고내항성 무인 수상정 구조체의 수분 확산 특성에 관한 연구

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A Study on Characteristics of Water Diffusion on High Endurance Structure Hull of Unmanned Surface Vehicle

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Abstract : It is known that Fiber-Reinforced Polymer (FRP) Composite are very sensitive and are friendly to water or moisture in any forms. Moisture in polymer composites often causes degradation by swelling and hydrolysis. Especially, if polymer composites will be immersed in water and seawater, faster degradation can be caused by water uptake than any other moisture environments. While general investigations regarding water uptake are concentrated on the composite materials cured in ambient temperature, the immersion effects of polymer composites exposed to elevated temperatures were studied because underwater applications of composite materials can be exposed to the various heat sources. For example, fires on naval vessels and underwater vehicles can be started by any number of causes such as electrical faults and ignition of flammable gases or liquids. Furthermore, in case of Unmanned Surface Vehicle (USV), more high endurance structure hull will be required to operate at high speed and worst seawater environment. For that, a study on degradation due to water diffusion will be carried out.

Key Words : Fiber-Reinforced Polymer (FRP), Degradation, Immersion effect, Unmanned Surface Vehicle(USV), High Endurance Structure Hull

1. Introduction

In early, use of composite materials was constrained to the construction of small patrol boats and landing craft in displacement due to relatively poor fabrication quality and low stiffness of the hulls. However, as fabrication technique and mechanical properties were improved, composite materials can be applied to larger patrol boat, minecountermeasure vessels, and corvettes. Skjold (Figure 1) is the Royal Norwegian Navy's first fast patrol craft/littoral combat ship of the Skjold-class and is currently being evaluated by the US Navy. The ship is based on a catamaran hull where lift fans blow air into an air cushion between the hulls. The structure is built with FRP sandwich using uniaxial glass fiber and carbon laminates with vinyl-ester or polyester resin. Polyvinyl chloride (PVC) core material is used in main structural elements below main deck and polymethacrylimide (PMI) core material is used elsewhere and for the complete superstructure. The total length of Skjold is approximately 157 feet at a displacement of 260 tons. The Swedish Navy is operating the Visby-class corvette (Figure 2) from 2000. Visby class is designed to be a multi-purpose vessel with capabilities for surveillance, combat, mine laying, and anti-submarine warfare operations[23]. The visby corvette is built from sandwich composite panels having face skins of hybrid carbon- and glass fiber polymer laminate covering a poly (vinyl chloride) foam core. With carbon reinforced composite, Visby class can get the benefit of adequate electromagnetic shielding.

Fig. 1. Skjold class patrol boat built with FRP sandwich

Fig. 2. Visby corvette having hybrid carbon and glass fiber polymer laminate

FRP composite materials are being used in a variety of underwater applications based on their stiffness, strength, reduced weight, and corrosion-free capabilities. Until recently, the use of FRP composite materials for military applications was limited to aerospace and US air force for high-performance applications. Currently, applications of FRP composite materials in the U.S Navy are widely broaden into sonar bow domes, windows, hulls and so on. Moreover, there is a resurgence of interest for the use of composites in military applications including naval vessels, army combat vehicles, underwater robot fish and unmanned underwater vehicles. Beside inherent advantages of FRP composites such as high strength-to weight and stiffness-to-weight ratios, composites materials using the carbon fiber as a reinforcement are particularly useful because they exhibit better mechanical properties than other FRP composites as well as provide the ability for electromagnetic shielding for stealth purpose. The all-composite naval ships are currently operating to perform multi functional operation with the benefits for FRP composite materials. In early, use of composite materials was constrained to the construction of small patrol boats and landing craft in displacement due to relatively poor fabrication quality and low stiffness of the hulls. However, as fabrication technique and mechanical properties were improved, FRP composite materials can be applied to larger patrol boat, minecountermeasure vessels, and corvettes.

2. Diffusion in Polymer Composites

In general definition, diffusion is the movement of molecules from a region of high concentration to a region of low concentration by means of random molecular motion. Fick's laws provide a theoretical basis for the diffusion of a fluid into a distinct sorbing medium from a higher concentration to a lower concentration. Also, Fick's second law provides a theory for non-steady-state diffusion. Fick's law refer to that the mass of absorbed water increases linearly with the square root of time and then gradually slows until an equilibrium plateau or saturation is reached. The rate of diffusion and the attainment of an equilibrium content can be affected by materials characteristics, processing factor, environmental condition, and geometry. Since Fickian diffusion assumes no chemical reaction between the diffusion solution and composite materials, composites technically do not follow Fick's law. However, in a number of researches, the diffusion of moisture in fiber reinforced composites and cross-linking resin has been shown Fickian behavior. Fickian diffusion has following features.

1) Linear in the initial stage and the linear region until at least Mt/Mm=0.6

where:

M_t = the moisture absorbed by the composites at time t

M_m= the maximum moisture content absorbed by the composite

2) The decrease of the rate of diffusion until an equilibrium of moisture content

3) Diffusion coefficient as a function of temperature

$$D = D_0 \exp(\frac{-E_a}{RT}) \qquad (1)$$

where:

D = diffusion coefficient

D_0= a constant

E_a= activation energy

R = the universal gas constant

The theory of Fickian diffusion also assumes that only reversible physical reactions take place in the polymer matrix during the process of moisture sorption. Figure 3 shows schematic curves representing four categories of recorded non-Fickian weight-gain sorption compared to linear Fickian diffusion. This Figure was postulated by Weitsman[82]. Curve A means pseudo-Fickian diffusion characterized by a initial uptake in the beginning stages of immersion similar to Fickian behavior. However, saturation or equilibrium is not attained in this case. In the case of curve B describing two-stage diffusion behavior, the weight of composite materials initially increases due to moisture while this process experiences a quasi-equilibrium by the competition between moisture uptake and mass loss. Curve C caused by deformations, wicking, or mechanical failure is a type of diffusion where moisture is rapidly increasing. Curve D in Figure 3 shows weight loss that is attributed to hydrolysis or other types of irreversible degradations. Curve LF, which has the solid line, stand for linear Fickian diffusion that follows the Fick's law.

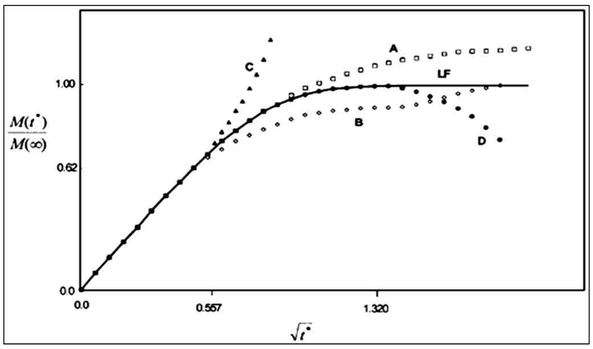

Figure 3. Schematic curves representing four categories of recorded non-Fickian weight-gain sorption

The diffusion coefficient can be calculated either by monitoring the concentration characteristic from the volume of composite materials or via gravimetric measurements. Ultimately, the diffusion coefficient can be determined according to a theoretical model used to fit experimental data trends. In case moisture uptake shows the Fickian diffusion, diffusion coefficient can be determined using the short-term approximation as expressed by Equation(2).

$$D = \frac{\Pi h^2}{16 M_\infty^2}\left[\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right]^2 \quad (2)$$

where:

D = the Fickian coefficient of diffusion, mm^2/s
h = the thickness of the specimen, mm
M_∞ = the weight gain after equilibrium, g
M_1, M_2 = the percent changes in weight at time t_1 and t_2, %

3. Conclusion

1. The results of the gravimetric measurements on specimens immersed in deionized water and seawater showed a Fickian response in all conditions.

2. Specimens post-cured from the increase of ageing time and exposure temperature showed the rapid saturation and the higher maximum weight gain compared to un-cured specimens.

3. The partially cured composite could be expected to have a greater concentration of unreacted chemical species with the epoxy resin and it appears that these species were released more rapidly into water resulting in a slower net mass gain.

4. Mass loss by leaching of organic species than mass uptake by sorption of salts largely contributed to lower maximum weight gain in seawater compared to the values of deionized water.

5. Overall diffusion coefficients calculated for deionized water immersion were higher than those for seawater immersion in all environmental conditions. Diffusion coefficients in deionized water were widely distributed with increase of ageing time and exposure temperatures.

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