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# Effect of Ethylene Glycol Exposure on the Mechanical Performance of E-Glass/Epoxy Composites

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## Abstract

Glass fiber-reinforced epoxy composites are widely used in aerospace, automotive, and structural applications due to their superior mechanical properties and resistance to environmental degradation. However, exposure to aggressive chemical agents such as ethylene glycol (EG), commonly found in de-icing fluids, can compromise their structural integrity. This study investigates the effects of EG exposure on the mechanical performance of glass/epoxy composites by examining changes in flexural strength, stiffness, and mass gain under varying concentrations (50%, 75%, 100%) and durations (up to 15 days) at 50°C to simulate accelerated aging. Results showed that flexural strength decreased by ~23% after 1 day of exposure to 100% EG, while stiffness declined by ~6%. Lower concentrations produced less degradation, with 50% EG exposure resulting in a strength reduction of only ~2%. A partial recovery in strength and stiffness was observed after 2 to 4 days of exposure, possibly due to post-curing or chemical interactions with the resin. Mass gain increased as EG concentration decreased, likely due to greater water diffusivity. Despite measurable reductions in mechanical properties, the composites retained structural integrity, supporting their continued use with appropriate protection strategies. These findings highlight the importance of understanding chemical compatibility in composite applications exposed to EG-containing environments.

*Keywords: Aerospace Composites, Composite Degradation, Ethylene Glycol, Durability, Flexural Properties*

## 1 Introduction

The aerospace industry has experienced a significant shift from traditional metals to advanced fiber-reinforced composites, such as glass and carbon fiber-reinforced polymers, due to their superior strength-to-weight ratios, durability, and resistance to environmental degradation (Skoczylas et al., 2019; Agarwal et al., 1990; Mallick, 2007). For instance, the Boeing 787 Dreamliner incorporates over 50% composite materials by weight to reduce structural weight and improve fuel efficiency (Boeing, 2025).

Beyond aerospace, fiber-reinforced composites are increasingly utilized in the automotive, marine, wind energy, and construction industries. In the automotive sector, these materials are employed to reduce vehicle weight and enhance fuel economy while maintaining structural performance (Wambua et al., 2003). Marine applications leverage the corrosion resistance and fatigue tolerance of composites for boat hulls, decks, and propellers (Hosseini et al., 2020). The wind energy sector utilizes composites for turbine blades due to their high strength and resistance to cyclic loading (Khan et al., 2021). In construction, glass fiber-reinforced polymer (GFRP) composites are used in bridge decks, retrofitting structures, and reinforcing concrete elements (Hollaway, 2010).

Despite these advantages, polymer composites—especially thermoset-based systems like epoxy—are susceptible to degradation when exposed to environmental stressors such as moisture. Moisture absorption often leads to matrix plasticization, swelling, and interfacial weakening between fiber and matrix, which compromise mechanical properties. Guloglu et al. (2020) reported a 15% reduction in tensile strength in carbon/epoxy composites (60% fiber volume) after 30 days of water exposure at 40°C. Similarly, Aktas et al. (2002) found that resin transfer molded glass/epoxy composites lost approximately 12% of their flexural strength after saturation at 60°C. Harper and Naeem (1990) confirmed that exposure to thermohumid conditions (25°C to 70°C) over 40 days reduced tensile strength and interlaminar shear strength of glass fiber-reinforced thermoset plastics, due to matrix hydrolysis and interface degradation. Haadar et al. (2023) found that moisture and salinity caused reductions in tensile and flexural properties of nano-silica reinforced thermoset composites. Hussnain et al. (2023) observed up to a 43% drop in flexural strength in fiber-reinforced composites aged in marine environments.

Ethylene glycol (EG), widely used as an anti-freeze and deicing agent, presents another chemical threat to composite structures across industries. It is commonly applied on aircraft before takeoff, used in automotive radiators, and appears in heat transfer systems for electronics and industrial equipment. Subramaniam et al. (1993) showed that glass fiber-reinforced polyester composites exposed to EG at room temperature for 7 days suffered a 20% decrease in shear strength. Charrier et al. (2022) exposed PA66 and PA66-GF composites to EG-water solutions at 60°C and observed reduced tensile strength and stiffness. Similarly, Zhang et al. (2024) reported a 15% decrease in interfacial adhesion and mechanical performance of PA6 and PA6-GF30 composites when exposed to glycol–water mixtures.

Temperature further influences these degradation processes. The Arrhenius equation predicts that diffusion rates increase exponentially with temperature, with a 10°C rise roughly doubling the rate. Studies such as Liu et al. (2012) and Michaeli et al. (2019) support this behavior for EG and other chemical diffusants in polymers. The current study uses 50°C to simulate accelerated EG exposure, aiming to replicate long-term environmental effects over shorter durations.

This study investigates how EG exposure time and concentration affect the flexural strength and modulus of E-glass/epoxy composites. No prior study was identified that evaluates EG exposure effects specifically in this material system, underscoring the novelty and practical relevance of this research in aerospace, automotive, and infrastructure applications where EG contact is likely.

# 2 Materials and Methods

## 2.1 Materials

Fiberglass/epoxy composite plates were fabricated using a vacuum-assisted resin infusion process. The epoxy matrix consisted of PRO-SET INF-114 infusion resin and PRO-SET INF-211 hardener, chosen for their low viscosity and compatibility with structural composite fabrication. Both components of the resin system, along with the reinforcement material, were obtained from Fibre Glast Development Corporation (Brookville, OH, USA). The reinforcement consisted of randomly oriented chopped strand fiberglass mat, which provided approximately isotropic in-plane mechanical properties.

Fiberglass mats were cut and carefully arranged within the mold to ensure uniform coverage and fiber distribution. The layup was infused under vacuum to achieve complete wet-out and to minimize void formation. Curing was performed at room temperature for 24 hours, followed by a post-cure cycle at elevated temperature according to manufacturer recommendations to ensure optimal cross-linking and mechanical performance.

Ethylene glycol (EG), used as the chemical exposure agent, was obtained from Walmart Inc. (Bentonville, AR, USA). EG solutions were prepared at three concentrations: 100%, 75%, and 50% by volume, using distilled water as the diluent. These concentrations were selected to simulate varying levels of chemical exposure representative of real-world service environments. All solutions were used as prepared without further purification.

## 2.2 Methods

### 2.2.1 Fiber Preparation

Two sheets of randomly oriented chopped strand fiberglass mat were prepared by cutting them to dimensions of 12 inches by 9 inches (304.8 mm × 228.6 mm). All handling was performed using nitrile gloves to minimize contamination and avoid disturbing the fiber architecture. During cutting and transfer, the sheets were handled only along their edges to prevent dislodging or damaging the fiberglass strands.

### 2.2.2 Resin Preparation

The epoxy system used was PRO-SET INF-114 resin and PRO-SET INF-211 hardener, mixed in accordance with the manufacturer's recommended weight ratio of 3.65:1. A total batch weight of 210 grams was prepared by combining 160 grams of resin with 50 grams of hardener. The mixture was stirred manually for 15 minutes using a clean wooden stir stick to ensure complete homogenization. Following mixing, the epoxy system was placed in a vacuum chamber and degassed for 15 minutes to eliminate entrapped air. The degassed mixture was then preheated to 40°C for 15 minutes using a Thermo Scientific OGS60 convection oven to reduce viscosity and facilitate better fiber wet-out.

### 2.2.3 Composite Panel and Specimen Manufacturing

Composite parts were molded using a hand layup technique on a flat working surface that had been cleaned with 70% isopropyl alcohol and coated with a mold release agent (FibRelease) to facilitate demolding. A thin layer of epoxy resin was first applied to the surface to act as a bonding layer for the initial fiberglass sheet. This first layer was then placed and fully saturated with the prepared epoxy resin using brushes, rollers, and plastic scrapers to ensure even distribution and complete wetting. The second fiberglass layer was then applied on top of the first and saturated using the same process. Once all resin had been applied, the layup was left to cure under ambient conditions (open-air cure) for 24 hours. A post-cure was then performed at 80°C for an additional 24 hours to complete cross-linking and enhance the mechanical properties.

Following curing, the composite panel was machined into test specimens in accordance with ASTM D790 standards for flexural testing. A conservative span length of 70 mm was selected, based on the maximum panel thickness and a minimum recommended ratio of span-to-thickness. The composite plate was marked and cut into preliminary specimens measuring 70 mm × 19 mm using a bandsaw. The edges were then finished using a belt sander to achieve the final width of 12.7 mm. A total of 44 specimens were extracted from the fabricated panel.

### 2.2.4 Exposure to Ethylene Glycol

To evaluate the effects of chemical exposure, specimens were immersed in ethylene glycol (EG) solutions of varying concentrations for different durations. Prior to immersion, all specimens were dried in a vacuum oven at 80°C for 24 hours to remove residual moisture. After drying, specimens were allowed to cool for 10 minutes at room temperature and were then weighed to obtain baseline masses.

Three EG concentrations were used in the exposure experiments: 100%, 75%, and 50% by volume. The 75% solution was prepared by mixing 37.5 mL of EG with 12.5 mL of distilled water, and the 50% solution consisted of 25 mL EG and 25 mL water. These concentrations were selected based on guidelines from the U.S. Federal Aviation Administration (FAA) for aircraft deicing fluids and reflect realistic field scenarios. Each specimen was fully submerged in a 50 mL solution contained in a sealed vessel. The vessels were then placed into a heated water bath maintained at 50°C, which served to accelerate diffusion and simulate long-term chemical aging within a compressed timeframe. Representative images of submerged specimens are shown in Figure 1.

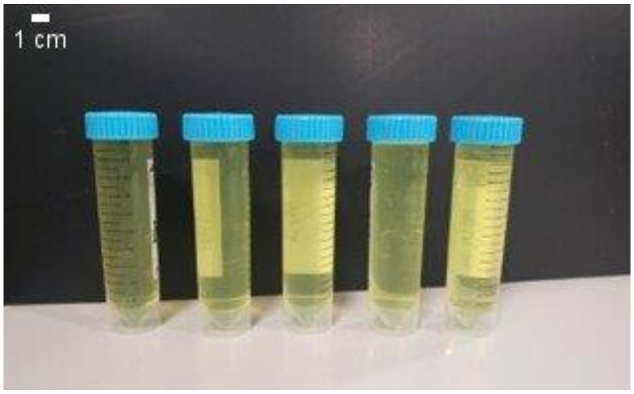

**Figure 1:** Representative image of E/glass composite specimens exposed in the EG solution

### 2.2.5 Mechanical Testing

Following chemical exposure, specimens were gently surface-dried using lint-free paper towels to remove any residual ethylene glycol. Each specimen was then re-weighed to monitor any mass changes prior to mechanical testing.

Flexural properties were evaluated using a three-point bending test in accordance with ASTM D790. Testing was performed using an Instron 5969 universal testing machine equipped with a 50 kN load cell (Model 2580-50kN). The flexural fixture used was an Instron 2810-400, designed to accommodate varying specimen geometries. The span length for each specimen was individually adjusted based on its measured thickness, following ASTM D790 guidelines, to ensure accurate calculation of flexural stress and modulus. All tests were conducted at a constant crosshead speed of 1 mm/min under ambient laboratory conditions.

Five replicate specimens were tested for each exposure condition. The resulting force–displacement data were used to compute average values of flexural strength and flexural modulus, which were then used to assess the degradation in mechanical performance due to EG exposure.

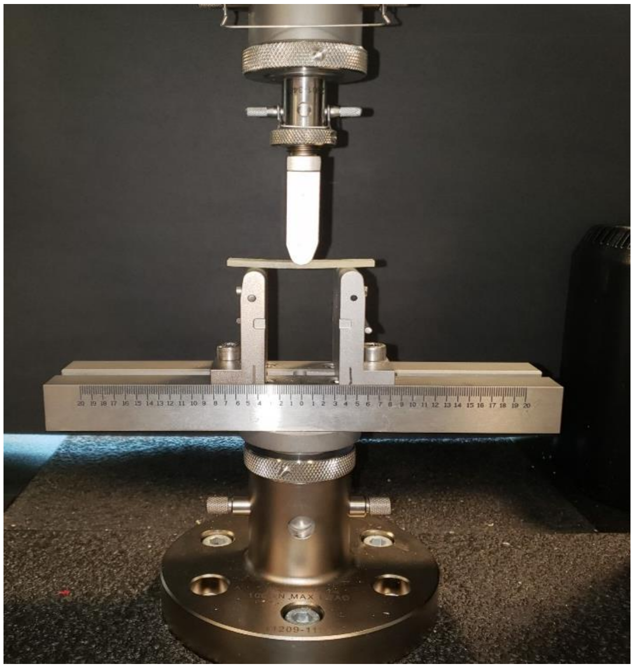

**Figure 2:** 3-point bend testing apparatus used for flexural characterization of the composite specimens

## 3 Results

### 3.1 Visual Changes

Figure 3 displays representative images of three composite specimens: an unexposed baseline sample, a sample exposed to 100% ethylene glycol (EG) for 4 days, and another exposed to 100% EG for 15 days. Across all exposure durations and concentrations, the most noticeable change in appearance was a slight yellow discoloration of the composite surface.

This yellowing effect became more pronounced with increased exposure time but was uniform across the specimen surface, suggesting superficial staining rather than chemical degradation of the composite constituents. The color change is likely attributed to the inherent tint of the ethylene glycol used in this study, which exhibited a yellow hue. No evidence of surface cracking, blistering, fiber delamination, or resin leaching was observed during visual inspection, indicating that the exposure conditions did not induce macroscopic physical damage or structural disintegration in the visible layers of the material.

Although subtle, these color changes may have implications for applications where aesthetic appearance or UV sensitivity is critical. However, visual inspection alone is insufficient to assess internal structural changes, necessitating mechanical testing to quantify performance degradation.

**Figure 3: Tested E-Glass/Epoxy Composites Samples: Baseline (Bottom), 4 days (Middle), and 15 days (Top).**

## 3.2 Absorption of Ethylene Glycol into Composite Samples

Ethylene glycol (EG) absorption into the composite samples was assessed by monitoring percent mass gain following exposure to 100% EG at 50°C over time. An overall increase in mass was observed with increasing exposure duration, indicating fluid uptake by the composite. After 1 day of exposure, specimens exhibited a mass gain of 0.60%, which increased to 0.84% after 15 days (Figure 4). Although the average mass gain at 96 hours was slightly lower than at 48 hours, the data generally followed a trend of increasing absorption with longer exposure.

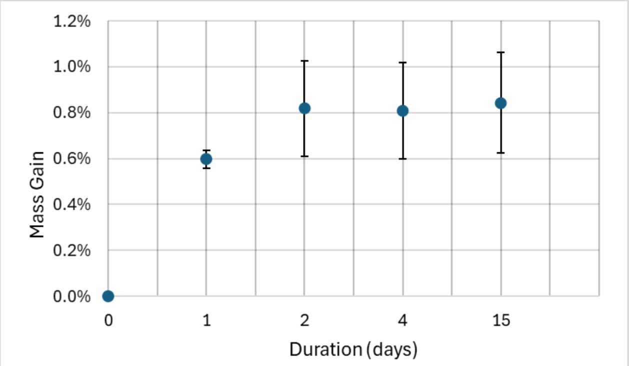

**Figure 4: Mass Gain of the Composite Samples as a Function of Exposure Duration**

Mass gain was also evaluated across different EG concentrations (100%, 75%, and 50%) after a fixed 24-hour exposure at 50°C. Interestingly, a higher percentage of mass gain was recorded as the water content in the solution increased. The 50% EG solution resulted in a mass gain of 0.77%, compared to 0.60% for the 100% EG solution (Figure 5). This observation may be attributed to the smaller molecular size and higher diffusivity of water compared to EG, allowing more rapid penetration into the polymer network.

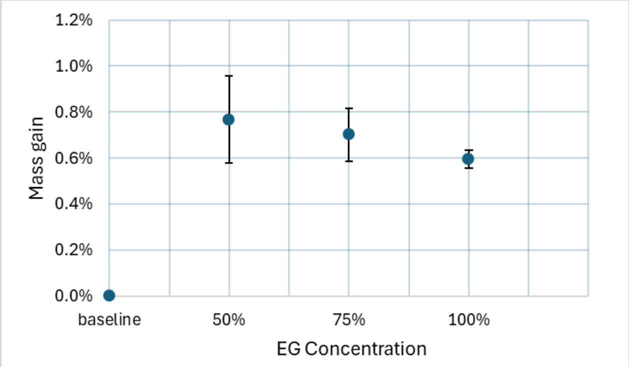

**Figure 5: Mass Gain of the Composite Samples as a Function of EG Exposure Concentration**

Similar trends have been reported in studies on moisture absorption in polymer composites. For example, Guloglu et al. (2020) observed progressive mass gain in carbon/epoxy composites subjected to distilled water at 40°C, with a 1.2% increase after 30 days. Liu et al. (2012) also noted Arrhenius-type behavior for water uptake in carbon/epoxy composites over 13.8°C to 30.6°C, with saturation levels varying by fiber orientation. However, studies specifically investigating ethylene glycol absorption in cured glass/epoxy composites remain limited. To the best of the authors' knowledge, no published results currently quantify the percent mass gain from EG exposure under the same conditions used in this study

## 3.3 Effect of EG Exposure Duration on Flexural Properties

The influence of ethylene glycol (EG) exposure duration on the flexural performance of glass/epoxy composite specimens was systematically evaluated through three-point bending tests. Figure 6 presents representative stress–strain curves comparing the mechanical behavior of unexposed specimens (baseline) to those exposed to 100% EG for 4 and 15 days. Baseline samples exhibited typical linear elastic behavior followed by gradual yielding, while specimens exposed to EG showed reduced peak stress and stiffness. The reduction in the slope of the elastic region for exposed samples is consistent with matrix plasticization and interfacial degradation due to EG uptake.

Quantitative analysis of flexural strength revealed a marked reduction following EG exposure. The average flexural strength for unexposed specimens was 185.67 MPa (standard deviation: 18.93 MPa). After 1 day of exposure to 100% EG, strength dropped to 143.17 MPa, corresponding to a 22.89% decrease. Interestingly, a slight increase in strength was observed after 2 and 4 days, possibly due to post-curing effects from the elevated temperature exposure.

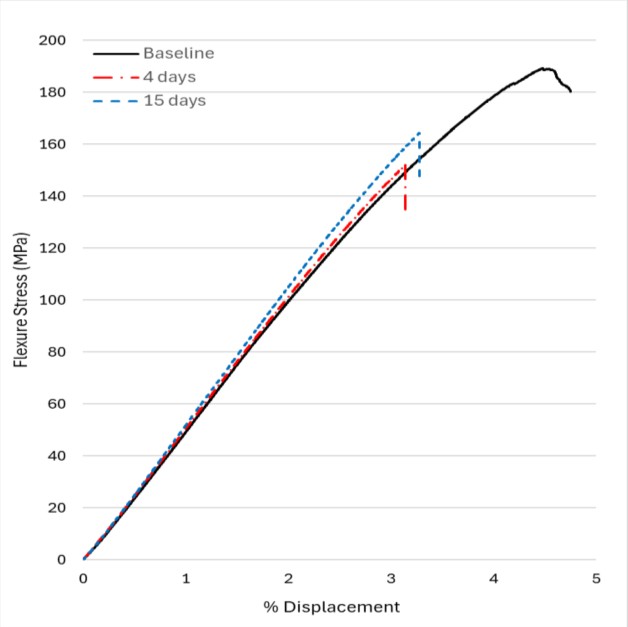

**Figure 6: Representative Flexural Stress-Strain curves for Composite Specimens exposed to 100% concentration EG for 4 and 15 days compared to the unexposed baseline.**

Additionally, this temporary improvement may be attributed to potential chemical interactions between EG and the epoxy matrix. EG, being a diol, can interact with the epoxy network, potentially leading to secondary cross-linking or plasticization effects that temporarily enhance mechanical properties. However, extended exposure led to continued degradation, with strength at 161.45 MPa after 15 days, representing a 13% reduction from baseline (Figure 7). This non-monotonic trend may reflect competing mechanisms of chemical degradation and thermally driven matrix reorganization.

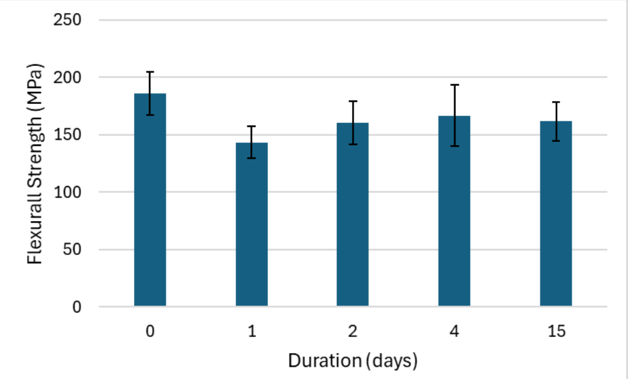

**Figure 7: Effect of EG Exposure Duration on Flexural Strength**

Flexural stiffness followed a similar but more complex trend (Figure 8). The baseline average stiffness was 5.47 GPa with a standard deviation of 0.113 GPa. After 1 day of exposure, stiffness dropped by 5.91% to 5.14 GPa. The highest stiffness, 5.69 GPa, was recorded after 4 days of exposure, representing a 4.2% increase from baseline. This temporary improvement may also be attributed to additional resin cross-linking induced by prolonged thermal exposure or interactions between EG and the epoxy matrix. Beyond 4 days, stiffness values again began to decrease, likely due to plasticization and fiber–matrix interface deterioration caused by continued EG absorption.

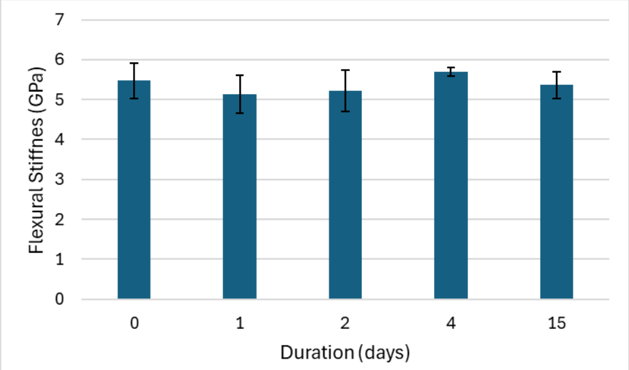

**Figure 8: Effect of exposure time on flexural stiffness**

A comprehensive literature review indicates that while several studies have investigated the effects of various environmental exposures on epoxy composites, specific data on time-dependent flexural strength and stiffness degradation due to EG exposure in glass/epoxy composites are limited. For instance, Coppola et al. (2018) evaluated the mechanical properties of epoxy composites exposed to a 50% EG solution at 95°C for two weeks, observing a 15–20% reduction in tensile strength of epoxy composites immersed in coolant-like glycol environments after 30 days at 80°C. However, detailed time-dependent analyses, especially at varying exposure durations and concentrations, remain scarce. Therefore, the findings presented in this study contribute valuable insights into the temporal evolution of mechanical properties in glass/epoxy composites subjected to EG exposure.

## 3.4 Effect of EG Concentration on Flexural Properties

The mechanical properties of the composite specimens exposed to varying concentrations of ethylene glycol (EG) for 24 hours were investigated using three-point bending tests following ASTM D790 guidelines. These tests were performed to evaluate the effect of chemical concentration on the composite's flexural response, which is critical for load-bearing applications in chemically aggressive environments. The representative stress-strain curves for specimens exposed to 50% and 100% EG concentrations are shown in Figure 9, capturing changes in deformation behavior across different levels of chemical exposure. Corresponding results for flexural strength and flexural stiffness are provided in Figures 10 and 11, respectively. These figures help to highlight not only the average mechanical response but also how changes in EG concentration can influence the composite's structural integrity after short-term immersion at elevated temperature.

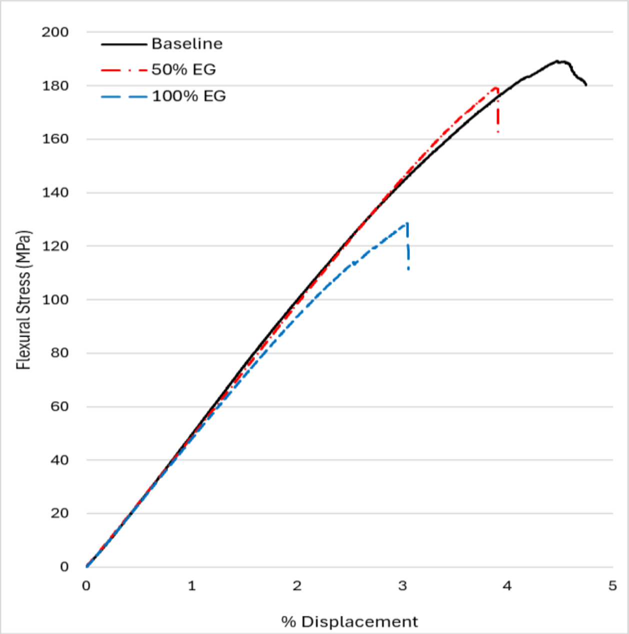

**Figure 9: Representative Flexural Stress-Strain Curves for Composite Specimens Exposed to different concentration of EG for 24 hours at 50C compared to the unexposed baseline.**

Exposure to increasing concentrations of EG demonstrated a clear trend in mechanical degradation. After 24 hours of exposure to 100% EG, the average flexural strength was measured at 143.17 MPa, representing a 22.89% decrease from the unexposed baseline of 185.67 MPa. At 75% EG concentration, the average flexural strength was 169.01 MPa, reflecting an 8.97% reduction. At 50% EG concentration, the flexural strength was 182.80 MPa, corresponding to a minimal decrease of 1.54%. This trend indicates that higher EG concentrations lead to more pronounced deterioration in flexural strength.

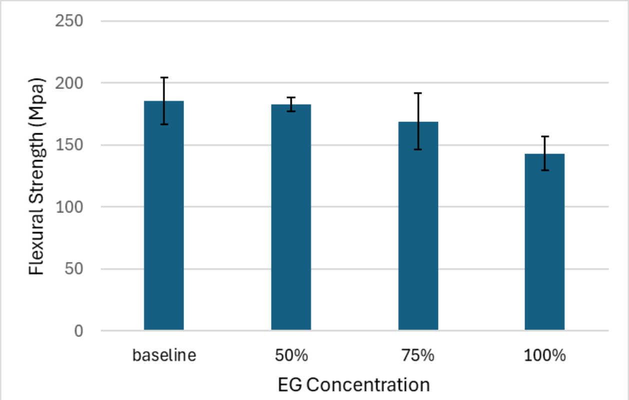

**Figure 10: Effect of EG Concentration on Flexural Strength**

Flexural stiffness followed a similar concentration-dependent trend. The baseline stiffness of 5.47 GPa decreased to 5.14 GPa after exposure to 100% EG, marking a 6.07% reduction. At 75% EG concentration, the stiffness measured 5.41 GPa, a 1.13% decrease. Interestingly, specimens exposed to 50% EG showed a slight increase in stiffness to 5.57 GPa (1.87% higher than baseline), potentially due to post-curing effects or moisture-induced swelling.

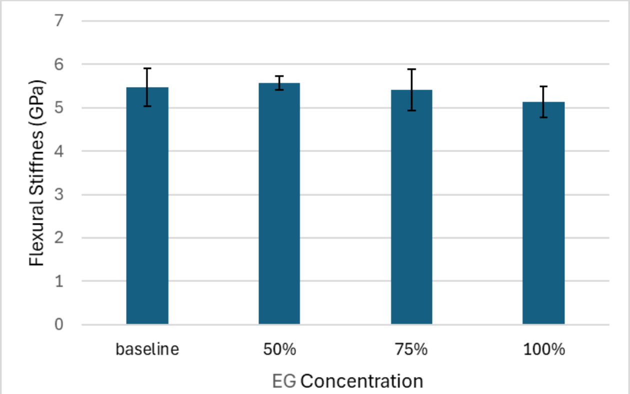

**Figure 11: Effect of EG Concentration on Flexural Stiffness**

These findings are consistent with general literature trends showing degradation in composite mechanical performance following chemical exposure. For instance, Subramaniam et al. (1993) reported a 20% decrease in shear strength of glass fiber-reinforced polyester composites after 7 days of EG exposure at room temperature. While that study did not vary concentration, the magnitude of degradation at full-strength EG aligns well with our findings. Coppola et al. (2021) evaluated epoxy–amine coatings and found similar trends of mechanical degradation when exposed to deicing agents, including EG.

## 4 Conclusion

This study investigated the effects of ethylene glycol (EG) exposure on the mechanical performance of glass fiber-reinforced epoxy composites, focusing on both exposure duration and concentration. Three-point bending tests were conducted after exposing specimens to 50%, 75%, and 100% EG concentrations at 50°C for varying durations, simulating accelerated environmental aging relevant to aerospace and other industrial applications where EG-based deicing fluids are frequently used.

The results demonstrated that both longer exposure durations and higher EG concentrations generally led to greater degradation in mechanical properties. After only 24 hours of exposure to 100% EG, the average flexural strength decreased by 22.89%, while stiffness declined by 5.91%. A modest recovery in mechanical performance was observed after 2 to 4 days, potentially due to post-curing effects or chemical interactions between EG and the epoxy matrix. Nevertheless, prolonged exposure resulted in continued mechanical deterioration. When EG concentration was varied, similar trends were observed: flexural strength decreased from baseline levels by 1.54% for 50% EG, 8.97% for 75% EG, and 22.89% for 100% EG. Interestingly, stiffness slightly increased in the 50% EG condition, possibly due to moisture uptake effects.

Absorption data showed that mass gain increased as EG concentration decreased, with specimens in 50% EG gaining 0.77% in mass compared to 0.60% for 100% EG. This inverse relationship may be attributed to the smaller molecular size and higher diffusivity of water compared to EG, allowing greater permeation at lower EG concentrations.

Despite the reductions in strength and stiffness, the composite specimens retained a significant portion of their mechanical integrity. These findings confirm that while glass/epoxy composites are generally robust, their performance can be compromised under prolonged chemical exposure. This highlights the need for additional research into protective coatings, resin modifications, or barrier layers to enhance resistance to EG and similar agents. Moreover, further microstructural and thermomechanical analyses are recommended to fully elucidate the degradation mechanisms involved.

Overall, the study underscores the importance of accounting for chemical exposure in the design and application of fiber-reinforced composites, especially in sectors such as aerospace, automotive, and civil infrastructure, where contact with ethylene glycol is likely. Understanding and mitigating these effects will be critical to ensuring the long-term reliability of composite structures in chemically aggressive environments.

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## Conflict of Interest:

The authors declare no conflict of interest.

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