

Modified Charpy-Type Impact Analysis of Thin-Layer Composites After Short-Term Saline Exposure¹

Taha Yasin Eken²

ABSTRACT

Thin-layer composites provide strength and stiffness while protecting the part, and are exposed to various environmental factors. In this study, the short-term impact behavior of thin-layer composites in a 3.5% NaCl aqueous medium (seawater-like) was investigated. Double-layered glass-glass (GG), carbon-carbon (CC), and glass-carbon (GC) composites were produced with vacuum infusion methods. Then, these composites were cut and exposed to seawater for 24 hours. After 24 hours immersion, samples were subjected to a modified Charpy-type impact test using a 15 J hammer to evaluate changes in their energy absorption capacity. Short-term immersion caused an initial rise in the energy absorbing capability of homogeneous thin-layer composites due to matrix plasticization. Increases in impact resistance of 21.59% and 5.39% were observed in GG and CC samples, respectively. Despite a marginal increase in total absorbed energy in hybrid GC samples, a decrease of 3.81% in impact resistance was observed.

Keywords: Glass fiber, carbon fiber, hybrid composite, seawater, modified Charpy-type impact test.

1. INTRODUCTION

Composites are one of the four main classes of materials, consisting of at least two physically distinct components [1]. These materials comprise a matrix that serves as the structural body and reinforcement materials that act as load carriers. They are classified based on their matrix type, such as metal matrix, ceramic matrix, and polymer matrix composites (PMCs) [2]. PMCs are predominantly produced using epoxy as the matrix and various fibers as reinforcement. Commonly utilized fibers include aramid, carbon (CF), and glass fibers (GF) [3]. Due to their availability and superior properties, epoxy-based composites reinforced with CF and GF are widely employed in the aerospace, automotive, and marine industries [4–7]. These advantageous properties include high mechanical strength, corrosion and wear resistance, low density, and specific functional traits such as electrical conductivity for CFs and electrical insulation for GFs [8–12].

¹ This study is partly derived from the paper presented at the 4th International Conference on Modern and Advanced Research (2025).

² Assist. Prof., Department of Metallurgical and Materials Engineering, Faculty of Engineering and Natural Science, Bursa Technical University, Bursa, Türkiye, ORCID: [0000-0001-6693-8091](https://orcid.org/0000-0001-6693-8091)

² Corresponding Author: yasin.eken@btu.edu.tr

The marine industry produces a lot of interesting products such as yachts, ships, and submarines. For these vehicles, different PMCs are used as thin layers in inner and outer parts. For the outer parts, these PMCs are exposed to many different effects such as sunlight, different solvents, mechanical forces from sea animals, and seawater. To prevent these effects, there are many studies in literature. Jesthi and Nayak (2019) conducted a study on seawater-aged CF and GF PMCs and evaluated their mechanical properties and morphologies. They produced hybrid symmetric composites of $[C_2G_3]_s$, $[CG_3C]_s$ and $[CG_2CG]_s$ and they aged these composites with seawater from Puri, India. They found that compared to plain CF PMCs, there was a 207% and 293% improvement in Izod impact performance for $[CG_2CG]_s$ [13]. Yalçinkaya et al. (2025) studied the mechanical characterization of CF and GF PMCs under effect of seawater. They evaluated different composite materials and in real seawater. They used seawater from İzmir-Balçova-İnciraltı area, which was obtained every two days at a specific time between 09:00-10:00 on specific dates between 02.07.2022-29.08.2022. They applied the Charpy test with a 30 J of impact energy and found that seawater increased the Charpy impact performance [14]. Esleman and Önal (2022) investigated the effect of seawater on hybrid composites by applying mechanical tests. They produced composites using vacuum assisted resin transfer molding. The tensile and flexural properties of the CF and GF PMCs decreased and increased after 6 months [15]. Lu et al. (2022) worked on the durability of GF and basalt fiber PMCs under seawater effects. They prepared the solution according to ASTM D1141-13, and applied it at different temperatures (20, 40, and 60 °C). According to their results, increasing immersion time in the solution and increasing temperature reduced the tensile strength of the fibers [16]. José-Trujillo et al. (2019) studied seawater aging effects with different fiber and matrix types. They observed a strength reduction due to the seawater aging under flexural and shear loading [17]. Erklığ et al. studied two different temperatures (25 °C and 70 °C) of Charpy test behavior of glass fiber composites after immersion of 1000 hours. They observed a decrease in impact behavior with increase in temperature [18]. Oğuz et al. investigated hydrothermal aging behavior of glass and aramid epoxy composites with the same temperatures. After 1000 hours of seawater immersion, they found out the impact strength of the composites decreased. Also, with SEM analysis, it is approved that the number of delamination and fiber/matrix cracks increased [19].

In this study, a 3.5% NaCl aqueous solution was prepared to observe the effect of seawater on thin-layer composites. 3.5% NaCl aqueous solutions are described in the literature as being like seawater environments [20–22]. Then two-layered glass-glass (GG), carbon-carbon (CC), and hybrid glass-carbon (GC) PMCs were immersed in the solution. The immersion process was conducted at room temperature for a duration of 24 hours to simulate initial environmental exposure. Following the immersion period, the specimens were subjected to modified Charpy-type impact test to evaluate the degradation in their energy absorption capacities. Furthermore, the induced changes and potential damage mechanisms on the material surfaces were examined using a stereo microscope to correlate the macro-mechanical results with micro-structural observations.

2. MATERIALS AND METHODS

2.1. Materials

Vacuum infusion method (VIM) was chosen as the production method, and production was carried out on glass molds. The glass was purchased from a glass shop that cuts and sells glass. Carbon fiber fabric (plain weave, 200 g/m², [0°/90°]) and glass fiber fabric (plain weave, 200 g/m², [0°/90°]), release films, vacuum bag, flow media, and peel ply were obtained from TEKROM A.Ş. The resin system consisted of epoxy resin (MGS LR160) and amine-based hardener (MGS LH160) from Dost Kimya, with a mixing ratio of 100:25 by weight. Sodium chloride (NaCl) was used as Merck brand for seawater preparation.

2.2. Preparation of Composites

First, the surface of the glass mold was cleaned and dried with cloth and acetone. Then, a 450 mm x 450 mm piece of release film was cut, larger than the surface area of the composite, and carefully attached to the surface with packing tape. After that, 300 mm x 300 mm flow media, 410 mm x 410 mm peel ply, 400 mm x 400 mm fiber fabrics (2-layer), 410 mm x 410 mm peel ply, 300 mm x 300 mm flow media, and a 500 mm x 500 mm vacuum bag were placed on top of each other, respectively. In this study, the layers were designated as glass-glass (GG), glass-carbon (GC), and carbon-carbon (CC), and the specified fiber fabrics were laid on each layer. Then, the sealing tape was applied to the glass mold, ensuring that the vacuum pack adhered to the tapes. The vacuum bag was then adhered to the glass mold, ensuring no gaps were left. The prepared package was completely air-purified using a vacuum tank and checked for leaks. Once the leak-free condition was ensured, an epoxy mixture of 100 grams of epoxy and 25 grams of hardener was prepared and, with a vacuum pressure of 600 mbar, was introduced into the system through pipes. After ensuring the fibers were completely wetted, the pipe ends were tightened with screw clamps and allowed to cure. After 24 hours, the composite was cured in the open air, separating from the peel ply and achieving its final form. VIM method is shown schematically in Figure 1. Composites were cut into 80 mm lengths for modified Charpy-type impact testing in accordance with the ISO 179-1:2023 standard. In asymmetric hybrid GC samples, the pendulum impactor was adjusted to strike on the carbon fiber side, thereby putting the glass fibers in tension under dynamic bending conditions. Calibration of the pendulum system for dynamic zero correction to compensate for aerodynamic and bearing losses was performed prior to conducting the impact tests to ensure accurate resolution of the absorbed energies. The width and thickness of the samples were determined to allow comparisons across different conditions. Five samples were prepared for each condition (GG, GC, CC), and a total of 30 samples were cut to be examined under conditions with and without seawater exposure. Samples, conditions and the device are shown in Figure 2. Figure 2a shows the PMCs are produced as two-layers; GG is glass-glass, CC is carbon-carbon, and GC is glass-carbon. Figure 2b shows the real picture of the final shape of the specimens; five different samples used for each condition (before and after seawater immersion). The specimens used in the environmental exposure

study (Figure 2c) were immersed in a 3.5% aqueous solution of NaCl using reagent grade NaCl and distilled water. This immersion process took place for 24 hours at a controlled room temperature of 23 ± 2 °C with the solution volume being more than 30 mL for each specimen to avoid any concentration gradient. After the 24-hour exposure time, the specimens were taken out of the solution and rinsed with deionized water to remove any salt deposits and dried using lint-free tissue paper prior to conducting the modified Charpy-type impact test.

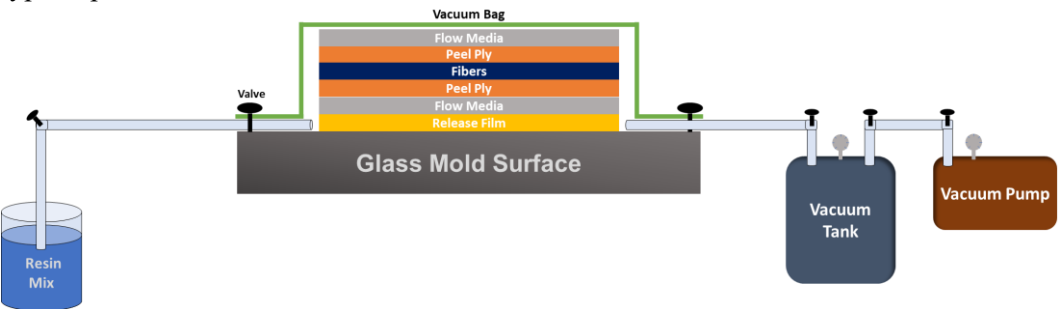


Figure 1. The detailed VIM method is shown schematically.

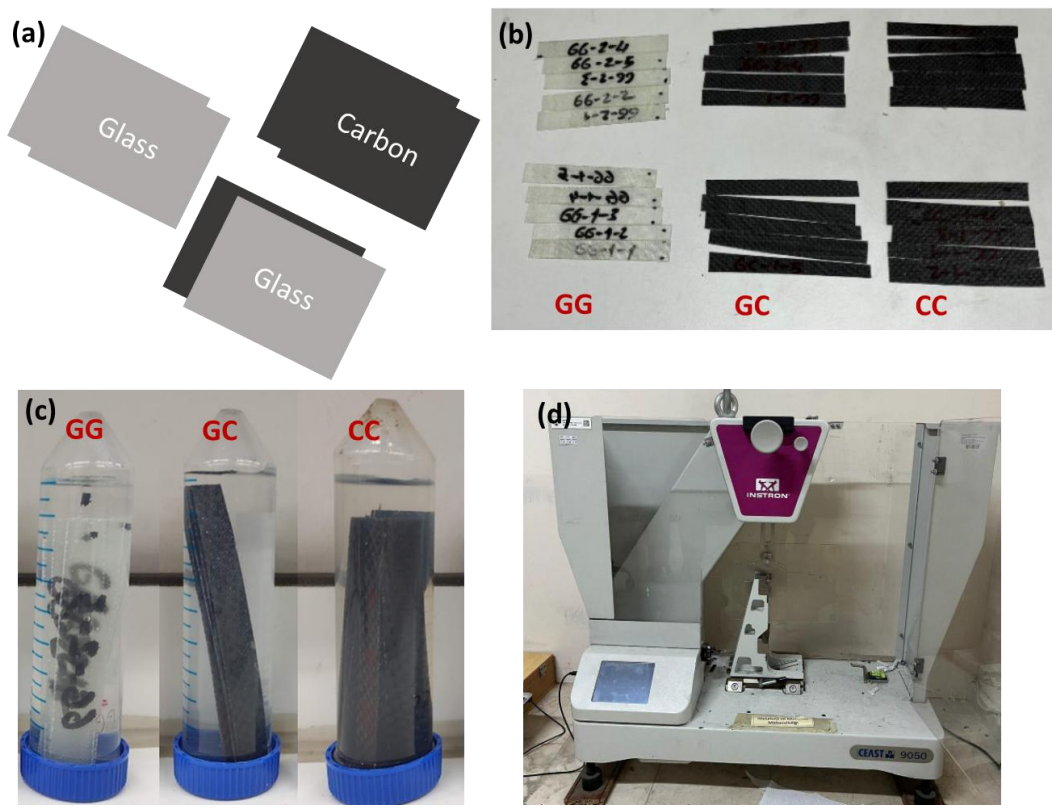


Figure 2. (a) Schematic depiction of two-layer composites, (b) specimens ready for seawater exposure, (c) seawater exposure on specimens, (d) modified Charpy-type impact test device.

3. RESULTS AND DISCUSSIONS

The samples and their measurements are given in Table 1. GG samples were studied before in a conference study [23], after that CC, and GC samples were also prepared and 24-hour seawater exposure was applied. In this study, the modified Charpy-type impact test results investigated with absorbed energy, impact strength, and impact energy. According to the recorded data, there was an initial indication that short-term salt water treatment increased the total dynamic energy absorption of homogeneous samples. Average absorbed energy, impact strength, and impact energy values increased within the 24-hour period. For GG samples, increments of 35.06% for absorbed energy, 21.59% for impact strength, and 33.33% for impact energy were observed. Similarly, these values rose by 5.26%, 5.39%, and 5.26% for CC samples, and by 4.51%, -3.81%, and 4.50% for GC samples, respectively. These relative variations are illustrated in the specific impact strength comparison in Figure 3a and the corresponding percentage changes in Figure 3b. Rule of mixtures (ROM) effect refers to the theoretical prediction of the properties of a hybrid composite based on the weighted average of its components [24]. In an ideal hybrid system, a linear transition in mechanical performance is expected between the properties of the reinforcing fibers. However, the experimental results in this study revealed a negative deviation from the ROM for hybrid GC samples following exposure to seawater. This negative deviation indicates that the synergistic effect expected from hybridization may not be realized in a saline environment. A possible reason for this is that difference in water uptake by the two layers can lead to the development of shear stress leading to early debonding [13,25], but more detailed investigations will be necessary to validate this. Consequently, the data generated only give an insight into the immediate effects of moisture absorption, whereby early plasticization of the matrix results in an increase in the energy dissipation of the homogeneous thin plies. This should be noted, as the 24-hour exposure does not imply marine durability of the material, because extended exposure generally results in extensive degradation of the material.

Table 1. Modified Charpy-Type Impact Test Results of GG, CC, and GC Thin-Layer Composites Before and After 24-Hour 3.5 wt.% NaCl Exposure (Values Are Reported as Mean $\pm$ SD)

Sample Designation	Average Cross-Sectional Area (mm ²)	Average Absorbed Energy (%) ^a	Average Impact Strength (kJ/m ²)	Average Impact Energy (J)
GG-1-D (Dry)	6.359 $\pm$ 0.81	0.77 $\pm$ 0.09	18.11 $\pm$ 0.53	0.117 $\pm$ 0.013
GG-2-A (Aged)	7.116 $\pm$ 0.35	1.04 $\pm$ 0.19	22.02 $\pm$ 4.19	0.156 $\pm$ 0.029
CC-1-D (Dry)	7.184 $\pm$ 1.13	1.90 $\pm$ 0.84	38.96 $\pm$ 12.87	0.285 $\pm$ 0.126

Sample Designation	Average Cross-Sectional Area (mm ²)	Average Absorbed Energy (%) ^a	Average Impact Strength (kJ/m ²)	Average Impact Energy (J)
CC-2-A (Aged)	7.196±1.09	2.00±0.61	41.06±7.15	0.300±0.092
GC-1-D (Dry)	6.411±0.65	1.33±0.29	31.00±5.12	0.200±0.044
GC-2-A (Aged)	6.972±0.41	1.39±0.28	29.82±4.67	0.209±0.042

^aNote: Absorbed Energy (%) is calculated relative to the total pendulum hammer capacity of 15 J as $(E_{\text{absorbed}}/15 \text{ J}) \times 100$.

Figure 4 represents the comparison of theoretical and experimental results of ROM effect of GC. Theoretical impact strength has been calculated as follows in Equation (1) [26]:

$$a_{c,ROM} = (a_{c,GG} \cdot V_{GG}) + (a_{c,CC} \cdot V_{CC}) \quad (1)$$

where a_c is the impact strength, V_{GG} is the volume of glass fiber (0.5), and V_{CC} is the volume of carbon fiber (0.5). From this equation, dry ROM is calculated as 28.535 kJ/m², and aged ROM is 31.54 kJ/m². Since the specimens were only subjected to severe plastic deformation rather than full catastrophic failure upon impact, the computed impact strengths (kJ/m²) are the total amount of energy dissipated by bending, yielding of matrix, and damage initiation. Under dry conditions, the experimental impact strength of GC samples exceeded the theoretical ROM value. This is because the combination of carbon and glass layers in the open atmosphere effectively dissipates impact energy. However, a decrease in the ROM value was observed when exposed to seawater compared to the theoretical value. This indicates that seawater exposure primarily targets the heterogeneous interface between the carbon and glass layers. One possible cause could be the difference in hygroscopic expansion coefficients between the glass and carbon plies that could generate internal residual stresses at the interface and affect cooperative load transfer under dynamic bending.

While this study yields results regarding the dynamic performance of thin-layer composite laminates under environmental exposure for a short period of time, it is necessary to note some limitations both methodological and structural. First, the unnotched 2-ply laminates had very thin structure (0.55-0.63 mm) which did not lead to any catastrophic failure during impact. Then, the energy dissipation mechanism included dynamic flexure, localized matrix cracking, and interlaminar shearing, which means that the results reflect only dynamic bending energy absorption and not full fracture toughness.

Also, testing these thin specimens using 15 J pendulum leads to consuming only 0.78%-2.00% of the full hammer capability, implying certain sensitiveness and relative scatter of the results. Regarding the environmental conditioning, 24-hour immersion in the 3.5 wt.% NaCl aqueous solution represents only temporary matrix plasticization and not real marine durability or hydrolytic saturation, and continuous water uptake measurements and glass transition temperature determination have not been carried out. Finally, the asymmetric hybrid GC laminates have been tested only under impact to the carbon fiber side, and the

influence of bidirectional fiber orientation has not been taken into account, while the used rule of mixtures represents just a simple arithmetic approach with equal volume.

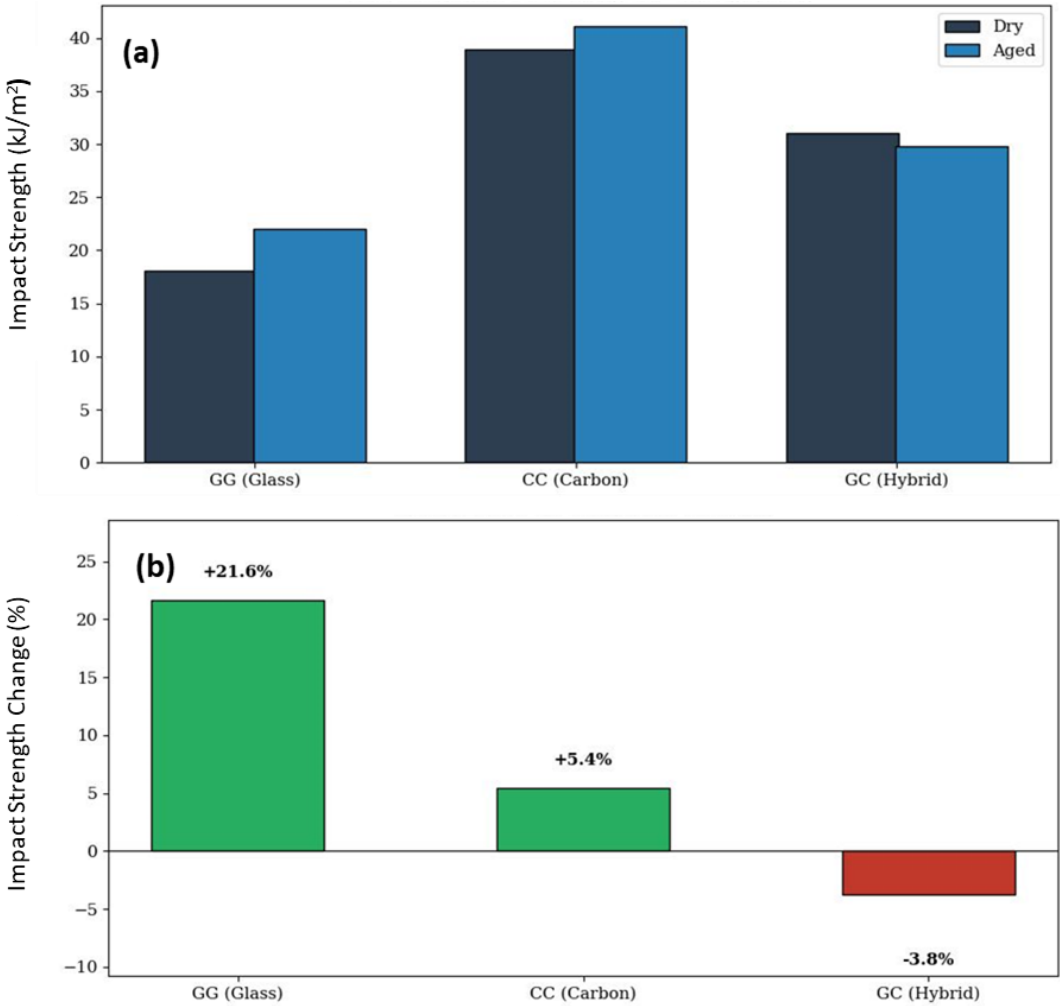


Figure 3. (a) Specific impact strength comparison and (b) percentage change in impact properties after 24-hour saline exposure.

In modified Charpy-type impact test, the specimen did not break using 15 J hammer but only deformed plastically. It did not break when subjected to high energy, for instance, 50 J hammer; hence, it was brought back to 15 J hammer in accordance with the literature [18]. The reason why the specimen failed to break is that it was 1 mm thick, which is thinner than that recommended by the ISO 179-1:2023 standard (4 mm). Due to the main aim of

this research being the investigation of thin-layer composite behaviors, the deviation was intended. In order to visually inspect the internal interfaces of plies using qualitative methods after the non-destructive dynamic impact test, the specimens were bent manually until separation (Figure 5). These pictures are purely used for qualitative observations of failure after the test using manual bending and not for fracture mechanics after dynamic impact testing. When subjected to manual bending, GG specimens exhibited fiber and matrix tearing, GC specimens displayed separation between laminates at the hybrid interface, and CC specimens displayed fiber pullout and debonding.

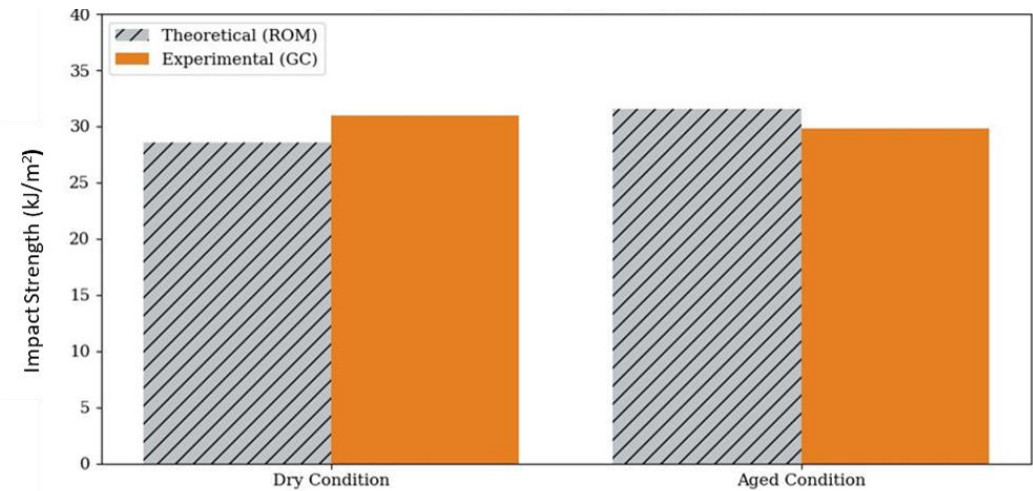


Figure 4. Comparison of theoretical (ROM) and experimental impact strength values for the hybrid GC composites in dry and 24-hour saline-exposed conditions.

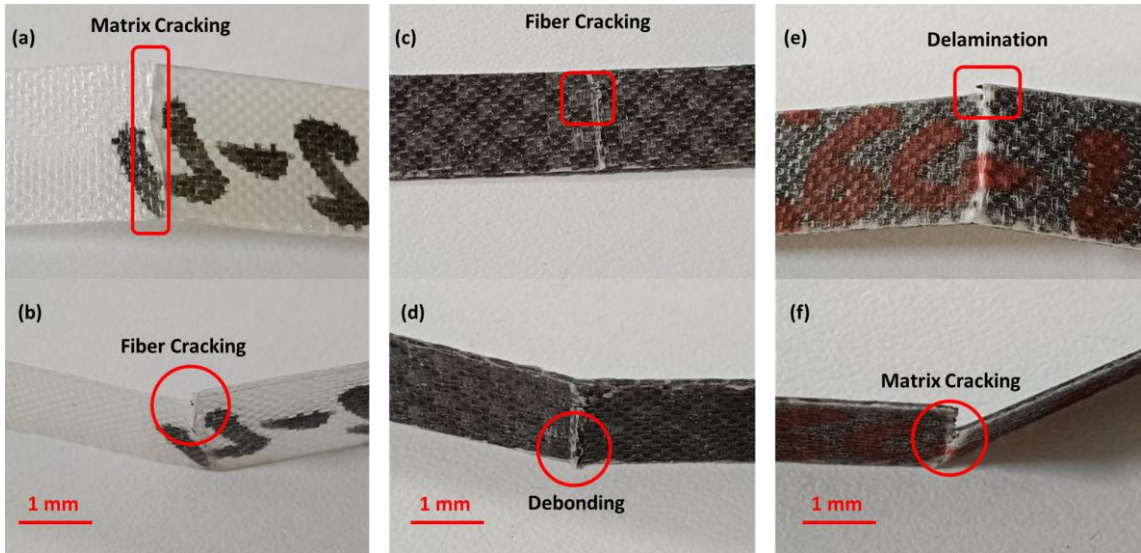


Figure 5. Qualitative photographic observations of post-impact, manually broken (a)-(b) GG, (c)-(d) CC, and (e)-(f) GC specimen interfaces illustrating general failure morphologies.

4. CONCLUSION AND RECOMMENDATIONS

In this work, the dynamic energy absorption performance of unnotched 2-ply thin-laminate (0.55-0.63 mm thick) glass, carbon, and hybrid glass/carbon epoxy composite laminates was studied under the conditions of short-term (24 hours) immersion in a 3.5 wt.% NaCl aqueous solution by means of a specially modified Charpy-type impact system. The key findings of this research, which strictly apply to the tested thin laminates and testing conditions only, include the following:

- a. The tested thin-ply laminates do not experience catastrophic failure under the 15 J impact load. Energy dissipation occurs predominantly via dynamic flexural deformation, local matrix cracking, and interlaminar shear.
- b. After 24-hour immersion into the salt solution, the homogeneous GG and CC thin laminates experienced minor enhancement in absorbed energy (from 0.117 ± 0.013 J to 0.156 ± 0.029 J in GG and from 0.285 ± 0.126 J to 0.300 ± 0.092 J in CC). These preliminary results can be considered early trends of matrix plasticization.
- c. Asymmetric GC laminate showed lower energy absorption after exposure than expected according to the linear ROM model, meaning early sensitivity of the laminate interface in case of impact on carbon side.
- d. Since this type of 24-hour immersion test only accounts for the transient conditioning effect, future studies need to include more extensive aging procedures and thermal and microstructural investigations in order to determine the saturation effect and corrosion kinetics at the interface.

Research and Publication Ethics Statement

The entire process of the manuscript was carried out in compliance with the research and publication ethics guidelines of the Celal Bayar University Journal of Science.

Author's Contributions

Taha Yasin Eken: Drafted and wrote the manuscript, performed the experiment and result analysis.

Acknowledgement

The author of this article declares that the work studied in this article was carried out without any financial support.

REFERENCES

- [1]. Chawla, KK. Carbon fiber composites. In: Chawla KK (ed) Composite Materials: Science and Engineering. Springer, New York, 1998, pp 252-277.
- [2]. Das, TK, Ghosh, P, Das, NC. 2019. Preparation, development, outcomes, and application versatility of carbon fiber-based polymer composites: a review. *Advanced Composites and Hybrid Materials*; 2(2): 214-233.
- [3]. Sathishkumar, TP, Satheeshkumar, S, Naveen, J. 2014. Glass fiber-reinforced polymer composites - a review. *Journal of Reinforced Plastics and Composites*; 33(13): 1258-1275.
- [4]. Reinhart, TJ. Overview of composite materials. In: Peters ST (ed) Handbook of Composites. Springer, Boston, 1998.
- [5]. Peters, ST. Handbook of Composites. Springer Science & Business Media, Berlin, 2013.
- [6]. Eken, TY, Kaykilarli, C, Kucukelyas, B, Tabakcioglu, MB. 2024. Electromagnetic shielding effectiveness and impact test performance of carbon fiber reinforced polymer composites with hematite and goethite. *Macromolecular Materials and Engineering*; 309(2): 2300271.
- [7]. Kaboglu, C, Eken, TY, Yurekturk, Y. 2022. Impact performances and failure modes of glass fiber reinforced polymers in different curvatures and stacking sequences. *Journal of Composite Materials*; 56(7): 1123-1138.
- [8]. Kumar, S, Doshi, H, Srinivasarao, M, Park, JO, Schiraldi, DA. 2002. Fibers from polypropylene/nano carbon fiber composites. *Polymer*; 43(5): 1701-1703.
- [9]. Wang, M, Kang, Q, Pan, N. 2009. Thermal conductivity enhancement of carbon fiber composites. *Applied Thermal Engineering*; 29(2): 418-421.
- [10]. Nitai, AS, Chowdhury, T, Inam, MN, Rahman, MS, Mondal, MIH, Johir, MAH, Hessel, V, Fattah, IMR, Kalam, MA, Suwaileh, WA, Zhou, JL, Zargar, M, Ahmed, MB. 2024. Carbon fiber and carbon fiber composites - creating defects for superior material properties. *Advanced Composites and Hybrid Materials*; 7(5): 169.
- [11]. Kaboglu, C, Eken, TY, Guney, S. 2023. Effect of curvature and stacking sequence on flexural strength in glass fiber reinforced composites. *Materials Testing*; 65(8): 1273-1280.
- [12]. Singh, J, Kumar, M, Kumar, S, Mohapatra, SK. 2017. Properties of glass-fiber hybrid composites: a review. *Polymer-Plastics Technology and Engineering*; 56(5): 455-469.
- [13]. Jesthi, DK, Nayak, RK. 2019. Evaluation of mechanical properties and morphology of seawater aged carbon and glass fiber reinforced polymer hybrid composites. *Composites Part B: Engineering*; 174: 106980.

- [14]. Yalçinkaya, S, Mertgenç Yoldaş, D, Yoldaş, MF. 2025. Experimental investigation of the effect of seawater on glass and carbon fiber composites via mechanical characterization. *Journal of Composites Science*; 9(3): 107.
- [15]. Esleman, EA, Önal, G. 2022. Effect of saltwater on the mechanical properties of basalt/carbon/glass-epoxy hybrid composites. *Journal of Composite Materials*; 56(25): 3783-3799.
- [16]. Lu, Z, Jiang, M, Pan, Y, Xian, G, Yang, M. 2022. Durability of basalt fibers, glass fibers, and their reinforced polymer composites in artificial seawater. *Polymer Composites*; 43(4): 1961-1973.
- [17]. José-Trujillo, E, Rubio-González, C, Rodríguez-González, JA. 2019. Seawater ageing effect on the mechanical properties of composites with different fiber and matrix types. *Journal of Composite Materials*; 53(23): 3229-3241.
- [18]. Erklığ, A, Oğuz, ZA, Bozkurt, ÖY. 2021. An experimental investigation on the Charpy impact response of glass/epoxy composites aged in seawater. *The International Journal of Materials and Engineering Technology*; 4(1): 51-60.
- [19]. Oğuz, ZA, Erklığ, A, Bozkurt, ÖY. 2021. Effects of hydrothermal seawater aging on the mechanical properties and water absorption of glass/aramid/epoxy hybrid composites. *International Polymer Processing*; 36(1): 79-93.
- [20]. Li, W, Lin, K, Yan, Y, Yu, C, Cao, Y, Chen, X, Wang, CW, Kato, K, Chen, Y, An, K, Zhang, Q, Gu, L, Li, Q, Deng, J, Xing, X. 2022. A seawater-corrosion-resistant and isotropic zero thermal expansion (Zr,Ta)(Fe,Co)₂ alloy. *Advanced Materials*; 34(34): 2109592.
- [21]. Kootsookos, A, Mouritz, AP. 2004. Seawater durability of glass- and carbon-polymer composites. *Composites Science and Technology*; 64(10): 1503-1511.
- [22]. Kirar, E, Demircan, G, Kisa, M, Ozen, M. 2025. Deformation rate effect on compression behaviour of glass fiber-epoxy composites under seawater aging. *Applied Composite Materials*; 32(5): 2035-2050.
- [23]. Eken, TY. Investigation of the effect of 24-hour seawater exposure on the Charpy impact behavior of glass fiber layered epoxy matrix composites. In: 4th International Conference on Modern and Advanced Research, 2025.
- [24]. Liu, GR. 1997. A step-by-step method of rule-of-mixture of fiber- and particle-reinforced composite materials. *Composite Structures*; 40(3): 313-322.
- [25]. Schutte, CL. 1994. Environmental durability of glass-fiber composites. *Materials Science and Engineering: R: Reports*; 13(7): 265-323.
- [26]. Sayer, M, Bektaş, NB, Sayman, O. 2010. An experimental investigation on the impact behavior of hybrid composite plates. *Composite Structures*; 92(5): 1256-1262.