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A Study on Composite Material for Drain Pipe in Subsea Tunnel

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ABSTRACT

In the design of a tunnel of which environment is sea water condition, consideration in material sustainability for drainage system is important. In recent years, FRP composite material is commonly used for water related facilities due to its high resistance to corrosion. In this study, it is attempted to use the FRP material as a drainage system of subsea tunnel. Material tests for small flat specimens were carried out for various fiber lamination angles. In addition, tests for real-scale perforated pipe specimens were also performed. In case of the flat specimen the highest tensile strength was obtained for the right angle of fiber lamination. Meanwhile, in the test of perforated pipe, maximum tensile strength was obtained when the fiber lamination angle is 30°. Throughout this study, it is identified that the main influencing factors governing the tensile strength of the FRP composite material are the angle of fiber lamination, existence of holes and temperature, and the maximum structural benefits can be obtained by optimizing those factors.

1. INTRODUCTION

Since infinite amount of sea water exist above subsea tunnel, the characteristics of tunnel construction and management of subsea tunnel differs from that of land tunnel. Thus, at the phase of tunnel management system design, such characteristics must be considered. The procedures of inflow controls in general tunnels are that the ground water is collected through a drain line of down slope and the force applied by a pump. That is, groundwater which is flowing through the lateral drain and longitudinal drain collected in drainage well and discharged into the sump pump. Considering the proportion occupied by the tubular material in the drainage system of the tunnel, it is important to design the material and structure of the drain pipe used in the tunnel so that the drain function is not damaged by the salty sea water. Therefore, the inflow control and management system made of FRP(Fiber-Reinforced Plastic) composite material can be an alternative to sustain operation.

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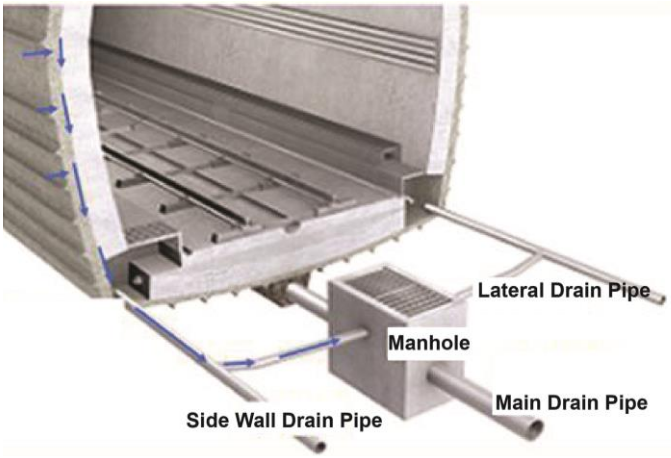


Fig. 1 System of management and control for the tunnel drainage

In this study, the composite material, FRP(Fiber-Reinforced Plastic) was evaluated at room and sea water temperature in the static test. First, a tensile test of flat specimen was carried out on the basis of ASTM(American Society for Testing and Materials). Tests were conducted with imperforated and perforated specimen at the room temperature(20°C) and sea water condition(0°C). And comparative analysis was investigated with respect to changes in the mechanical properties of the materials due to temperature. Then FRP perforated pipe specimen that can be used for drainage in actual tunnel was produced and tensile-fracture test was carried out. The reason of tensile tests is to determine mechanical properties differences in arrangement angle of lamination.

2. TEST METHOD

2.1 Flat specimen test

The glass fiber was made of fiber and the vinyl ester that has high properties of chloride resistance was used as matrix. Two kinds of laminated form are each LT(0°/90°) and DB(-45°/+45°). The laminated direction of specimen is longitudinal direction(L; Longitudinal, 0°), transverse direction(T; Transverse, 90°), and diagonal direction(DB; Double Bias, ±45°). With specimen of the two types of laminate form, 3 imperforated and 3 perforated specimens were produced for room temperature and sea water temperature tests respectively and a total of 12 specimens were prepared. The flat specimen is shown in Fig. 2.

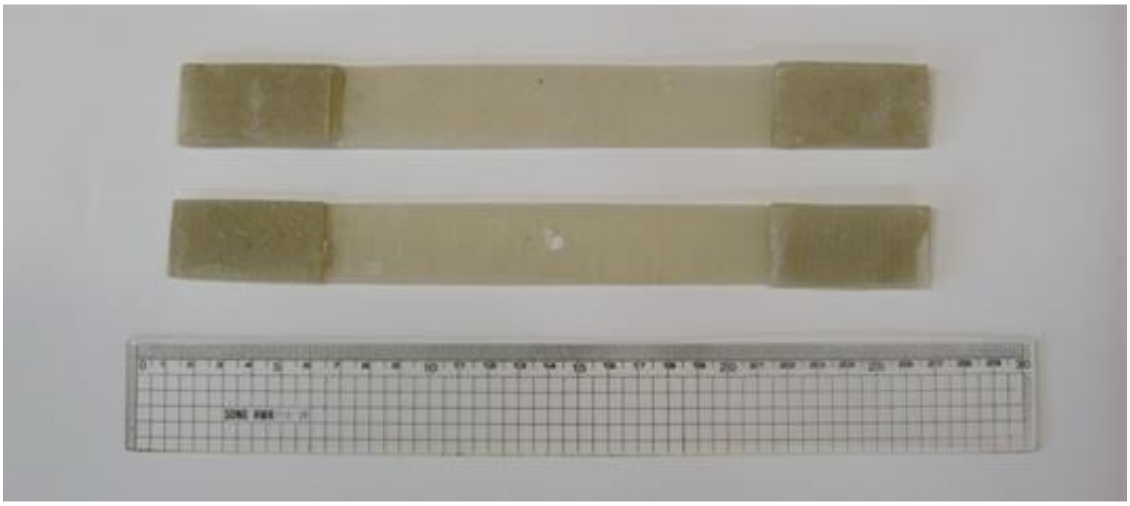


Fig. 2 Coupon specimen for tensile tests

Fiber content of the test specimen was 30%. And the test was carried out with MTS testing machine that equipped with 322 Test Frame, 647 Hydraulic Wedge Grip, and chamber that can maintain the room temperature and a specific temperature. Loading rate was 1mm/min.

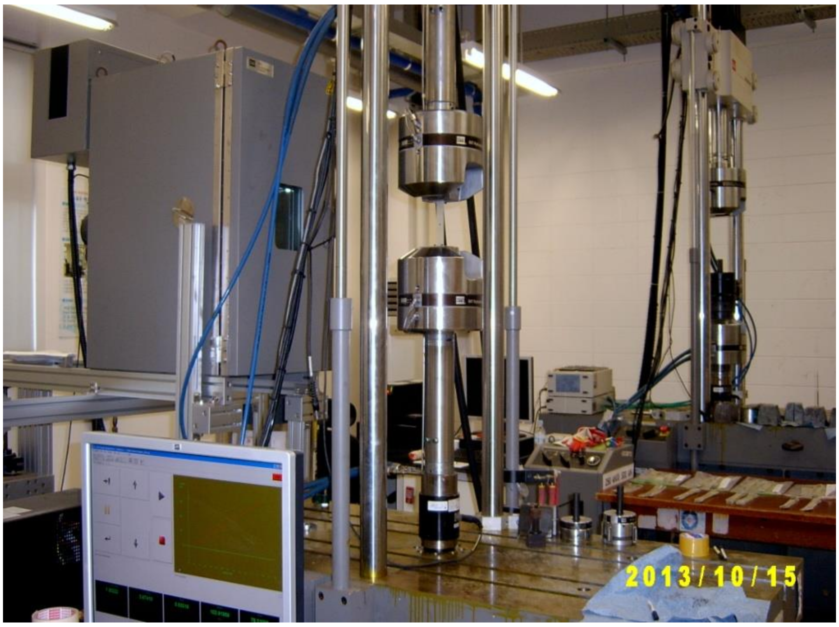
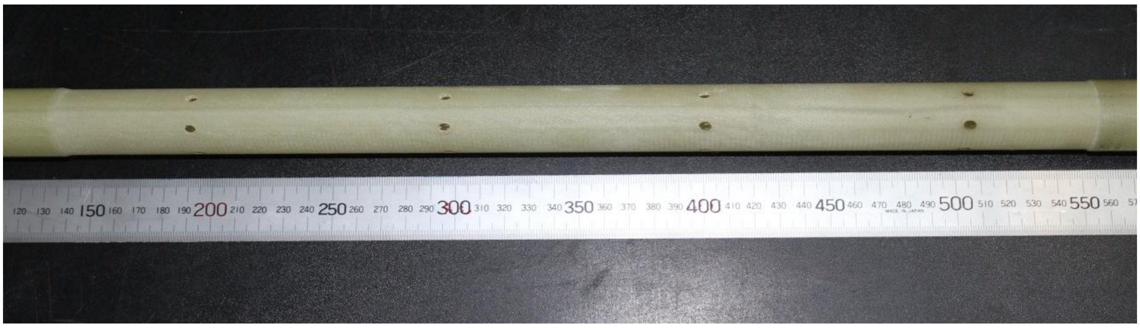


Fig. 3 Tensile-fracture load test (FRP flat specimens at room temperature)

The tensile fracture test was conducted in the sea water temperature. The exposure time to sea water temperature of the test specimen was set to 20 to 60 minutes range.

2.2 Perforated pipe specimen test

In making the pipe specimen, Prepreg method that is widely used commercially was applied to produce the specimen. Prepreg method is the process of making the form of a thin sheet by impregnating in advance the reinforcing fibers in the base, and wrapping the prepared prepreg on plastic pipe mold of predetermined shape, and curing the pipe in a high temperature oven. Glass fiber was used as fiber and epoxy was used as matrix. Fiber content was 60%. Whole pipe length is 1650mm, and the hole was placed in section of center that has 800mm length(from center to each side 400mm). To induce fracture at a desired section, thickness for a total of 400mm length, 200mm from the center line to each side, was reduced by 1mm to minify the cross-section. Therefore, the entire inner diameter of the pipe is equal to 30mm, and the thickness is 2mm from the center line to the each side (external diameter is 34mm), and 3mm at the remainder(external diameter is 36mm). The diameter of the hole is 5mm, and the drilling was performed with spreading water to prevent the pipe specimen from being deformed by the friction heat when being perforated. Laminate angle means that the angle is rotated through the counterclockwise direction from horizontal direction of the pipe. Laminate angle is 30°, 45°, 60°. Straight line arrangement(ST) and zigzag line arrangement were tested respectively. In both cases, the same size and number of the hole are set, and longitudinal spacing of the hole are also identically disposed.



(a) Straight line hole arrangement(ST)

(b) Straight line hole arrangement(ST)

Fig. 4 Hole arrangement of perforated pipe specimen

Summarizing the test cases can be classified into three types, depending on the total angle of lamination. And test cases are total 6 cases with the division of straight line arrangement and zigzag line arrangement. All the test cases are shown in table. 1.

Table. 1 Perforated Pipe test case

Laminate angle		Hole arrangement type	
		Straight line(ST)	Zigzag line(ZG)
①	30°	30°-ST	30°-ZG
②	45°	45°-ST	45°-ZG
③	60°	60°-ST	60°-ZG

In general, universal testing machine (UTM) is used as tensile test equipment. Though the test kits are available to precise test with electronic equipment, the specimen used in this test shall be flat specimen. In case of this common tensile test, the pipe is cut into longitudinal direction and stretched flat. Conducting the test with this specimen, influence of the hole cannot be arranged. Also, it is difficult to directly exert a tension using UTM equipment without cutting the pipe because end of the specimen can be crushed and hard to fix the position. Therefore, the tension-fracture test for perforated pipe was conducted by setting a new device which is not constrained by the above-mentioned problems. Since the process of the pressure proceeded with hands, the test was not that so precise. However, the pressure was maintained at the same level as much as possible for uniformity of the tests.

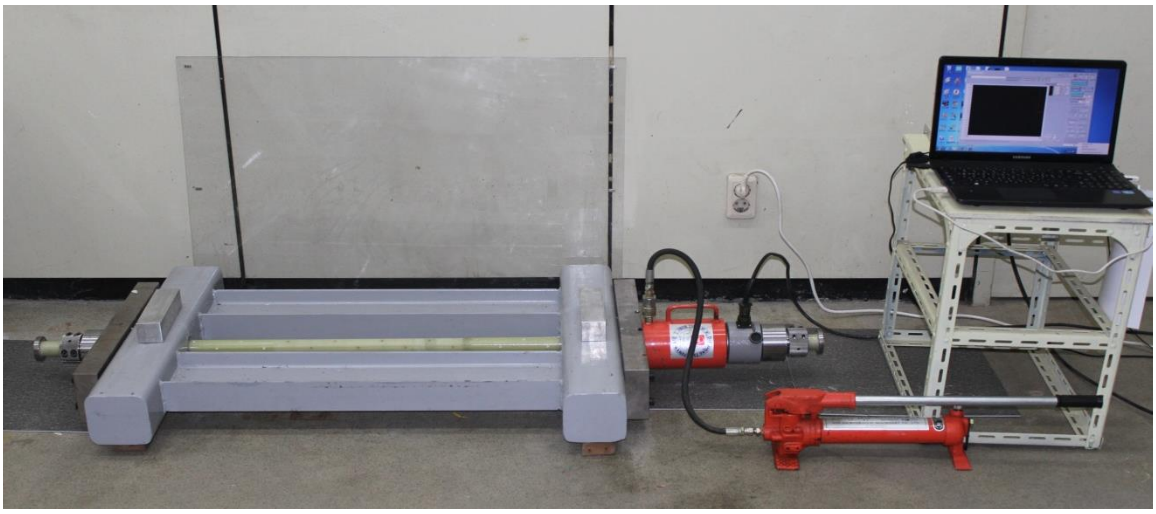


Fig. 5 Experimental equipment of perforated pipe test

3. TEST RESULTS AND ANALYSIS

3.1 The flat specimen test

The data that fracture was occurred outside of the gauge range was excluded in accordance with ASTM D3039. Other normally fractured data was gathered except maximum and minimum data and the properties were extracted. The average maximum load at failure of the LT(0°/90°) laminated, imperforated specimen was measured in 14.77kN in room temperature, and the average maximum stress was measured in 407.77Mpa. The average maximum load was 4.89kN and the average maximum stress was 60.41Mpa in case of perforated specimen with same condition. The test of imperforated pipe specimen shows that ultimate stress of LT(0°/90°) lamination was higher than DB lamination but in case of perforated specimen, DB(+45°/-45°) lamination shows higher ultimate stress. Considering the drainage pipe is produced with hole generally, it is more advantageous to design the drainage pipe with lamination of diagonal arrangement.

The test was performed in sea water temperature. In case of the imperforated specimen test, LT(0°/90°) laminated specimens show higher ultimate stress, and in perforated test, DB(+45°/-45°) laminated specimens present higher ultimate stress. The result shows that it is beneficial to design drainage pipe with diagonal angle of lamination. The whole test results are shown in table. 2.

Table. 2 Test results for flat specimen

Properties	Room Temperature				Sea Water Temperature			
	Without hole		With hole		Without hole		With hole	
	LT (0°/90°)	DB (+45°/-45°)	LT (0°/90°)	DB (+45°/-45°)	LT (0°/90°)	DB (+45°/-45°)	LT (0°/90°)	DB (+45°/-45°)
Ultimate Strength (Mpa)	407.77	258.33	60.41	77.96	187.78	143.88	63.71	84.79
Max Strain (%)	3.165	2.182	1.372	2.172	3.364	2.952	1.429	2.345
Tensile Modulus (Mpa)	12,884	11,839	4,403	3,589	5,582	4,873	4,458	3,616
Max Load (kN)	14.77	7.98	4.89	6.42	19.26	12.87	5.76	7.15

3.2 Perforated pipe specimen test

The results were compared on hole arrangement with same lamination angle. Specimens showed brittle fracture. Table 3 shows the results that calculated with clear cross section and load at failure. And Fig. 6 shows the fractured shape of pipe specimen.

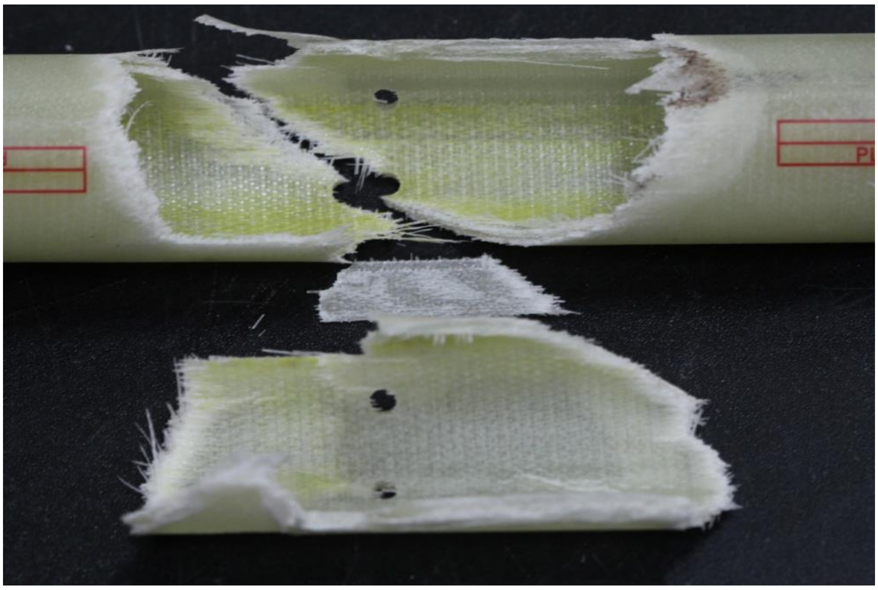
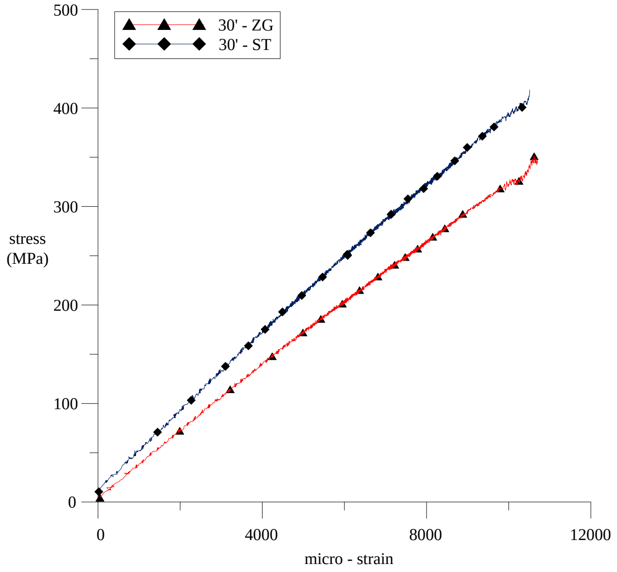
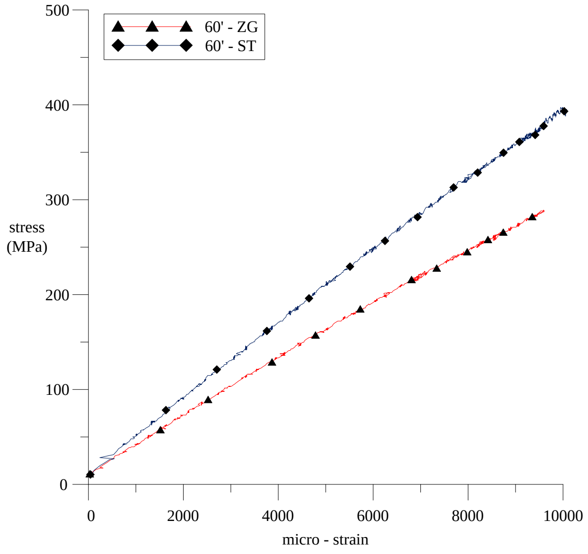


Fig. 6 Fracture shape of pipe specimen(Laminate angle : 30°, ST)



(a) Strain-stress graph
(Laminate angle : 30°)



(b) Strain-stress graph
(Laminate angle : 60°)

Fig. 7 Strain-Stress graph of perforated pipe test

Table. 3 Test results for perforated pipe specimen

Laminate angle	Max Load(tonf)		Ultimate Strength(Mpa)	
	ST	ZG	ST	ZG
30°	6.08	6.00	422.48	344.09
45°	5.33	5.03	370.33	288.18
60°	5.70	5.10	396.41	292.48

In test results, the largest ultimate stress and ultimate loads appeared in the lamination angle 30°, and straight line arrangement was beneficial in terms of strength compared to zigzag arrangement. It stems from the matrix cut several times in a zigzag pattern. The closer to 30° of lamination angle, the higher strength was appeared. So effect of lamination angle is generally advantageous as the angle of lamination is smaller. Also, rather than placing the hole, the lamination angle has a great effect on the mechanical properties.

4. CONCLUSIONS

The aim of this study is to develop new structural material for the drainage system of subsea tunnel. Tension-fracture test was performed to investigate the application of FRP composite materials to subsea tunnel. Generally, the mechanical properties of FRP composite material are excellent for drainage system of subsea tunnel under the salty environment.

Conclusions obtained in this study are as follows.

a. From the results obtained from the flat specimen test, the change of material properties under the sea water temperature (0°C) must be considered in case of imperforated specimen.
b. The results obtained through perforated pipe test that tensile strength increased as close to lamination angle of 30°, and it is advantageous to place the hole in straight line.
c. It is required to consider arrangement of holes, temperature and lamination angle while designing tunnel drainage system using FRP composite material.

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