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Hygrothermal Effect on Glass Fiber Reinforced Plastic (GFRP) Under Seawater Immersion

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ABSTRAK

Plastik yang Diperkuat Serat Kaca (Glass Fiber Reinforced Plastic/GFRP) banyak digunakan di Indonesia, khususnya untuk lembaran atap bergelombang dan talang di lingkungan yang korosif, karena ketahanan korosinya yang lebih baik dibandingkan baja. Meskipun penggunaannya meluas di wilayah pesisir, studi mengenai ketahanan GFRP terhadap paparan air laut dan panas masih terbatas. Penelitian ini bertujuan untuk menyelidiki pengaruh kondisi higrotermal terhadap sifat fisik dan mekanis GFRP. Sampel direndam dalam air laut pada suhu 30°C, 40°C, dan 60°C selama 3 dan 6 bulan. Hasil menunjukkan bahwa paparan higrotermal mengakibatkan degradasi pada sifat fisik, tetapi tidak signifikan memengaruhi sifat mekanis. Pengujian sifat fisik dilakukan dengan pengukuran kenaikan massa, uji kekerasan, dan analisis Mikroskop Elektron Pindai (SEM). Sementara itu, sifat mekanis diuji melalui uji tarik. Kenaikan massa pada spesimen tercatat hingga 3,8%, sedangkan kekerasan menurun hingga 56%. Analisis SEM menunjukkan adanya titik-titik gelap yang mengindikasikan pembentukan rongga. Temuan ini mengungkapkan kerentanan GFRP terhadap kondisi higrotermal, sehingga menimbulkan kekhawatiran terkait daya tahan jangka panjangnya pada aplikasi di wilayah pesisir.

Kata kunci: GFRP, Hygrothermal, Penyerapan fluida

ABSTRACT

Glass Fiber Reinforced Plastic (GFRP) is extensively used for corrugated roofing sheets and gutters in Indonesia, especially in corrosive environments, due to its superior corrosion resistance compared to steel. Despite its widespread application in coastal areas, limited studies have examined the durability of GFRP when exposed to seawater and heat. This research investigates the influence of hygrothermal conditions on the physical and mechanical properties of GFRP. Samples were immersed in seawater at temperatures of 30°C, 40°C, and 60°C for 3 and 6 months. Results show that hygrothermal exposure leads to degradation in physical but not mechanical properties. Physical properties were evaluated using mass gain measurements, hardness testing, and Scanning Electron Microscopy (SEM), while mechanical properties were assessed via tensile testing. The result shown all specimen have increased mass up to 3,8% and decrease in hardness up to 56%. SEM also shown several dark spot which indicate void. SEM analysis revealed the presence of dark spots, indicating void formation. These findings underscore the vulnerability of GFRP to hygrothermal conditions, raising concerns about its long-term durability in coastal applications.

Keywords: *GFRP, Hygrothermal, Fluid Absorption*

1. INTRODUCTION

Indonesia, the world's largest archipelagic nation, boasts extensive maritime territories that exceed its land area. Coastal settlements and industries are prevalent, with many utilizing Glass Fiber Reinforced Polymer (GFRP) for roofing and gutter systems due to its superior corrosion resistance. Compared to traditional metallic materials, GFRP offers several advantages, including lightweight characteristics and high strength, making it ideal for use in corrosive coastal environments where high salinity accelerates metal degradation.

GFRP materials offer several advantages over traditional metallic materials, making them a preferred choice in coastal applications. Notably, GFRP exhibits excellent corrosion resistance, coupled with a lighter weight, while maintaining comparable strength to metals. This enhanced resistance to corrosion is particularly advantageous in coastal environments, where the high levels of salinity accelerate the degradation of metallic materials. Consequently, GFRP is increasingly utilized over metal-based alternatives in these areas [1].

Roofing and gutter systems installed in coastal regions are continuously exposed to both atmospheric conditions and seawater, in addition to thermal stresses induced by solar radiation. These environmental factors contribute to hygrothermal effects, which have a profound influence on the physical and mechanical properties of GFRP materials.

Despite the widespread use of GFRP in coastal areas, research on the impact of hygrothermal effects on GFRP materials, particularly those used in roofing and gutters in Indonesia, remains limited. This gap in knowledge is critical, as understanding the long-term performance of GFRP under such conditions is essential for the design and durability assessment of these materials.

Globally, several studies have investigated the hygrothermal effects on GFRP materials, primarily focusing on structural applications within civil engineering. These studies typically examine GFRP components produced via pultrusion, subjected to immersion in distilled water. The findings indicate a degradation in GFRP quality with prolonged exposure and increasing temperature. The impetus for these studies stems from the growing use of GFRP as a fundamental material in construction, particularly in load-bearing structures [2].

Given the importance of GFRP in coastal applications, it is imperative to conduct research aimed at understanding the hygrothermal effects of sea water on the physical and mechanical properties of GFRP materials used in roofing and gutters. This study will explore the influence of varying immersion temperatures and durations on the performance of GFRP, providing valuable insights for future material design and application in coastal environments.

2. METHODOLOGY

Given the increasing use of GFRP in coastal applications, this study addresses the gap in knowledge regarding the effects of hygrothermal conditions on the material's performance, particularly in Indonesia's tropical coastal regions.

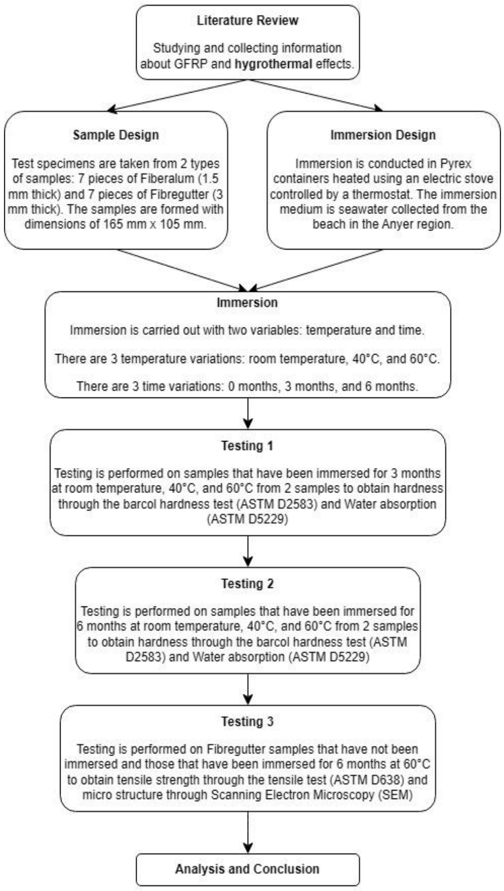


Figure 1. Research flowchart

As shown on figure 1 the research utilized 7 samples each of FibreGutter and FibreAlum. Six samples of each type were immersed in seawater, while one was retained as a reference for comparison. Prior to immersion, the initial mass of each sample was measured. Immersion tests were conducted at three temperatures: 30°C, 40°C, and 60°C. At each temperature, two FibreGutter and two FibreAlum samples were immersed.

After 3 and 6 months, samples were removed, weighed, and subjected to hardness testing. Tensile tests and SEM analysis were performed on FibreGutter samples both before immersion and after 6 months of exposure at 60°C.

2.1 Sample Selection and Preparation

The initial step in the testing process was to select the samples. The samples used were 3 mm thick FibreGutter and 1.5 mm thick corrugated FibreAlum roofing sheets, both produced by PT. Intec Persada. FibreGutter consists of 5 layers of fiber, including 2 layers of CSM 300 fiberglass, 2 layers of CSM 400 fiberglass, and 1 layer of woven roofing fiberglass, impregnated with orthophthalic resin, a type of unsaturated polyester resin [3]. FibreAlum consists of 2 layers of fiber, including CSM 300 and CSM 400 fiberglass, also impregnated with orthophthalic resin. Additionally, FibreAlum is coated with a UV-resistant gel coat and a UV-resistant plastic film [4]. For this test, the UV-resistant plastic film on FibreAlum was removed. Seven samples, each measuring 165 mm x 105 mm, were prepared from both FibreGutter and FibreAlum.

2.2 Immersion Medium and Equipment

The immersion medium was seawater sourced from Paku Beach, located in Anyer, Banten. The immersion containers were 5L Pyrex vessels. The heating method involved using an electric stove, with the temperature regulated via a thermostat.

2.3 Fluid Absorption Test

Fluid absorption testing was conducted according to ASTM D5229. The samples were weighed before and after immersion using an electronic scale with an accuracy of 0.1g. Testing is carried out by immersing the specimen in liquid for a certain period of time. For composite materials, ASTM D5229 standard is used. Weight measurements of the specimen, are taken before and after immersion. To measure the fluid absorption, Equation 1 is used [5].

$$M,\% = \frac{W_i - W_o}{W_o} \times 100 \tag{1}$$

W_i = Weight after immersion
W_o = Weight before immersion

2.4 Hardness Test

Hardness testing was performed using a Barcol hardness tester (COLMAN GYZJ-934-1) following ASTM D2583 standards [6]. Each sample was tested 10 times at different points on both sides, and the average values were recorded. The data reveal a clear trend: as immersion time increases, hardness decreases, particularly at higher temperatures. This reduction in hardness corresponds to the amount of fluid absorbed, which weakens the material structure.

2.5 Tensile Test

Tensile testing followed the ASTM D638 standard and was conducted at the Center for Materials Processing and Failure Analysis (CMPFA) at the University of Indonesia [7]. The tests were performed using a Shimadzu UTM EHP-EB20186838 machine with a 20-ton capacity and a pulling speed of 30 mm/min. Tensile tests were conducted on FibreGutter samples before immersion and on samples immersed for 6 months at 60°C.

2.6 Scanning Electron Microscopy (SEM)

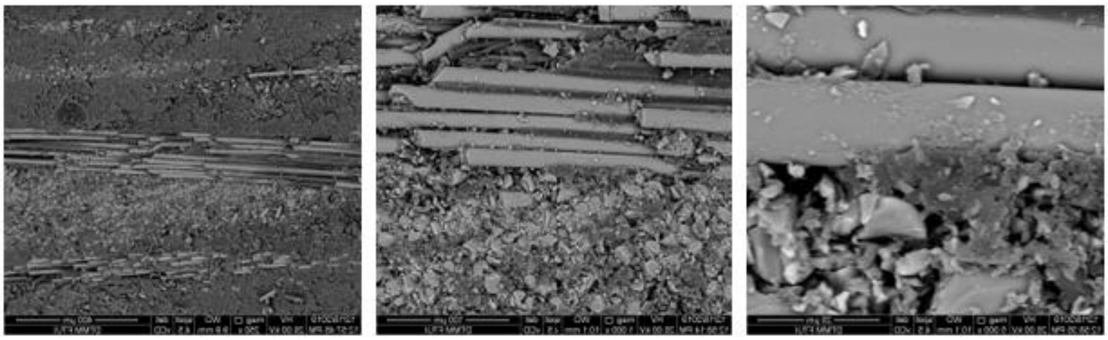
SEM analysis to see the microstructure of GFRP was also conducted at the Center for Materials Processing and Failure Analysis (CMPFA) University of Indonesia, with magnifications of 250x, 1000x, and 5000x. The SEM was performed on the cross-section of the samples.

3. HASIL DAN PEMBAHASAN

In this hygrothermal effect testing, two types of samples were used, namely FibreGutter and FibreAlum. The FibreGutter used has a thickness of 3 mm, composed of 2 layers of fibreglass CSM 300, 2 layers of fibreglass CSM 400, and 1 layer of fibreglass woven roofing, as shown in Figure 8. Meanwhile, the FibreAlum used has a thickness of 1.5 mm, composed of fiberglass CSM 300 and CSM 400. In addition to the difference in fibre composition, there is also a difference in the manufacturing method. FibreGutter was made using the Hand-Layup method, while FibreAlum used the continuous laminating method. In the hardness test of the samples before immersion, it was found that FibreGutter has higher hardness and tensile strength compared to FibreAlum. FibreGutter has a hardness of 56.9 and a tensile strength of 127 MPa, while FibreAlum has a hardness of 47.1 and a tensile strength of 113 MPa [4][5].

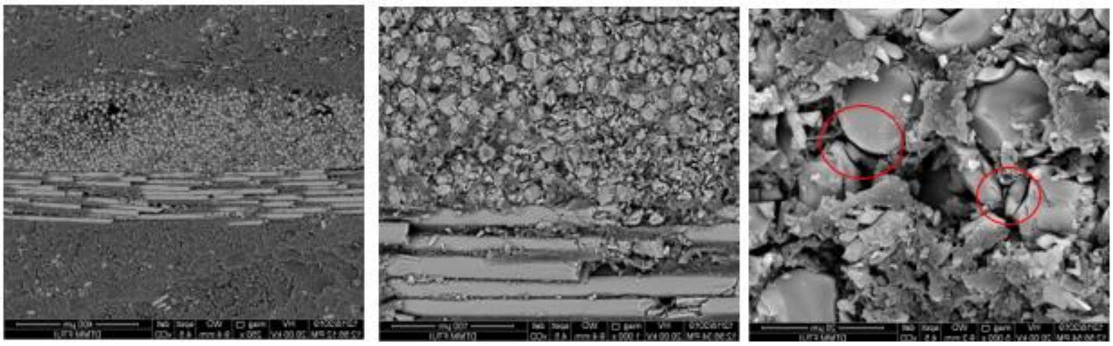
3.1 SEM

The SEM analysis was conducted on two specimens: FibreGutter in its initial condition and FibreGutter that had been immersed for 6 months at 60°C. These two specimens were selected because they are considered to represent the visual changes in GFRP due to hygrothermal effects. The initial condition specimen was chosen to represent GFRP before immersion, while the 6-month, 60°C specimen was selected to represent GFRP after immersion. The SEM was performed on the cross-sectional area of the specimens.



(a) (b) (c)

Figure. 2 SEM images FibreGutter 0 month (a) 250x magnification, (b) 1000x magnification, and (c) 5000x magnification



(a) (b) (c)

Figure. 3 SEM images FibreGutter 6 months (a) 250x magnification, (b) 1000x magnification, and (c) 5000x magnification

In the figure 2 and figure 3, several dark areas can be observed, which represent voids in the FibreGutter sample. These voids in the GFRP material may form during the manufacturing process. Additionally, the type and form of fibers selected also influence the amount of voids present in the GFRP. These voids contribute to fluid absorption in the GFRP. During immersion, the fluid fills these voids, leading to an increase in mass and subsequent weakening of the GFRP.

The observations from Figures 2(b) and 3(b) reveal an increase in the black regions between the fibers, indicating a greater separation between them and the formation of voids. This phenomenon corresponds to debonding between the resin and fibers, which is indicative of the breakdown of the interfacial bonding within the composite structure.

3.2 Fluid Absorbstion

Fluid absorption was evaluated according to ASTM D5229 standards by measuring the weight increase of samples before and after immersion. The percentage mass gain is presented in figure 4 and figure 5. Results indicate a direct correlation between immersion temperature and fluid absorption rate; higher temperatures result in increased moisture uptake. After 6 months, FibreGutter samples showed a maximum mass gain of 2.37% at 60°C, compared to 1.33% at 40°C and 1.13% at 30°C.

Table 1. Mass gain (%) of FibreGutter

Temp	3 months	6 months
30 ± 1°C	0,69832	1,13269
40 ± 3°C	0,81301	1,33730
60 ± 3°C	1,48515	2,37203

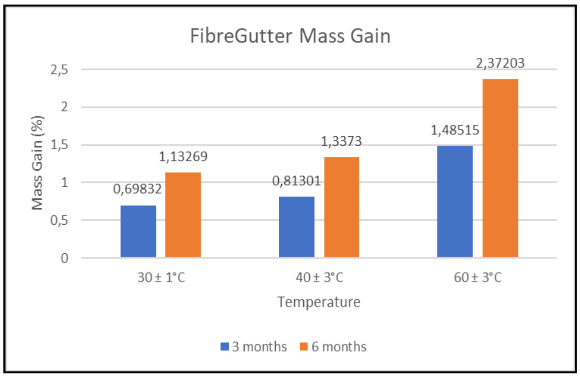


Figure 4. Temperature vs Mass gain comparison of FibreGutter

Table 2. Mass gain (%) of FibreAllum

Temp	3 months	6 months
30 ± 1°C	1,00629	1,31926
40 ± 3°C	1,65517	2,16837
60 ± 3°C	3,41997	3,89610

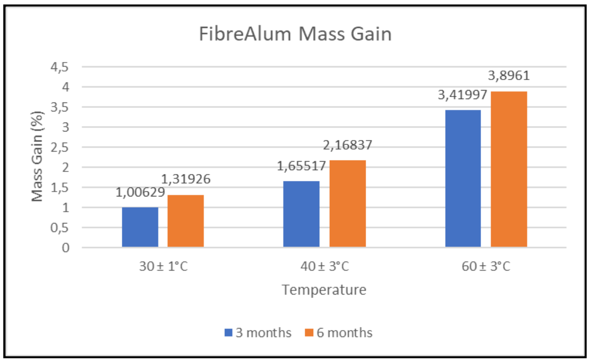


Figure 5. Temperature vs Mass gain comparison of FibreAlum

Increased fluid absorption in GFRP materials is primarily attributed to the presence of voids within the structure. As observed in the SEM analysis, GFRP materials exhibit voids that become filled with liquid, leading to an increase in the material's mass. In addition to manufacturing-related voids, SEM analysis also revealed instances of debonding between the resin and fibers. This debonding creates gaps that can also be filled with liquid, further increasing the mass of the GFRP material.

Data from the two sample types indicate a notable difference in fluid absorption. FibreAlum exhibited higher absorption compared to FibreGutter, despite the expectation that FibreAlum, produced via the continuous laminating method, would have fewer voids than FibreGutter, which was produced using the hand lay-up method. This discrepancy may be due to the removal of the UV-protective plastic film from FibreAlum prior to immersion, which likely exposed new surface voids. Additionally, the removal of the plastic film rendered the surface of FibreAlum rougher, effectively increasing the surface area. Furthermore, FibreAlum is composed solely of chopped strand mat glass fibers, which tend to generate more voids than the woven roofing structure of FibreGutter.

The results of this study align with previous research by Grammatikos et al., which demonstrated that higher immersion temperatures result in greater fluid absorption. A particularly striking difference was observed at 60°C, where mass gain was nearly double that at 40°C, indicating that elevated temperatures significantly enhance the fluid absorption capacity of GFRP.[3] Unlike Grammatikos' study, however, this experiment did not reach equilibrium mass, where the sample mass stabilizes due to maximum fluid absorption having been achieved.

3.3 Hardness

The Barcol hardness test was conducted in accordance with ASTM D2583 standards. Data was collected 10 times, and the results were then averaged. The Barcol hardness test results, as shown in figure 6 and figure 7, indicate that as immersion time increases and water absorption in the samples rises, the hardness of the material correspondingly decreases.

Table 3. Barcol hardness data of FiberAlum

Temp	0 months	3 months	6 months
30 ± 1°C	47,1	37	24,3
40 ± 3°C	47,1	32,2	22,5
60 ± 3°C	47,1	26,8	16,7

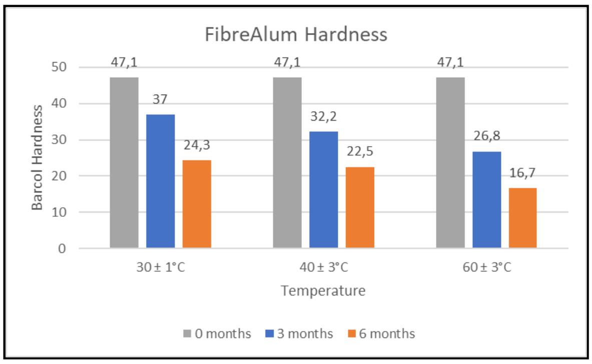


Figure 6. Temperature vs hardness comparison of FibreAlum

Table 4. Barcol hardness data of FiberGutter

Temp	0 months	3 months	6 months
30 ± 1°C	56,9	46,8	42,4
40 ± 3°C	56,9	40,3	38,9
60 ± 3°C	56,9	34,1	24,9

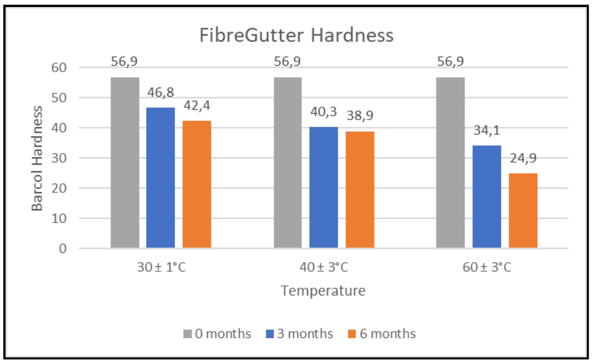


Figure 7. Temperature vs hardness comparison of FibreGutter

This can be observed in the decrease in hardness with increasing temperature. As the temperature rises, the hardness of both FibreAlum and FibreGutter decreases. This is consistent with the absorption test results, which showed that higher temperatures and longer immersion times lead to greater fluid absorption in GFRP. It can be inferred that the reduction in hardness corresponds to the amount of fluid absorbed by the GFRP. The absorbed fluid weakens the GFRP structure, and the occurrence of debonding further reduces hardness as the bond between the fibers and the resin is compromised.

Temperature also showed a significant effect on hardness. As seen in Table 3 and Table 4, specimens exposed to a temperature of 60°C experienced the largest drop in hardness compared to those exposed to 30°C and 40°C. While both types of GFRP showed a decrease in hardness, FibreAlum exhibited a more pronounced reduction than FibreGutter. This indicates that the type of material used plays a critical role in determining the extent of hardness degradation.

This observation aligns with the findings of A. A. Mohammed, who reported that the longer GFRP is immersed, the greater the reduction in hardness. This reduction in hardness indicates a decline in the mechanical quality of GFRP following exposure to hygrothermal effects [8].

3.4 Tensile Strength

Tensile strength was determined based on the ASTM D638 tensile test. The tensile test was conducted similarly to the SEM analysis, with specimens consisting of FibreGutter in its initial condition and FibreGutter that had been immersed for 6 months at a temperature of 60°C. These two specimens were selected as they effectively represent the hygrothermal effects before and after immersion. Additionally, FibreGutter contains woven roofing fibers with known fiber orientations, which minimizes the likelihood of errors in the test results.

Table 5. Tensile strength of FiberGutter

Duration	Strength (MPa)
0 month	127
6 months	137

As seen in Table 5, the tensile test results show an anomaly where the tensile strength increased after immersion. This anomaly could be attributed to several factors, one of which is the increase in cross-linking related to post-curing in the polymer. However, this effect should not be significant, as the majority of the tensile strength in GFRP materials is provided by the fibers. Another factor that could influence tensile strength is the fiber orientation in the GFRP. As previously mentioned, FibreGutter contains reinforcing fibers in the form of woven roofing with a known fiber orientation, which reduces potential errors. However, FibreGutter also includes fibers in the form of chop strand mat, where the random fiber orientation introduces uncertainty. When a large number of fibers are aligned with the direction of the tensile force, the tensile strength will be higher. In the tensile test specimens of FibreGutter, the specific fiber orientation for each specimen was not known.

This anomaly has also been observed in other studies. As noted by Grammatikos et al., tensile strength increases can occur in certain tests [3]. This suggests that tensile testing may not accurately represent the effects of hygrothermal exposure on GFRP materials, as the data obtained can be inconsistent. To obtain reliable tensile test results, GFRP materials with uniformly conditioned fiber orientations must be used, ensuring that no errors arise from fiber orientation differences.

SUMMARY

This study has investigated the hygrothermal effects on Glass Fiber Reinforced Polymer (GFRP) materials, specifically FibreAlum and FibreGutter, under varying temperatures (30°C, 40°C, and 60°C) and immersion durations (3 months and 6 months) in seawater. The following key conclusions were drawn from the experimental results.

Degradation of Physical Properties: Hygrothermal exposure leads to a noticeable degradation in the physical properties of GFRP materials. The extent of deterioration is influenced by both the duration of exposure and the temperature of the environment.

Influence of Temperature on Fluid Absorption: The study demonstrated that an increase in temperature significantly enhances fluid absorption in GFRP materials. Higher temperatures result in greater moisture uptake, which can accelerate the degradation process.

Reduction in Hardness: A consistent decline in hardness was observed with prolonged immersion time and increased temperature. This indicates that hygrothermal conditions adversely affect the structural integrity of GFRP materials over time.

Tensile Strength Limitations: The tensile strength data was found to be unreliable in representing the impact of hygrothermal effects on GFRP. This unreliability is attributed to the random orientation of fibers in the chopped strand mat, which introduces variability in the test results.

These findings underscore the importance of considering hygrothermal effects in the design and application of

GFRP materials, particularly in coastal environments where exposure to heat and moisture is prevalent. Further research is recommended to explore alternative testing methods that can more accurately capture the effects of hygrothermal aging on the mechanical properties of GFRP.

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