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TECHNICAL ARTICLE—PEER-REVIEWED

Tensile Strength Alteration of GFRP Composite Pipes Under Seawater-Dominated Conditions

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Abstract Glass fiber-reinforced epoxy composite pipes are used in submarine applications, natural gas, and oil transportation lines, transfer of chemical liquids. Especially in the transport of pressurized fluids, changes in the strength of the pipes are important. The corrosive effect of seawater has an important impact on the mechanical properties of the composite material. In particular, the alteration in hoop tensile strength is one of the issues to be investigated. In this experimental study, glass fiber-reinforced epoxy resin composite pipes were exposed to the seawater aging process for different time periods (1, 2 and 3 months) in order to determine the effects of seawater absorption behavior on hoop tensile strength. Hoop tensile strength test was realized in accordance with ASTM D2290 Procedure A. As a result of this work, the average tensile strength values of the composite pipes decreased as the waiting times in seawater increased.

Keywords Composite pipes · Seawater effect · Mechanical properties · Hoop strength

Introduction

In these days, filament wound GFRP composite pipes have been extensively used for the transportation of liquids, such as water, corrosive fluids, oil, and natural gas [1, 2]. Composite pipes have high specific strength and hardness properties, as well as good fatigue and corrosion resistance [3–5]. Glass fiber composite pipes have a longer life against shocks caused by sudden internal pressure changes due to the lower elasticity modulus than other pipes [6].

Glass fiber-reinforced epoxy composite pipes may be exposed to environmental conditions such as humidity, distilled water, seawater, rainwater, acidic solution, sun, and wind. These conditions give rise to a significant disruption of the mechanical characteristics of the composite materials [7, 8]. In order to determine the effect of different environmental conditions on composite pipes and to prevent or minimize the deformation of this effect on the material, it is necessary to know the mechanical properties of the pipes under different environmental conditions.

Seawater creates two macroscopic effects in the form of deterioration of mechanical properties in composite materials and weight gain of the material [9]. Generally, composites perform water absorption in the presence of water due to their hydrophilicity behavior [10]. This absorbed water causes the material to swell and permanently deform. Thus, the mechanical properties of the material are weakened [11, 12]. The capillarity and hydrophilic group located in the glass fiber cause the acceleration of water absorption with longer immersion time [13, 14].

In the literature, there are many studies on the influence of seawater on the mechanical characteristics of GFRP composites [15–19]. Wu et al. [20] investigated the mechanical performance of the glass fiber-reinforced composites exposed to seawater, synthetic seawater, and without ion water. It was determined that there was the highest decrease in tensile strength without ion water and seawater, respectively. Kootsookos et al. [21] investigated experimentally the resistance of glass- and carbon fiber-

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reinforced polymer composites to seawater. They exposed the materials to aging in seawater at 30 °C for 2 years. They observed that the mechanical properties of GFRP composites disrupted more than carbon fiber-reinforced composites after aging in seawater. Belevi et al. [22] investigated the effects of ambient conditions such as temperature, humidity and salt on the mechanical properties and impact strength of composites in their studies. It was concluded that environmental factors and impact loads had significant effects on the physical properties and post-impact strength of many composite materials. Gu [23] observed the change in the mechanical properties of GFRP composites exposed to the seawater. It was found that the deterioration of the matrix and interface surfaces of the composite material increased as the seawater exposure time increased in his study. Sari [24] investigated the effect of seawater on fatigue behavior of GFRP pipes subjected to impact damage. It was observed a slight increase in impact and blasting strength of GFRP composite pipes exposed to seawater for 3 months. Örçen et al. [25] studied the influence of seawater on glass fiber epoxy composite materials. The samples were exposed to seawater for 3 and 6 months. The mechanical properties of non-aged and seawater aged specimens were examined and found that the non-aged specimen had the highest modulus of elasticity. They also found that as the residence time of the samples increased in seawater, the modulus of elasticity decreased. Karakuzu et al. [26] investigated the influence of seawater on the impact response of GFRP plates. Composite samples were exposed to seawater for 1, 3, 6 and 9 months and impact tests were then performed on the samples. At the end of the study, they determined that salt of seawater, impact energy and impact mass had a significant effect on impact behavior of composite plates. José-Trujillo et al. [27] investigated the influence of seawater aging on the mechanical characteristics of glass/epoxy, glass/vinyl ester, glass/polyester, carbon/epoxy and carbon/vinyl ester composite materials. As a result of their studies, they observed that seawater caused the decrease in mechanical characteristics of glass/epoxy composites.

In this study, glass fiber-reinforced polymer composite pipes produced by filament winding method were exposed to seawater aging for 1, 2 and 3 months and then mechanical properties of non-aged and aged composite pipes were compared.

Material and Method

Production of Composite Pipes

In this study, GFRP pipes with a winding angle of ± 55° were used. Vetrotex 1200 tex E-glass with a diameter of 17 μm diameters was used as glass fiber and Ciba Geigy, Cyanate (Bisphenol A), Epoxy CY225 was used as the matrix material. Composite pipes have a length of 300 mm and an inner diameter of 72 mm. The wall thickness is 2.25 mm. The geometry of composite pipe is given in Fig. 1 [28] and the mechanical properties of the matrix and fiber used are given in Table 1 [29].

Seawater Aging

Mediterranean water, which has a high salinity (3.8%), has an abrasive effect on the matrix of composite pipes. There are high amounts of NaCl, MgCl, $MgSO_4$, $CaSO_4$, K_2SO_4, $CaCo_3$, $MgBr_7$ salts in Mediterranean water [30]. The GFRP composite pipes exposed to aging in seawater for 1, 2 and 3 months are shown in Fig. 2.

Hoop Tensile Strength Test

The test of hoop tensile strength was performed in accordance with ASTM D2290 Procedure A [31]. The test method given in this standard covers the work of determining the comparative tensile strength of many plastic products under certain prerequisites such as temperature, humidity and test speed using a split disk or ring part. Test specimens were prepared from six-layered GFRP composite pipes in accordance with the measurements given in Fig. 3.

According to Procedure A [31], notching on both sides of the sample is left to the user's preference. In the hoop tensile test, conditions such as tensile speed, humidity, temperature and specimen thickness of the test machine jaw were taken into consideration. The standard laboratory ambient temperature is 25 °C ± 0.5 °C; humidity, %50 ± 5. The test speed is at least 0.1 inch/min. Hoop tensile strength test instrument is shown in Fig. 4.

In this test, the strength values of composite pipe specimen could be determined by Eq 1, where σ_T, P_b, A_m represent the hoop tensile strength value (MPa) of the

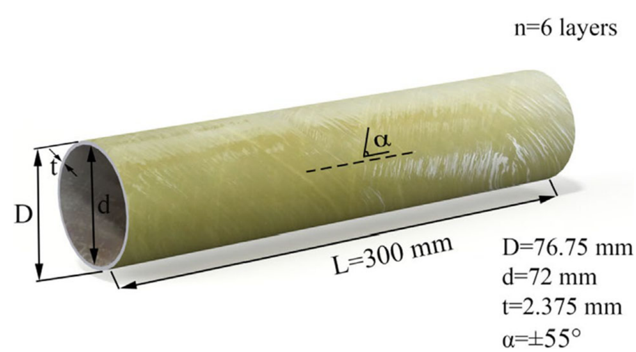

Fig. 1 Geometry of pipe [28]

Table 1 Mechanical characteristics of matrix and fiber used in composite pipe production [29]

	E (GPa)	$\sigma_{tensile}$ (MPa)	ρ (g/cm^3)	$\varepsilon_{rupture}$ (%)
Epoxy	3.4	50–60	1.2	4–5
E-glass	73	2400	2.6	1.5–2

Fig. 2 Samples exposed to seawater aging

specimen, the maximum load value (N), and the minimum cross-sectional area (mm^2), respectively.

$$\sigma_T = \frac{P_b}{2A_m} \quad \text{(Eq 1)}$$

Results and Discussion

As stated in the literature, the mechanical properties of GFRP pipes exposed to seawater are changed after 30 days of aging. Composite pipes absorb water molecules in seawater environment within 30 days. Water molecules enter the specimen and cause weight increase [32].

Hoop tensile tests were performed according to ASTM D 2290 Procedure A [31]. Each experiment was continued

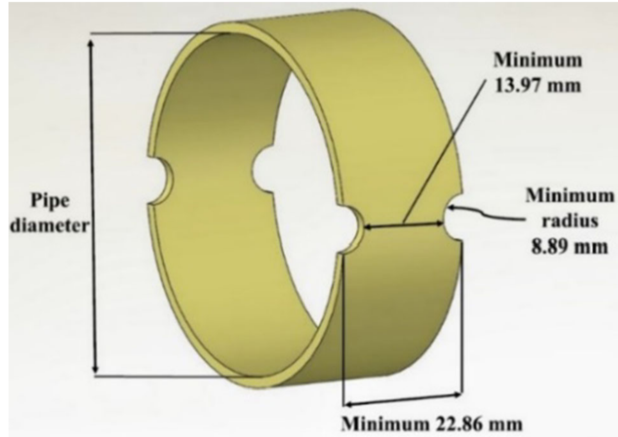

Fig. 3 Reduced section specimens in accordance with Procedure A [31]

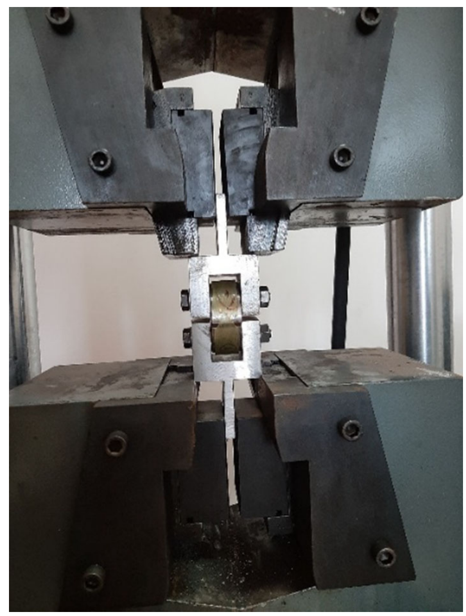

Fig. 4 Hoop tensile test instrument

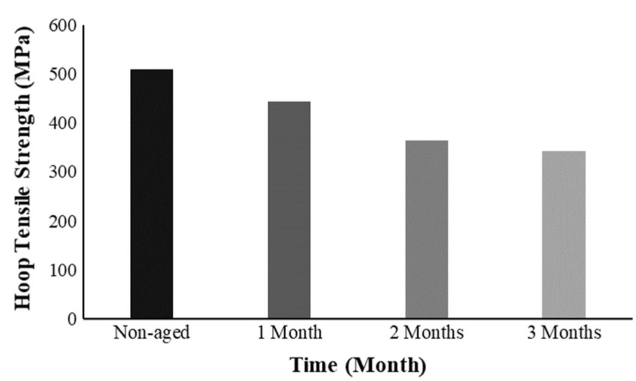

Fig. 5 Hoop tensile test results of the composite pipes unexposed to and exposed to seawater

Fig. 6 (**a**) Non-aged, (**b**) 1 month aged, (**c**) 2 months aged, (**d**) 3 months aged GFRP composite pipes

until the sample ruptured. The hoop tensile strength values were determined by using Eq 1, which is the largest tensile strength value obtained from hoop tensile tests. Experiments were repeated three times for each case and the mean values were determined. Average hoop tensile strength values of samples exposed to seawater and unexposed to seawater are given in Fig. 5. As a result of the experiments, the average hoop tensile strength values of the glass fiber epoxy pipes which were not exposed to seawater aging was found to be 509.9 MPa. After 1 month of aging of GFRP composite pipes, the tensile strength values were measured as an average 443.7 MPa with a 13% decrease compared to the tensile strength values of the non-aged pipes. After 2 months of aging of GFRP pipes, the tensile strength values were measured as an average 364.1 MPa with a 29% decrease compared to the tensile strength values of the non-aged pipes. As a result of measurements after 3 months, the tensile strength values were measured as an average 342.2 MPa with a 33% decrease compared to the tensile strength values of the non-aged pipes.

When Fig. 5 is evaluated, it is seen that the strength values of composite pipe samples decrease as a result of exposure to seawater. Composite test specimens absorb water molecules while remaining in seawater. The absorbed seawater molecules are corrosive to the epoxy forming the composite structure. Epoxy abrasion results in weakening of the bond between the fiber and the matrix. The weakening of the matrix and fiber bonds reduces the strength of the composite structure. The bonds between matrix and fiber are the most important bonds in terms of the stability of the composite structure.

The damage to the six-layered composite pipes (a) unexposed to and (b), (c), (d) exposed to seawater as a result of the hoop tensile strength test is seen in Fig. 6. When the hoop tensile strength value was reached in both samples, fibers were ruptured and the specimens were split from the notch region. It is seen in all specimens that the split is in the direction of the filament winding angle of ± 55°.

Conclusions

In this work, GFRP composite pipes were exposed to seawater aging process for 1, 2 and 3 months. And then the hoop tensile strength test was realized in accordance with ASTM D2290 Procedure A to determine the hoop tensile strength values of GFRP composite pipes exposed to seawater and unexposed to seawater. The results of this work:

- It was determined that the strength values of the samples waiting in seawater decreased due to abrasion in epoxy.
- In the damage images of the composite test specimens, it was seen that the rupture of the specimens occurs in the filament winding angle direction.
- It was determined that the seawater aging and aging time of GFRP composite pipes affected severely the hoop tensile strength.

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