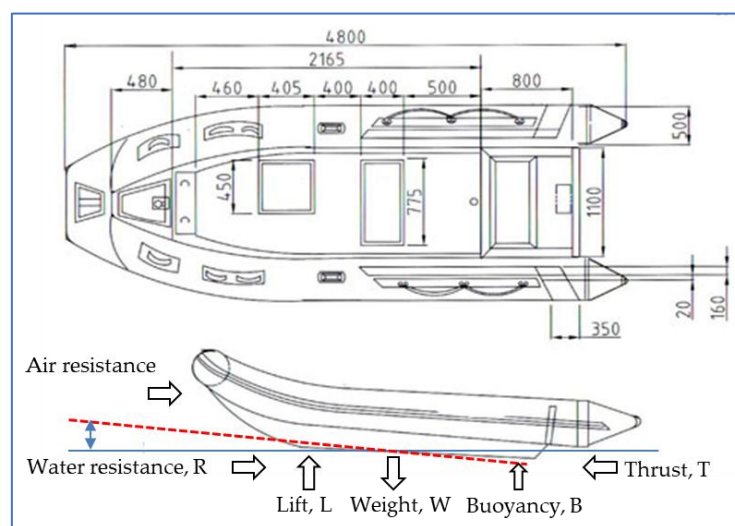


Figure 3. Force diagram in running boat condition.

During the suspension, the static buoyancy force (B) and the dynamic force, the flotation force (L), are in equilibrium with the hull weight, and in this process, the thrust force (T) by the thruster and the moment by the resistance (R) of the hull addition are added to determine the suspension posture. These forces and moments have an equilibrium relationship with the forward direction, the vertical direction, and the moment as shown in the following equation [6].

$$R = T(1-t)\cos \theta \quad (1)$$

$$W = B + L + T(1-t)\sin \theta \quad (2)$$

$$W \cdot LCG' + B \cdot LCB' + L \cdot LCL' + T(1-t)\cos \theta \cdot LCT' = 0 \quad (3)$$

Here, t is the thrust reduction coefficient, and LCG' , LCB' , LCL' , and LCT' are respectively. The distance between the force and the center of the moment, θ , has a trim angle C . In the case of a high-speed runway, most of the weight of the hull is due to the flotation force. It is supported, and the hull weight, buoyancy, and flotation force are each centered in the port position. In the process of equilibrium with, it appears in the form of trim and flotation.

2.2. Air boat mold design and implementation

The key to the design and molding of the built-in extended mold of the boat is to secure durability through reinforcement of the lattice at the back of the mold. The manufacture of boat equipment is based on automatic bonding using a coupling device and 3D flow analysis through vinyl ester gel coating, and design optimization plays an important role in standardizing and stable production of the system by reducing multiple work processes [7]. Figure 4 shows the equilibrium and weight-centered 3D flow analysis of the boat. The force moment balance equation for flow analysis is as follows.

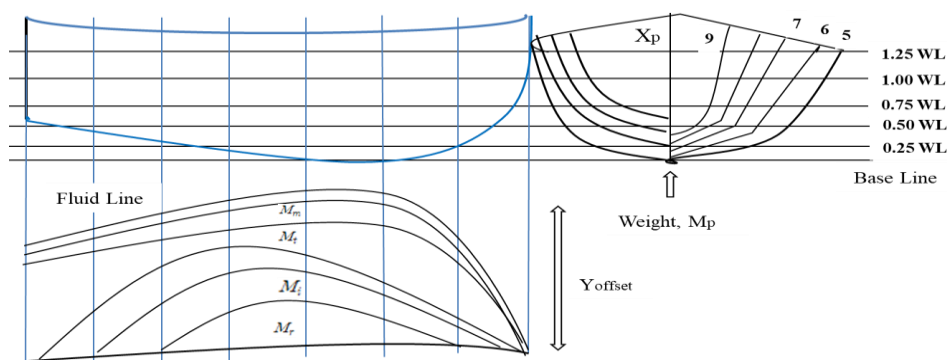


Figure 4. Equilibrium and weight-centered 3D flow analysis of the boat.

$$M_p = F_b - (M_r + M_i + M_t + M_p) \quad (4)$$

$$X_p = \frac{1}{M_p [F_b X_b - (M_r X_r + M_i X_i + M_t X_t + M_m X_m)]} \quad (5)$$

In Equation (4), M_p is the overall center of gravity of the ship, M_r , M_i , M_t and M_p shows the center of gravity variable that is converted from the presented lower hull to the upper body. In Equation (5), X_p represents the distance of the center of gravity that changes from the lower body to the upper body. Based on these equations (4) and (5), the force and moment balance equation and center of gravity are designed for 3D flow analysis [4].

2.3. Vacuum infusion process convergence automation system

The development of automation technology for vacuum infusion process fusion automation has the function of automatically adjusting the mixing ratio of the resin and curing agent and automatically adjusting the discharge amount of the mixed resin and curing agent [4,7,9]. Figure 5 is a converged process of mold device and resin injection vacuum infusion process.

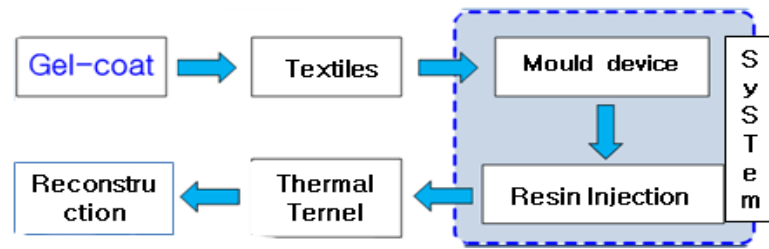


Figure 5. Process convergence flow diagram of vacuum infusion.

Figure 6 is a layout of the vacuum infusion wiring diagram for preparing an optimization plan by analyzing information on working conditions such as resin flow rate and resin flow chart by time. The vacuum facility resin injector can efficiently manage the production process with a small number of workers in multiple workplaces.

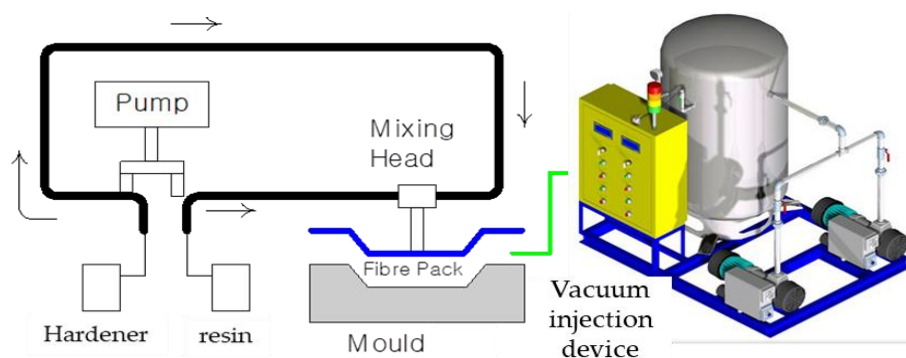


Figure 6. Layout of the vacuum infusion wiring diagram.

The development of the fiber lamination and vacuum resin injector in Figure 6 enables the combination of RTM and infusion, which can perform the adjustment function after calculating the discharge amount per desired time [4]. At this time, Equation (6), which is the curing agent mixing method Q , is a variable equation according to the mixing ratio of 0.5 to 4%, and Equation (7), ξ represents the impregnation rate.

$$Q = \frac{kA}{\eta} \left[\frac{P_1 - P_2}{L} \right] \quad (6)$$

$$\xi = \frac{\text{fabric permeability}}{\text{Resin viscosity x flow distance}} \quad (7)$$

Here, Q represents the resin flow ratio, fabric permeability, flow longitudinal section, viscosity, silver length, and pressure difference.

Figure 7 shows the PLC algorithm of the automated interlocking circuit control unit. When power is input, it is controlled by each relay through the SSR output. At this time, RS485 manages data in parallel with a PC as necessary, and each relay part performs the function of mixing a resin material, and it is connected to a nozzle and used for molding. In improving the process of mold design and manufacturing process, it is possible to standardize and optimize the design process through CAE/CAD design, and by identifying quality problems that appear during the manufacturing process, quality and productivity can be improved through the usefulness of the verified data [4,10].

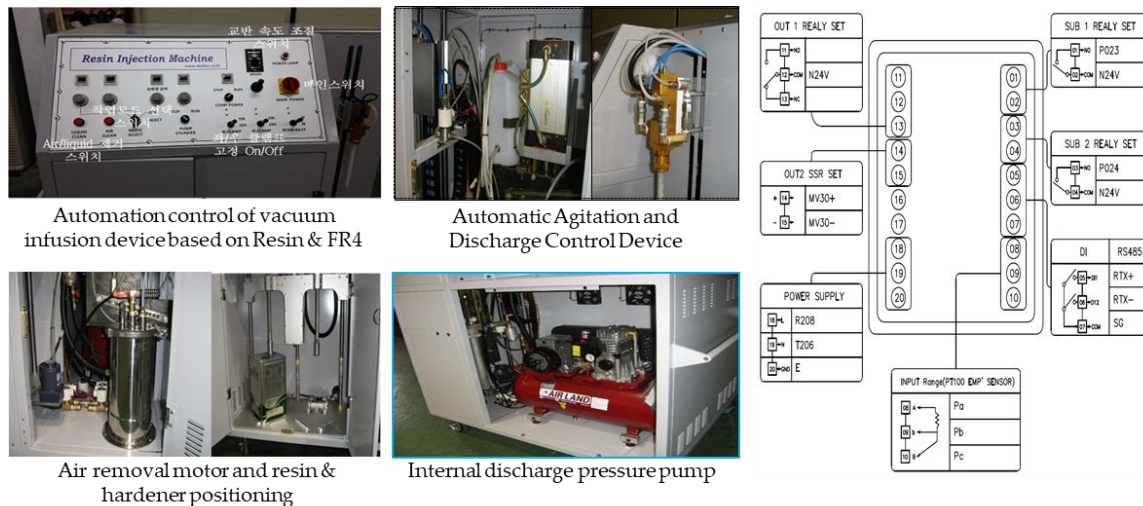


Figure 7. PLC algorithm of the automated interlocking circuit control unit.

The vacuum infusion automation device consists of an instrument panel, a stirring device and a discharge amount adjustment device, an air removal motor, a resin hardener position calibration, and an internal discharge pressure pump.

3. Manufacturing convergence of air instrument and boat floor molding

3.1. Air instrument implementation technology

When manufacturing the air appliance in Figure 1, all processes are carried out manually, so the work efficiency and product quality are determined by the operator, and it is very difficult to actively cope with defects in case of occurrence [4]. Figure 8 shows examples of manual processes such as air tubing and accessories.

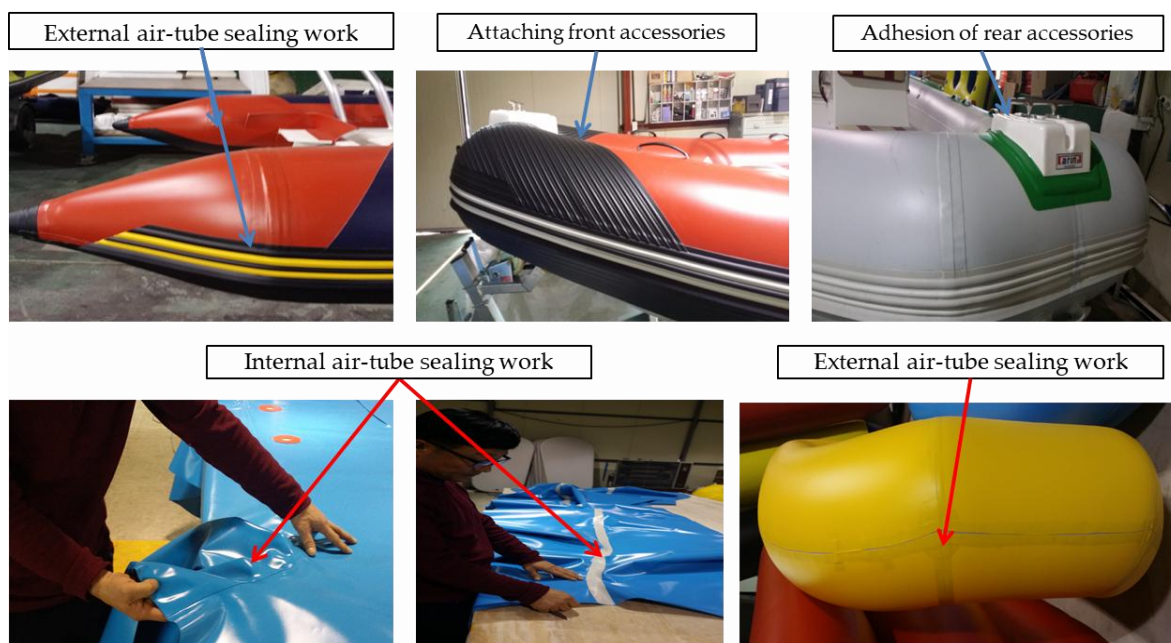


Figure 8. Examples of manual processes such as air tubing and accessories.

Table 1 shows the main facilities, daily working hours, and weight used for each unit operation.

Table 1. Unit action details.

Process name	Unit work	Major facilities	Time/Day	Unit weight	
1	Tailoring work	Drawing a fabric pattern	Hand cutting machine	More than 4 hours	20 Kg
		Bottom drawing foundation			-
2	Making and working with accessories	Making Accessory Membrane	Manual operation	More than 4 hours	3 Kg
		Fabric adhesion			3 Kg
3	Width joint	Fabric piecxe adhesion	Manual operation	More than 4 hours	3 Kg
4	Addition width	Fabric cylindrical bonding	Drier, sharp knife, Scissors	More than 4 hours	5 Kg
		Press to trim the adhesive area			-
5	Make-up tape	Make-up tape gluing	Manual operation	More than 4 hours	5 Kg
		Trim the adhesive area			-
6	Bottom adhesion	Boat post adhesion	Cutter, Knife	More than 4 hours	5 Kg
		Boat bottom adhesion			-
7	Accessory adhesion	Rubbing & bottom adhesion	Manual operation	More than 4 hours	5 Kg
		Adhesion of accessories			-
8	Packaging	Boat-folding box	Bending, Packaging, Boxing	More than 4 hours	25 Kg
		Place movement after bending			25 Kg

In the main process of Table 1, risk factors arise from improper posture and repetitive work. In particular, there are human threats for each process according to the production experience of workers, and systematic quality management is required. In the production of small-scale production of various types of boats, production efficiency is linked to an increase in production cost. Therefore, a burden appears on the musculoskeletal system according to the manual operation of accessories and wide joints according to the efficient arrangement of workers at each workplace. Table 2 shows a task check table that is a burden on the musculoskeletal system.

Table 2. Task check that is a burden on the musculoskeletal system.

Sortation	Exposure time/day	Body parts	Working posture content	Weight/exposure frequency	
Work 1	More than 4 hours	Hand, wrist, arm, shoulder	Data input	Frequency	
Work 2	More than 2 hours	Wrist, elbow, shoulder	Repeat the same action		
Work 3	More than 2 hours	Arm, shoulder	Task in which the elbow is heard by the body		
Work 4	More than 2 hours	Neck, waist	Bending or twisting without changing posture		
Work 5	More than 2 hours	Knee, waist	Squatting knees		
Work 6	More than 2 hours	Finger	Finger-grabbing work		Carrying more than 1 kg Catch more than 2 kg
Work 7	More than 2 hours	Hand	Act of lifting or catching an object		Lift and hold objects greater than 4.5 kg

Work 8	More than 2 hours	Waist	Work of carrying things	25 Kg/day at least 10 times
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According to the investigation of working conditions according to the production of accessories and width joint manual work, mold accessories that are repeated for more than 4 hours a day when manufacturing a diaphragm, and repetitive work using arms, elbows and waist according to width joint manual work are closely related to workers' safety and production quality. In addition, when air-tube leaks and defects occur, it is a fatal cause of productivity decline. Table 3 suggests improvements from the problems of this process. Currently, all of the width joints and cosmetic tapping processes of air-tube are manually carried out, causing falls, damage, or leaks. Accordingly, standardization and work speed must be accelerated, and adhesion that does not fall off should be maintained once attached. Mechanization and automation are required to minimize human body impact due to the smell of bonding adhesion by checking the location of the air-tube accessory and bonding it at once, and the accessory and mold can be integrated accurately. In particular, as bonding work increases as production increases, it is necessary to develop a convergence process capable of improving productivity and reducing cost to prevent peeling. According to the working conditions of accessory production and width joint manual work, mold accessory production work repeated for more than 4 hours a day during diaphragm production, and repetitive work using arms, elbows and waist according to width joint manual work are closely related to the safety and production quality of workers. Therefore, in the event of an air-tube leak or defect in Figure 8, the reliability of the boat decreases, and it is a fatal cause for safety [13–15]. Table 3 proposes a method for reliability and safety of the boat from these process problems.

Table 3. Proposed method for reliability and safety of the boat.

No.	Analysis contents	Improvements
1	Prediction of boat position through 2D flow analysis	Prediction of boat posture by performing optimized flow analysis through 3D design
2	Rely on the operator's skill by hand during the production of Air-Tube	Standardized automation process from experiential fabrication in tube fabrication
3	Boat performance based on the angle of the mold and operator's experience in designing the mold	Secure the safety and reliability of the boat through the development of the proposed construction method
4	Production yield problems and boat performance depend on manual work and affect safety and reliability when making molds	Contribute to improved production yield, improved boat performance and stability through the development of convergence processes and automation of production lines
5	Insufficient production quality control	PC-based database and monitoring with daily, weekly, and monthly resource management

3.2. Manufacturing convergence of boat floor molding

The molding is constructed in consideration of the variable that changes the center of gravity in the process of converting the entire center of gravity of the ship and the lower hull to the upper body [16–18]. At this time, the force and moment balance and center of gravity for 3D flow analysis are designed according to the center of gravity and distance that changes from the lower body to the upper body as shown in Equation (2). Figure 9 shows the manufacturing process of the boat floor molding based on the flow analysis.

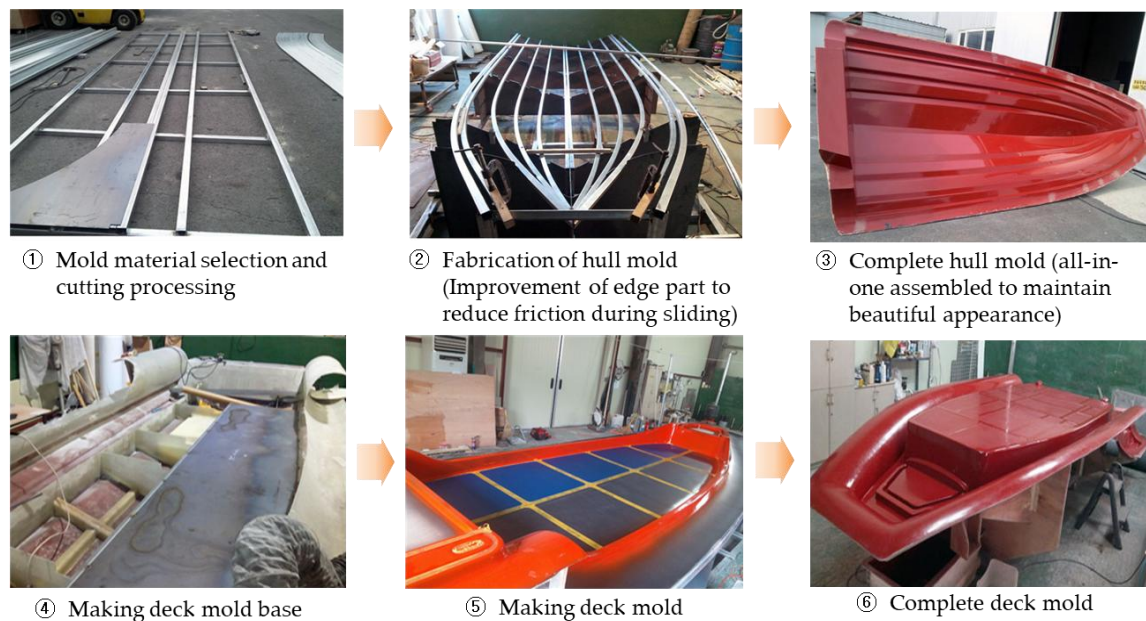


Figure 9. Manufacturing process of the floor molding.

It is important to develop specimens in order to produce elemental elements of the boat. In particular, various types of specimens are data based depending on the boat part. Figure 10 shows various specimen cases and hot-sealing system. Hot-sealing with excellent adhesive performance is manufactured and used in the width joint or taping process of air-tube to prevent damage or leakage [4]. In particular, it is necessary to maintain a high degree of adhesion, check the exact location of air-tube accessories, and minimize human body impact due to harmful odors generated during bonding. In addition, as bonding work increases, peeling prevention plays an important role in the production efficiency, reliability, and safety of boats.

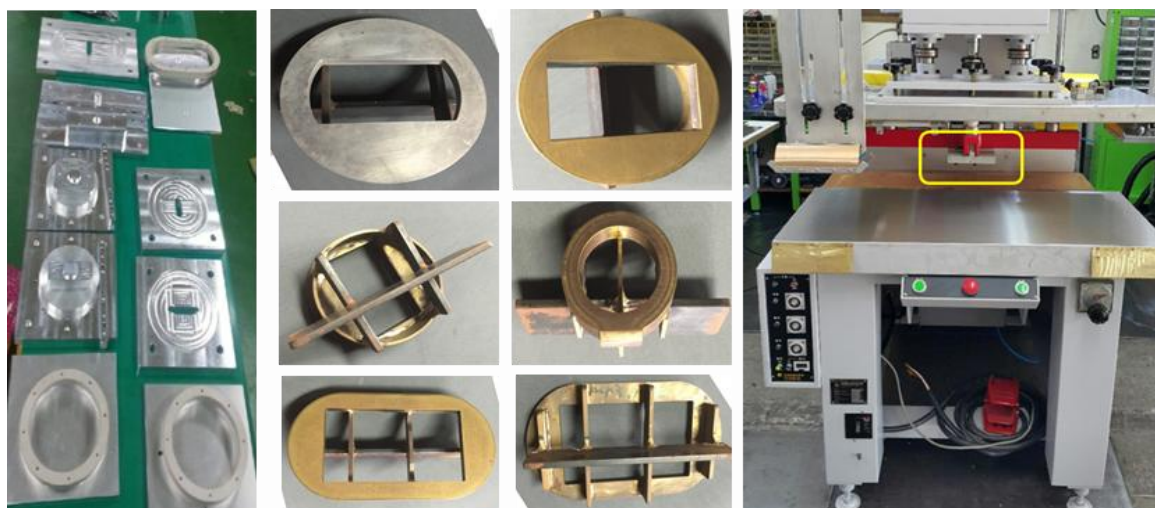


Figure 10. Various specimen cases and hot-sealing system.

4. Experimental results

Figure 11 is a sample of 5 samples, (a) hand-crafted specimen, and (b) specimens by vacuum infusion device. Pieces made by manual and bequem infusion method can have a ratio of tensile and compressive strength. Despite the specimens of the same size, the weight of the specimen made of bequem infusion is about 48% lighter on average than that of the specimen made by hand, and the amount of resin used is smaller.

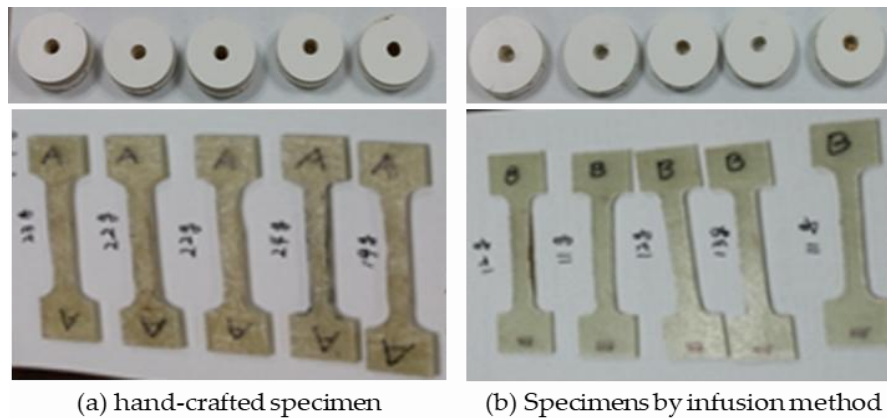


Figure 11. Sample of 5 samples.

By comparing the tensile strength test of manual and vacuum infusion by the Korea Institute for Construction and Living Environment, it is possible to improve product quality through automation in process automation technology.

The introduction of the database automatically adjusts the precise mixing ratio of resin and curing agent, the discharge amount of resin and curing agent mixture using sensors and drivers, and guarantees the performance of vacuum maintenance work through tensile strength and compressive strength of hull and deck manufactured according to the mixing ratio of resin and curing agent. Figure 12 shows the process of specimen production and weight-centered analysis during vacuum infusion work for database construction and performance analysis of specimens [4,7,8].

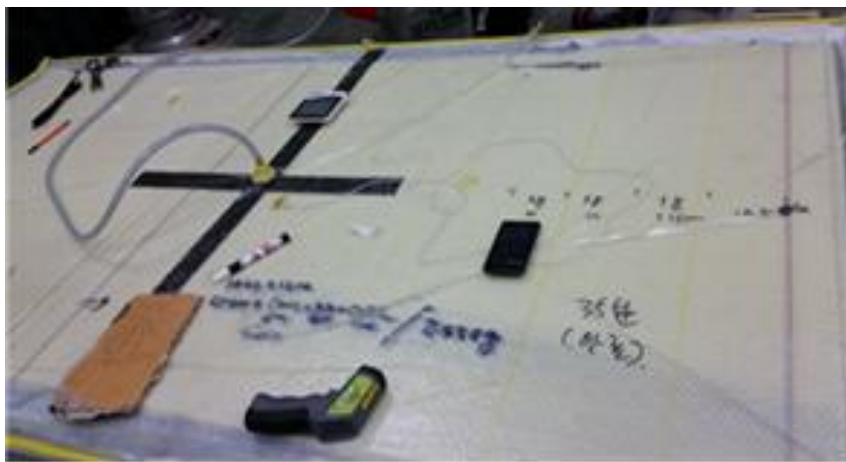
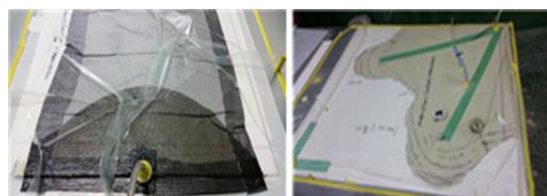
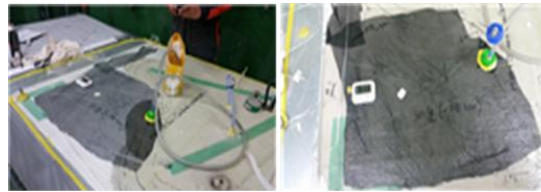


Figure 12. Process of specimen & weight-centered analysis.

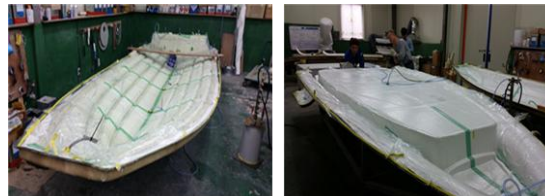
Figure 13 shows a performance evaluation test for manufactured process device using the vacuum infusion method, and showing (a) resin injection flow test, (b) resin flow direction and injection time test, (c) hull strength and vacuum film test.



(a) Resin injection flow test



(b) Flowing direction & injection time of resin



(c) Hull strength and vacuum film test

Figure 13. Performance evaluation test for manufactured device.

Table 4 shows comparison values for the thickness and weight of specimens manufactured by manual and vacuum infusion methods shown in Fig. 10 and Fig. 11 as data.

Table 4. Comparison values for the thickness and weight of specimens.

Sortation		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Manual Process 01	Thickness (mm)	11	9.2	9.5	10	11	10.1
	Weight (g)	11.5	12	9.6	11	10	10.7
Manual Process 02	Thickness (mm)	10.8	12	9.2	10	10.5	10.5
	Weight (g)	10.9	12.1	9.6	10.2	10.6	10.6
Vacuum infusion 01	Thickness (mm)	6	6.2	6	6	6.3	6.1
	Weight (g)	5.8	6	6	5.8	6.1	5.9
Vacuum infusion 02	Thickness (mm)	6	5.6	5.8	6	5.9	5.6
	Weight (g)	5.9	5.6	5.7	6	5.9	5.8

In the study of Table 4, the difference in thickness and weight was almost negligible, which means that the resin content is constant. Therefore, when comparing the hull, deck weight, and resin consumption through the infusion method, it is possible to reduce by more than 40% compared to the case of manual work. Compared to manual work in the entire boat, it is possible to expect a reduction in the hull weight as well as a reduction in the resin of 50% or more during the vacuum infusion method. As a result, the decrease in the total weight of the boat can also be expected to increase fuel efficiency.

Table 5 compares the tensile and compressive strength of vacuum infusion and hand-made composite materials. A database of physical properties was established based on the test and certification of the nationally accredited agency (Korea Institute for Construction and Environmental Testing). Here, the tensile strength of the specimen produced by the Becum infusion method is only 30% thick, but the tensile strength is superior to that of the specimen made manually.

Table 5. Comparisons of the thick, the tensile and compressive strength.

Sortation	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Manual	Thickness (mm)	6.7	6.8	6.6	6.7	6.7
	Strengthen power	Ave. 18.46 kg/mm^2 (181 MPa)				
	Depression power	Ave. 20.40 kg/mm^2 (200 MPa)				
Vacuum infusion	Thickness (mm)	2.4	2.2	2.3	2.3	2.3
	Strengthen power	Ave. 27.44 kg/mm^2 (269 MPa)				
	Depression power	Temp. value (Thickness 6.7mm) - Ave. 32.68 kg/mm^2 Real value (Thickness 2.3mm) - Ave. 11.22 kg/mm^2				

In Table 5, it can be seen that in the case of specimens having the same thickness, the compressive strength is also much better made of the Becum infusion method. In addition, analysis conditions for analyzing the thickness, weight, and resin flow rate according to the mat lamination and resin type were presented in the DB. When the number of stacks was the same, both thickness and weight of the Becum infusion were smaller than those of the manual case, which means that the proportion of the resin absorbed by the products made by the Becum infusion is small.

Table 6 shows the database for analyzing thickness, weight, and resin flow rate (min/cm) according to the mat lamination and resin type. As confirmed, when the number of stacks was the same, both thickness and weight of the becum infusion were smaller than those of the manual operation, which means that the proportion of the resin absorbed by the products worked with the becum infusion is small.

Table 6. Database for analyzing thickness, weight, and resin flow rate (min/cm).

No	Stacking method	Resin	Tempered glass fiber	Number of stacks and order	Thickness (mm)	Weight (cm/g)	Flow rate (m^3/hr)	Operation mash
01	Manual	G-713BT	M450, ROVING570	M.M.Rx2 (six sheets)	49	5.7	-	Part Distribution
02		FH-123NHL			49	5.9	-	
03		UV-R1			49	5.6	-	
04	Infusion -01	G-713BT	2.63	2.5	0.43			
05		FH-123NHL	2.61	2.3	0.42			
06		UV-R1	2.6	2.1	0.46			
07	Infusion -02	G-713BT	M450, LT600, DB400, COER, DBL600	M, LT, DB, CO, DBL (five sheets)	6.1	5.94	0.27	
08		FH-123NHL			6.0	5.96	0.3	
09		UV-R1			5.8	5.65	0.31	
10		G-713BT			6.1	6	0.7	
11		FH-123NHL			6.15	5.9	0.75	

12	UV-R1	6	5.8	0.78	entire Distrib ution
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Table 7 compare the results of changes in thickness, weight, and flow rate of products manufactured according to conditions, and it can be confirmed that the Becum Infusion method has advantages such as thickness and weight reduction effect, reduction of working time, and uniformity of molding production

Table 7. Comparison of the results of changes in thickness, weight, and flow rate of products.

No	Terms	Manual	Vacuum	Note
1	Resin weight	160 kg	80 kg	50% (↓)
2	Glass fiber	80 kg	60 kg	25% (↓)
3	Ship weight	240 kg	140 kg	42% (↓)
4	Manufacture	10	8	20% (↓)
5	Intensity	181 MPa	269 MPa	49% (↑)
6	Pressure strengthen	200 MPa	320 MPa	60% (↑)
7	Ship edge effectiveness	Minimize the friction area between ship and water for the sharpened ship edge part		
8	Ship out part	no bending the line and surface		
9	Speed up	About 15 %		
10	Fuel efficiency	10%		
11	Safety	Safety sense for 7 estimated terms		

5. Conclusion

In this study, a vacuum infusion method was presented and the performance of manual work was compared through boat design and manufacturing. In particular, in order to differentiate the samples that can build the safety and reliability of the boat, a database was constructed through process fusion during the manufacturing process.

For the three-dimensional flow analysis of force and moment, the boat was designed in consideration of the variable that changes the center of gravity in the process of converting the entire center of gravity of the lower hull to the upper body through balance and center of gravity. At this time, it shows the process of manufacturing a boat floor molded product based on flow analysis according to the center of gravity and distance that changes from the lower body to the upper body.

As a result of comparing the tensile strength and compressive strength of the vacuum injection method and the handmade composite material through specimen manufacturing, it was confirmed that the tensile strength of the specimen manufactured by the vacuum injection method was only about 30% thick compared to the handmade specimen, but the tensile strength was more than 50%. In addition, it can be confirmed that the working time is shortened and the possibility of uniformly manufacturing molded products is confirmed, in addition to the effect of reducing thickness and weight.

This study can secure the safety and reliability of boats according to the activation of the leisure industry, and prevent possible safety accidents as the center of an unevenly designed ship changes during the high-speed process. In addition, an infusion method was proposed to minimize damage that may occur during underwater rocks or collisions.

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