

Evaluation of the Manufacturing Processability of Exploration Vessels Applied with Carbon fibre reinforced plastic

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ABSTRACT

Carbon fibre reinforced plastic (CFRP) is a high-strength, lightweight material that is widely used in the aerospace and automobile industries, and recently is also used in the shipbuilding field. However, the fibre volume fraction of the shipbuilding composite material process is less than 35% due to the hand lay-up process and the low-vacuum liquid resin transfer moulding process technology. The autoclave process and vacuum oven curing process are difficult to apply to the shipbuilding industry due to high equipment and processing costs. A vacuum liquid forming process must be used to increase the fibre volume fraction. In the project under study, the Autonomous Surface Vehicle (ASV) must be equipped with various equipment, so it must be light and strong. Accordingly, ASV is being studied using CFRP among composite materials for shipbuilding. In this study, a vacuum liquid moulding process capable of manufacturing high-quality carbon composites is applied to the hull of an unmanned probe. In order to evaluate the manufacturing process of the unmanned probe carbon composite hull, the viscosity of the resin and the permeability of the fibre mat were measured. The permeability coefficient of the preform was determined as the in-plane time flow rate using the radial flow method. The fibre volume fraction was measured at 48, 50, and 52 per cent, and a study was conducted after process simulation based on the measurement results and basic data such as pressure gradient, inlet and outlet design, and process optimization. RTMWORX was used as a simulation program.

Keywords: Autonomous surface vehicle, Carbon fibre reinforced plastic, Permeability, Fibre Volume Fraction

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1. INTRODUCTION

The topic of this abstract fits best within Session 19 because the technology under study is the construction of technologies and systems for underwater cultural heritage surveys. In the case of carbon fibre reinforced plastics (CFRP), they are mainly used in the aerospace field due to their high specific strength and specific stiffness. Recently, interest in eco-friendly ships has increased and research for application to the shipbuilding field to improve fuel efficiency is being actively conducted. The composite manufacturing process currently used in the shipbuilding field is a hand lay-up process, which is mainly used for manufacturing low-quality composites. Recently, a high-quality composite manufacturing process has become required, with a fibre volume ratio of 45 per cent or more (Um et al. year). In this study, the vacuum liquid forming process, which can manufacture high-quality carbon composites, will be applied to the hull of an unmanned probe. The vacuum liquid moulding process is a method in which resin is impregnated by fluidizing it by a difference in air pressure in a vacuum state and is mainly used in the production of large composite materials. In order to evaluate the manufacturing suitability of the carbon composite hull of the unmanned probe, a process simulation was performed based on basic data such as viscosity measurement of resin, permeability coefficient of fibre mat, and pressure gradient, and then inlet and outlet design and process optimization research were conducted.

2. CASE STUDIES

The case study under consideration is the development of an Autonomous Surface Vehicle (ASV) for underwater cultural heritage investigation using autonomous navigation technology, and includes reference to a field demonstration. The outline of this research and development is to create a platform system that can operate autonomously in shallow waters and simultaneously utilise equipment used for underwater surface surveys. This research study aims to develop a twin-hull ASV platform that reduces errors by using autonomous navigation and ICT technology through machine learning. The ASV platform can automatically return in case of an emergency, has a navigation error of $\pm 1\text{m}$, and aims to develop a Dynamic Position (DP) system for apex three dimensional (3D) exploration. An autonomous driving system was introduced for cost-effective data acquisition. This study aims to develop unmanned technology that incorporates the core technologies of the fourth industrial revolution (artificial intelligence, internet of things, etc.). As for the use and application areas of the developed product, all survey activities listed in the buried cultural heritage work guidelines (topographic survey, high-frequency strata survey, seabed survey, geomagnetic survey, diving survey, etc.) be performed.

3. RESOURCES

The resources available to conduct the work include resin, fibre utilisation knowledge, understanding of underwater environment and hull design, and manufacturing technology. Regarding the resin, all resin systems used in composite materials require properties such as excellent mechanical properties, excellent adhesive performance, excellent toughness, and excellent resistance against environmental degradation. Resins used in marine composites are thermosetting resins, and polyester or epoxy resins are mostly used. Thermosetting resins such as polyester and epoxy are more convenient to use in the process because they are cured without generating volatile by-products (ref. CMH). The mechanical properties of the resin should have high maximum strength and stiffness and exhibit high strain until fracture, which means that it is hard but not weak against brittle fracture at the same time. When the composite is subjected to tensile forces, the resin must deform at least as much as the fibres. The adhesive performance of resin is important because excellent adhesive performance between resin and fibre is required in the manufacture of composite materials, so to effectively transfer the load when a load is received, and to prevent cracks or separation between fibres and resin. Fibres used in manufacturing composites can be largely divided into carbon fibres, glass fibres, and natural fibres, and most of the fibres used in hull manufacturing are glass fibres. Carbon fibre has the highest mechanical properties, but its utilisation rate is low in hull manufacturing in terms of price. In order to increase the stability of the hull, the fibres are arranged in a fibre stacking pattern according to the direction of the load received by the hull. Since ASVs used in shallow waters are always exposed to marine environments such as salt water, ultraviolet rays, sea wind, and wave power, they have a high risk of corrosion and have a problem in that their lifespan is shortened by repeated loads from waves. As a solution to this, we want to manufacture an ASV hull using composite materials.

4. FRAMEWORK

The research approach uses the hull concept of unmanned self-driving vehicles/unmanned probes and uses high-frequency geological exploration technology to investigate underwater cultural assets, the national heritage and heritage of human civilization. Underwater surface survey is conducted using underwater survey equipment, but there is no standard for systematic exploration research, exploration equipment, or methods for underwater cultural heritage exploration. The majority of underwater artefacts currently being excavated come from shallow coastal areas. When it is necessary to investigate these shallow seabed and intertidal areas, such as coastal areas and coastal estuary

wetlands, which are inaccessible to general ships, shallow draft vessels are used, such as rubber boats. Although underwater surface surveys are being conducted using a micro-vessel, there are cases in which these surveys cannot be conducted due to problems in the operation of the vessel and or the safety of the investigators. The possibility of autonomous underwater surface survey for shallow water can be expected to increase the possibility of finding underwater artefacts several times. Recently, as the 4th industrial revolution is emerging, it is a national project in Korea for the development of unmanned free-running ships (autonomous USVs) that combine ICT and convergence industries to revitalise coastal surveys and observations, logistics transportation, and the stagnant shipbuilding industry. Research and development for self-driving ships is in progress, and miniaturised self-driving ships for marine surveys are developing rapidly. If an unmanned ASV for underwater cultural heritage research is developed, it will be possible to conduct a large-area underwater surface survey very efficiently, compared to the current underwater surface survey method. In addition, as economic and industrial activities in coastal waters increasingly occur, such as offshore plant construction, it is clear that data is important for preserving and managing underwater cultural heritage properties. It is therefore important to acquire high-quality marine information to determine the exact location of underwater cultural assets existing in sedimentary layers or on the seabed, and based on this, precise underwater surface survey (secondary survey) and excavation work must be conducted. In addition to the survey and exploration equipment currently used for underwater surface survey, there is 3D exploration to obtain more precise and accurate survey results, and based on the information obtained through this, accurate and precise result data suitable for the purpose of underwater surface survey. If a small self-driving marine survey vessel suitable for underwater cultural heritage exploration is developed and fitted out with equipment capable of precise investigation, the possibility of discovering underwater cultural heritage increases, even if the investigation is carried out in shallow water areas.

Competing organisations that have technology related to unmanned autonomous ships in Korea are national research institutes such as Korea Institute of Ocean Science and Technology, Korea Ocean Research Institute, Daewoo Shipbuilding & Marine Research Institute, Daewoo Shipbuilding & Marine Engineering ENR, and university industry-university cooperation foundations. In the case of ships, some small and medium-sized enterprises conducted research related to detection of hazardous materials through remote control and collection of wastes on the water, but it was confirmed that there was no research related to complex unmanned autonomous marine survey vessels (boats).

As for technologies related to autonomous ships overseas, China and the West (USA and Europe) are leading the research and development of technologies and commercialised ships (boats) in marine-related companies. Representative companies include ASV Global, Unmanned Marine Systems, Maritime Robotics, and Oceanalpha (China), but the development of commercialised boats related to complex unmanned autonomous marine research vessels (boats) was developed by marine research related companies. In commercialised boats, marine survey equipment (baywater surveying equipment, etc.) is individually installed and operated on autonomous unmanned ships.

5. RESULTS

The results are establishment of basic design conditions through identification of resin characteristics and inlet and outlet design and process optimization research were conducted. To evaluate the manufacturing processability of the carbon composite material, the permeability coefficient of the fibre mat was measured. To measure the permeability coefficient, a radial flow type permeability coefficient measurement equipment was fabricated. The permeability coefficient of the radial flow method can determine the fluidity of the in-plane (in-plane) direction resin. Silicone oil was used for stable flow of the liquid phase, and the permeability coefficient was measured using Darcy's equation by measuring the advancing distance of the resin over time.

$$\bar{U} = -\frac{K}{\mu}P$$

[Darcy's equation($\bar{U}$: Resin speed, K : Permeability, μ : Viscosity, P : pressure)]

The rheological properties of the resin were analysed using a rheometer. The equipment used for rheological property analysis was HR-20 from TA Instruments, and the optimum temperature and pot life of the process were identified through dynamic and static analysis. Using the permeability coefficient and resin viscosity measured above, process design was performed using the RTMWORX program of POLYWORX in the Netherlands. The results of Table 1 below were obtained through the measurement of the permeability coefficient of the fibre mat. Based on the permeability coefficient measurement results, it will be applied to process simulation. In the process design of this study, the injection viscosity of the resin was determined to be 1 Pa.s, and at this time, the fluidity of the resin (1 Pa.s and pot life (about 70 min) were judged to be appropriate, and the optimal process design was performed through simulation in the future (Ha et al. 2022).

Table 1. Result of permeability coefficient

Vf	Test	K1	K2	K1/K2
48	1	1.10E-09	6.88E-10	6.85E-01
	2	1.28E-09	6.89E-10	5.37E-01
	3	1.26E-09	6.99E-10	5.56E-01
	Avg.	1.18E-09	6.92E-10	5.93E-01
50	1	6.19E-10	4.59E-10	7.42E-01
	2	6.03E-10	4.65E-10	7.70E-01
	3	6.67E-10	4.44E-10	6.65E-01
	Avg.	6.30E-10	4.56E-10	7.26E-01
52	1	2.98E-10	2.76E-10	9.26E-01
	2	2.89E-10	2.84E-10	9.83E-01
	3	2.16E-10	1.94E-10	8.98E-01
	Avg.	2.68E-10	2.51E-10	9.36E-01

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BIBLIOGRAPHY

CMH, "Resin system", Composites Materials Handbook

Ha, J.R Kim, J.YSeok, J. Cho, J. H. Evaluation of manufacturing fairness of hulls applied with CFRP for unmanned probes", KSMTE Annual Spring Conference 2022, 158

Um, M.-K, Lee, S.-K., Kim, T.-W., Kim, J.-H and Kim, S.-W. A Study on the Determination of In - Plane Permeability of Fiber Preforms, *Composites research* 75-83.