Effect of water and seawater on mechanical properties of fiber reinforced polymer composites: a review for amphibious aircraft float development

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Abstract. One of the composite applications is its utilize in the water and seawater environments like boats, ships and float device of amphibious aircraft. This environment can affect the mechanical properties of composites since water can diffuse into the composites. Many researches have discussed about the effect of water and seawater on mechanical properties of composites like tensile, compressive, shear, and impact properties. This review is conducted on the field of durability of composites in water and seawater environment. Most studies are carried out by immersing composites in water and seawater for a certain period of time. Almost all studies exhibit the degradation of the mechanical properties of composites with ageing time of the immersion process in water or seawater.

1. Introduction
Composites are widely used in engineering practice like aeronautics, automotive, marine, construction, and packaging because they are lightweight; resistant to corrosion, high temperature, and fatigue; high specific stiffness and strength [1–4]. Composites with vinyl ester and polyester resins are often used in marine applications [2]. Other composite applications are as float devices material of amphibious aircraft which mostly utilize fiber-reinforced polymer composites. In addition, composites are also used in the development of ocean energy conversion systems such as tidal turbine [5]. This review will be used as a basis for float devices development of amphibious aircraft operating in freshwater and seawater environment.

The amphibious aircraft can take-off and landing on land and water making it suitable for missions in sea and wet areas. It has landing gear and hull or floats which must bear the impact loads of water and assure the stability when landing on sea or water [6]. The floats initially used aluminum material for applications in the water environment and will be developed using composites due to the operation of aircraft in corrosive environment of seawater. Thus, need to know the effect of water and seawater on the composite properties by reviewing papers that discuss about that.

Many researches have discussed the effect of water and seawater on the fiber-reinforced polymer composite properties, however, none has been specifically for amphibious aircraft applications. Some research is conducted on synthetic fiber composites such as carbon and glass, and others utilize natural fiber composites such as flax [3, 7–11]. The researchers used different types of composites in their research such as conventional composites, hybrid composites [1, 12-13], pultruded composites [14–17], bar composites [18-19], and sandwich composites [20-21]. Composites are made with several fabrication processes such as hand lay-up, resin vacuum infusion, RTM (Resin Transfer Molding),
prepreg autoclave, and pultrusion process. The specimens is cut from the composite panel and tested for water absorption, tensile, compressive, shear, impact, etc. Researchers utilize different types of moisture as immersion media like tap water, natural seawater, and artificial seawater.

2. Water Absorption

One thing that needs to be known in the development of amphibious aircraft that will operate in the water and sea water environment is the behavior of water absorption of the float material which can affect its mechanical properties. The researchers conducted a water absorption studies using the ASTM D 570 and ASTM D 5529 standard by immersing composites on liquid media and then taking and weighing them at each specified time period. Visco, et.al., 2011 [2], showed that the water absorption of polyester and vinylester resin, and glass reinforced polyester and vinylester composites follows Fick's law with the initial linear portion and the balance plateau. Glass fiber fabric does not sufficiently influence the diffusion of water into its polymer network. Maximum water absorption value was 1.2% for polyester resin and glass-polyester composites, while for vinylester and glass-vinylester composites the value is lower by around 0.7%. Vinylester is better than polyester in avoiding diffusion of sea water so that its performance is superior than polyester in water environment. Similar to Visco et al., Boisseau, et. al. 2012 [22], showed that the diffusion of epoxy resin follows the Fick’s law with the the saturation of mass gain at 2.5%. The initial weight gain of E-glass, Advantex, and HiPer-tex composite at 60 °C also follows Fickian, then increases sharply which is probably caused by a decrease in the glass transition temperature (Tg) of the resin.

![Figure 1. Fickian diffusion process [23]](image)

In addition to the percentage of weight gain, water absorption studies also determine the diffusion coefficient of the composite. Alia, et. al., 2013 [12], showed that the diffusion coefficient of vinylester (5.14 x 10-13 m2s-1) is smaller than polyurethane (6.39 x 10-13 m2s-1) where the maximum water uptake value is also smaller (around 0.55% for vinyl ester and 0.6% for polyurethane).

The water absorption test was carried out by researchers both on GFRP and CFRP composites. The study of glass-vinyl ester composite pipes produced by filament winding conducted by Michael Berges et al. [9] stated that weight gain with water immersion was higher than humid conditions and acid immersion. Jiang, et. al., 2013 [23], showed that FRP (e-glass/polyester) experiments carried out in water produced higher saturation levels of moisture (3%). The experimental results showed that moisture uptake is more sensitive to temperature. For adhesive polyurethanes that are aging in 40 °C-water and 40 °C-96% RH, there was deviation from the Fickian diffusion that could be associated to the relaxation of the polymer at elevated temperature. Other study of Yuan Fang et al [24] stated that absorption of water and seawater in the e-glass/polyester composite mixed with cadmium sulfide (CdS) QDs did not follow the fick’s law. Mass loss occurs when the immersion time is increased, which is associated with leaching of unreacted monomers and hydrolysis of ester bonds. A study of e-glass/DER-31 epoxy composite pipes conducted by Fitriah et al. [25] showed the mechanism of non-fickian water absorption. The results showed an increase in degradation in the form of cracked matrix and debonding of the fiber/matrix. An increase in the quantity of water absorption caused matrix plasticization. Yian Zhao et al. [26] state that an increase in temperature accelerates the diffusion of
sea water into the e-glass/BMI composite at an early stage, then tends to decrease in the long term immersion. Increasing the immersion temperature strengthens the effect of matrix plasticization which can increase the ductility of the material and expand the area of damage. Yinghui Hu et al. [27] states that the weight gain in epoxy samples is much faster and higher than polydicyclopentadiene and is nearing saturation after 12 months. The water absorption of epoxy is much greater when immersed in deionized water than salt water, and the difference is even greater in glass-epoxy composites, due to water diffusion and capillary diffusion along the fiber/matrix interface debonding.

The researches were also carried out by adding nano clay to the GFRP composite. Study of the additional of nano TiO2 to e-glass/epoxy composites conducted by R. K. Nayak and B. C. Ray [28] shows that seawater absorption increases with increasing nano TiO2 content, whereas 0.1 wt% nano TiO2 content causes sea water absorption to decrease by 15% compared to neat composites. Other study of GFRP/quasi isotropic epoxy composites exposed to artificial seawater conducted by Acharya Pavan et al. [29] showed that at ambient temperatures the composites absorbed water 13.22% to equilibrium, whereas for conditions under 0 degrees the maximum water absorption at equilibrium was 2.61%. Water absorption follows Ficks’ law at the beginning but is gradual increment and decrements after saturation. Study of pultruded GFRP e-glass and polyester with 3% nano clay and 10% calcium carbonate conducted by A. V. Oskoueia et al. [16] showed that sea water diffusion increases with increasing immersion time and temperature, while high NaCl and chlorine content reduce seawater absorption. This is similar to Jiang et al. 2013 and Alessi et al. 2014 about the effect of elevated temperature on water diffusion.

The researchers also conducted a study of sandwich composites. Jiang, et. al., 2014 [30], conducted a study of glass-polyester sandwich wich was manufactured by vacuum infusion process exposed to variation in temperature of water and relative humidity. The results showed that the hot/wet environment can accelerate the water absorption process into the composite, as evidenced by the saturation level of the specimens which are conditioned at 40 °C-water six times the condition of 20 °C-50% RH. There was a decrease in the diffusion moisture curve from equilibrium which indicates physical and chemical degradation such as matrix hydrolysis, chain breaks, formation of small molecules and the release of these molecules from the composite. Study by Anxin Ding et al [20] at vinyl ester sandwich composites with PVC foam core showed that water absorption from composites immersed in pure water was higher than that in seawater. Water absorption for composites without void is caused by free volume between polymer molecular chains, infiltration of the polymer molecular structure which increases swelling, and capillarity in the fiber/matrix interface.

Many researchers conducted studies on carbon composites. Study of nanophased CFRP composites exposed to seawater conducted by Hossain, et. al., 2014 showed that after 12 months of immersion the sample with 2% nanophased absorbs moisture smaller (0.39%) than the conventional sample (0.67%) [31]. Alessi, et.al., 2014 [32], showed that for epoxy resins, water uptake increases gradually at an early stage then reaches a plateau as an equilibrium condition according to the Fickian mechanism. For CFRP composites, the water uptake is smaller than pure resin and showed a non-Fickian mechanism.

Water absorption mechanism in CFRP can be related to diffusion of water into meso-scale free volume, capillarity of fiber, and microcracks due to fiber-matrix debonding. Water absorption was significantly higher and faster at increasing aging temperatures from 30 °C to 70 °C. Water absorption at CFRP can also be related to water absorption at the fiber/matrix interface. Tual, et. al., 2015 [33], conducted a study of the effect of seawater on carbon/epoxy composites fabricated using prepreg-autoclave, RTM, and vacuum infusion. The results showed that the weight saturation level under high temperature conditions is higher than the lower conditions, due to the evolution of glass transition temperature. Water diffusion is very small influenced by the thickness and orientation of the composite, and not influenced by the geometry of the specimen. However, Garcia-Espinel et al. [34] state that the time to reach the saturation level of water absorption depends on the thickness and ambient temperature. Saturation levels of moisture are 0.58% (30 days), 0.44% (210 days), and 0.4% ((30 days) in glass/polyester, glass/vinyl ester, and glass/epoxy composites, respectively. Kafodya et al. [14] state that diffusion coefficient of pultruded CFRP-epoxy submerged in water is higher than
that submerged in seawater. This is caused by the dissolved particles of seawater which obstruct osmotic water diffusion. Water absorption and diffusion coefficient are reduced with increasing sustained bending due to reduced free volume fraction and evolution of swelling stresses. Arhart et al. [35] state that carbon/polyamide composites absorb water higher (3%) than carbon/polyetheretherketone (0.17%). Water absorption in composites can cause the phenomenon of palsticising, which is reversible and reduces the glass transition temperature. Study of PU resin and pultruded CFRPU immersed to seawater conducted by Bin Hong and Guijun Xian, 2018, [17] showed that the water absorption follow the Fick’s law. Water absorption of PU (~2.65%) and CFRPU (~0.70%) higher than epoxy (~0.44%) and epoxy-based CFRP (~0.58%) due to more hydrophilic groups. However, at high temperature of immersion, water absorption of CFRP epoxy-based (1.65%) higher than CFRPU (0.83%), due to hydrolisis of epoxy. Water absorption of CFRPU are caused from voids, mocr cracks, matrix, and interface of fiber/matrix. Zike Wang, et al, [36] states that water absorption of untread interface of CFRP exposed to distilled water higher than treated CFRP due to debonding or crack water molecules attack. Other study of Yucheng Zhong et al., 2019 [37], states that the water absorption of CFRP epoxy-prepreg immersed with tap water was higher than GFRP, due to higher resin volume fraction and the pattern of weave on CFRP. Another study of glass/carbon hybrid composites immersed to seawater conducted by Jesthi and Nayak, 2019 [13], states that the water absorption of hybrid composites was lower than plain glass and carbon composites, due to good bonding of interface between glass-carbon plies and epoxy matrix.

![Figure 2](image-url)

**Figure 2.** Water absorption curves of (a) vinyl ester, polyester, and composites [2], (b) polyurethane adhesive [23], (c) epoxy and CFRP at 70 °C [32], (d) sandwich FRP composite [30], (e) biocomposite and fiber [7]
Water absorption studies were also carried out on natural fiber composites. Assarar, et. al., 2011 [3], states that the water absorption of the flax–epoxy composite is established to follow Fickian law. Saturation of weight gain was reached at 13.5% for flax-composites and 1.05% for glass composites. Study of Duigou, et. al., 2014 [7], showed that the diffusion of natural sea water in the flax/PLA biocomposite reached saturation after 2 months of immersion of 3.3% where the weight of the saturation of the flax fiber was 12%. Libo Yan and Nawawi Chouw [8] state that water uptake for flax/epoxy submerged in water is higher than that submerged in sea water, due to the accumulation of salt particles which inhibits the diffusion of water. Weight gain on the flax-epoxy composite is more significant than synthetic fiber composites, that is related to the hydrophilic properties of flax fibers, and poor interfaces and poor fiber resistance to water absorption due to hydroxyl groups. Similar to Assarar et al., study of flax reinforced thermoplastic and thermostetting exposed to tap water conducted by Abderrazak Chilali et al. [10] showed that the diffusion behaviour follow Fickian diffusion mechanism. Mohamed Habibi et al. 2019 [11], states that maximum water diffusion of flax-epoxy composites manufactured by combined compressing molding and hand lay-up is 12.8%. The decrease of water diffusion after saturation level can be related to hydrophilic of flax, cause fiber swells, which present microcracks of epoxy matrix. This is similar to Libo Yan and Nawawi Chouw about the hydrophilic of flax fibre.

3. Mechanical Properties

Some mechanical properties that need to be known in the development of amphibious aircraft include tensile, compressive, shear, and impact properties.

3.1. Tensile properties

To obtain the tensile properties of composites, researchers conducted tensile testing using a universal testing machine with a constant crosshead speed. The standard that is usually used is ASTM D3039, although other standards are also used. The study of Assarar et al. [3] stated that the tensile strength of the e-glass/epoxy composite was reduced by 25% in saturated conditions (more than 40 days), whereas the flax/epoxy composite was reduced by 15% in the 20 day immersion. Furthermore, at saturation level, young modulus and maximum strain was reduced by 9% and 10% for glass/epoxy, while the reduction of young modulus was 39% for flax/epoxy. Otherwise, the maximum strain increases 63% at the saturation level.

Study of pure epoxy resin infusion by Boisseau et al. [22] show that strength and young modulus are reduced during immersion in seawater at 60 °C, but maximum strain is less affected. The tensile strength of vinyl ester and polyurethane resins after being immersed in seawater for 9 months was reduced by 12% and 21%, respectively [12].

Glass/polyester composites immersed in natural seawater for 2 years showed the tensile stiffness reduced by 10%, while the tensile strength of flax/PLA composites immersed in natural seawater for 18 months was reduced by 38% [7]. The study of Garcia Espinel et al. [34] exhibit that the tensile strength of glass/epoxy composites was reduced by 23.81% after 90 days of sea water immersion. Other study of glass/vinyl ester composites treated and untretated MMT clay powder by Garima Mittal et al. [38] showed that the tensile strength of the composite after sea water immersion was reduced by 8% and 7% respectively, while the modulus of elasticity is reduced by 4%. Another study of glass composites using polycyclopentadiene resin showed that the tensile strength was significantly lost, with only an average strength remaining 42% after one year water immersion [27]. Another study of glass/vinyl ester composite pipes by Essi Sarlin et al. [39] showed a reduction in tensile strength up to 63% after water immersion. Study on glass polyester modified cadmium sulfide show a decrease in tensile strength of 15.5% and 13.8% after water and sea water immersion, while the tensile modulus is slightly affected by the immersion process [24]. Water absorption results in degradation of the fiber, matrix, and debonding between the fiber and the matrix.

Research on quasi isotropic e-glass/epoxy composites [29] exposed to artificial sea water shows a 27% reduction in tensile stress due to plasticization, while the failure that occurs in the composite is
mainly caused by fiber failure and cracking of the reinforcement/resin interface. A study conducted by Mourada et al. [40] stated that the tensile strength was reduced by 47% for e-glass/epoxy composites, 64% for eglass/polyurethane, after soaking sea water 65 °C for 60 months to 90 months.

N. Tual et al. [33] stated that water absorption affects the tensile strength of the CFRP composite due to matrix plasticization and changes in the fiber/matrix interface. However, there is no significant effect on Young Modulus of composites. The degradation of composites is more influenced by the water than temperature. Another study of pultruded epoxy-based CFRP composites immersed in water and seawater by Kafodya et al. [14] shows anomalous trends of tensile strength. Tensile strength decreases after the first 2 weeks of immersion which is associated to residual stress due to pultrusion which causes specimen failure. The increase of tensile strength after 2 weeks can be attributed to the water ingress which causes relaxation of residual stresses, and accelerate the epoxy postcuring. The tensile strength reduction in unstrained specimens after 20 weeks of sea water immersion was dominated by plasticization. Tensile modulus increases at an early stage due to postcuring progression, and decreases after 12 weeks due to the effect of plasticization. Another CFRP study using polyamide resins by Arhant et al. [35] showed that the decrease in tensile strength occurred when the water content was more than 1%, but the tensile modulus value did not change significantly.

A study of CFRP-vinyl esters by Gargano et al. [41] states that composite degradation is affected by hydrolysis, cracks caused by swelling, reduction in strength of reinforcement and resin interface, and plasticization. Another study of vinyl ester sandwich composites showed that the tensile strength dropped by 1.28% and 7.35% after water and sea water immersion, respectively [20]. A study conducted by Bin Hong [17] shows that PU and CFRPU are more resistant to seawater than epoxy and CFRP-epoxy. Yucheng Zhong et al.'s [37] study of GFRP and CFRP showed a reduction in strength and tensile modulus after hygrothermal conditioning. However, after drying, the mechanical properties return to similar as the specimens without conditioning. Study on hybrid glass-carbon/epoxy composites manufactured with hand lay-up [13] show a decrease in tensile strength after immersion in seawater. Meanwhile, the modulus decreases for [GCG2C]s type and increases for [G3C2]s and [G2C2G]s types.
Study on flax/epoxy composites [8] show that tensile strength decreases after 12 months immersion by 28.3% for seawater, and 22.6% for water. Whereas the tensile modulus is reduced by 27.1% for seawater, and 24% for water. This reduction is associated with degradation of fiber, epoxy, and fiber/resin interface bonding. Another study of flax composites showed a decrease in tensile strength and tensile modulus by 42% after 30 days immersion in tap water [10]. Study on flax-epoxy immersed in water at 75 °C can reduce tensile strength and modulus by 68% and 61%, respectively [11].

3.2. Compressive properties

From the references there are still few papers that discuss the effect of water or sea water environment on compressive behavior of composites. One that discusses the influence of seawater on the compressive properties of composites is the paper of Mael Arhant et al. about CFRP composites with polyamide (PA) and polyetheretherketone (PEEK) matrices [35]. This paper states that the seawater diffusion on composites reduces the compressive strength of CFRPA to 50%, whereas in compressive modulus the effect is low. Otherwise, sea water does not reduce the strength and modulus of CFRPEEK composites. The compressive strength of the composite after sea water soaking can return to its original strength after the drying process.

![Figure 4. Effect of moisture on compressive strength of (a) CFRPA [35], (b) GFRP pipe [25], (c) flatwise sandwich composite [20], and (d) edgewise sandwich composites [20]](image)

A study of glass/epoxy composite pipes conducted by S.N. Fitriah et al. [25] showed a deterioration in compressive strength up to 84% as a result of the longterm water immersion and temperature rises. In line with previous references, Gargano et al. [41] stated that the compressive and other mechanical properties of CFRP-vinyl ester composites dropped in seawater as a result of plasticization. Meanwhile, a study of glass/vinyl ester sandwich composites with PVC foam core showed that the decline in edgewise compressive strength values in pure water (35%) was higher than seawater (9%), but this flatwise compressive strength increased [20]. Similar to water and sea water exposure, composite sandwiches exposed to solar radiation combined with water vapor, salt spray, and hygrothermal atmosphere alternating high low temperature also show an increase in the value of flatwise compressive strength and deterioration in edgewise compressive strength [21].
3.3. Shear properties

Several methods are used by researchers to obtain the interlaminar shear strength (ILSS) of composites exposed to water and seawater. The methods used include short beam shear test (SBS) (ASTM D2344), in-plane shear test (ASTM D3518), and transverse shear test (ASTM D761). ILSS studies of e-glass/silk/epoxy (medium viscosity resin) composites, show that seawater causes swelling, plasticization, and debonding of the resin/reinforcement interphase which results in decreased of ILSS composites [1]. Other ILSS studies of glass/epoxy composites (quasi unidirectional fabric, low viscosity epoxy) [22] show a small reduction in ILSS after sea water immersion. Specimens dried in the air for 6 months show that ILSS are irreversible.

Figure 5. Effect of water and seawater on shear strength of (a) GFRP (e-glass/silk/epoxy) [1], (b) pultruded CFRP [14], (c) GFRP rebar (glass/vinyl ester) [19], and (d) sandwich composites (PVC foam) [20]

Study on CFRP composites (UD carbon, epoxy) exposed to seawater show that ILSS is reduced by 20-30% [33]. Another study of CFRP (carbon UD, epoxy) [14] showed a significant decrease in ILSS in the early stages of immersion, due to debonding and plasticization. In line with previous studies, other research [42] states that sea water immersion causes damage of reinforcement and matrix interphase, as evidenced by a reduction in ILSS by 30%, 10%, and 20% in glass/epoxy, carbon/epoxy, and glass/polyester composites, respectively. In-plane shear test of carbon-polyamide composites showed a reduction in shear strength of 41% and reduction in shear modulus of 46% [35]. The short beam shear test showed that after a 1-year immersion, the shear strength retention of polydicyclopentadiene composite was 85%, whereas for epoxy composites it was reduced by 40% [27]. Other studies have shown an increase in ILSS with the addition of nano-TiO2 to both dry and submerged GFRP composites [28]. Another study on CFRP showed a rapid decrease in ILSS at 30 days immersion, SBS strength retention and in-plane shear after 4 months immersion were 27.2% and 39.6%, respectively [36]. Other studies of GFRP rebar composites with vinyl ester resins [19] show
that the transversal shear strength after immersion in ambient temperature sea water reduced very low, while at high temperatures it drops to 95.4% due to plasticization. Short beam shear strength GFRP rebar rise 2.6% in seawater 55 °C which is associated with anti-plasticization, whereas at high temperatures the value drops 4.5% after soaking 20 months.

Shear strength studies on sandwich composites show significant changes in water immersed composites, where failure on PVC cores shows shear strength of it [20]. Sandwich composite studies on water, seawater, salt spray, hygrothermal atmosphere alternating high low temperature, and water vapor treatments showed an increase in in-plane shear strength of 3.68%, 1.57%, -6.08%, 11.3% and 7.87% [21].

3.4. Impact properties
Float devices of amphibious aircraft receive impact loads when landing in water or sea water, thus, it is necessary to know the effect of them on the impact properties of float material. Standards used by researchers to determine the composite impact behavior based on existing references include ASTM D256 (izod test), ASTM D7136 (low-velocity impact), and ASTM D3763 (drop weight impact test). One study conducted by K.V. Arun et al. [1] discussed the effect of sea water on the impact properties of hybrid glass/silk/epoxy composites. Studies conducted by Arun et al. show that the impact toughness of hybrid composites increases with increasing glass fiber volume. Meanwhile, soaking time and sea water temperature accelerate the reduction in impact toughness of hybrid composites due to fusing of the resin. Another impact study conducted by D. K. Jesthi and R. K. Nayak [13] on hybrid glass/carbon/epoxy composites showed that hybrid composites type [GCG2C]S had the highest impact strength values compared to other hybrid types. Seawater immersion causes a decrease in the impact strength of hybrid composites where the value of the decline in composites [GCG2C]S type (9.6%) is smaller than other types of hybrids which reach 12% in [G3C2S] type. Another impact study conducted by Yucheng Zhong et al. [37] showed that after exposed to hygrothermal from tap water, the performance of the prepreg epoxy CFRP composite at a low speed impact was better, while for GFRP composites the performance had decreased.

The researchers not only did an impact test on conventional composites but also on other shapes such as composite pipes. The study of GFRP filament winding composite pipes subject to variations in impact energy conducted by M. E. Deniz and R. Karakuzu [4] showed that the absorbed energy reached a minimum after three months of sea water immersion, then continue to increase until the time of immersion for 12 months. Study by M. K. Hossain et al. [31] show that the energy absorbed by nanoclay-reinforced CFRP composites is higher than conventional CFRP, as well as after prolonged immersion in seawater. Increasing sea water immersion time decreases delamination energy, absorbed energy, and damage areas. Failures resulting from impact loads are usually resin cracks, delamination, and layer splitting.

![Figure 6. Impact strength of GFRP, CFRP, and hybrid glass/carbon composites [13]](image-url)
4. Conclusions
Research on the influence of water and seawater environment on mechanical properties of composite was conducted by researchers on conventional, pultruded, pipes, bars, hybrid, and sandwiches composites for both synthetic and natural fiber. Most studies show that the water absorption process in composites follows the Fickian mechanism, even several studies show a non-Fickian mechanism. The longtime duration of the immersion process and the elevated temperature increases the diffusion of water into the composite. Water absorption into composites is related to water diffusion into mesoscale free volume, capillarity of fiber, and microcracks due to debonding of resin-fibers. Sea water diffusion into the composites is lower than water due to the content of salt molecules in seawater that prevent water diffusion. Diffusion of water into the composite causes a decrease on the tensile, compressive, shear, and impact properties of the composite except the flatwise compression properties of the composite sandwich. This decrease is due to degradation of the fiber, matrix, debonding between the fiber and the matrix interface, and matrix plasticization resulted by water diffusion. Several studies have shown that the mechanical properties of composites exposed to water or seawater will return to normal after drying.

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