# The Effect of Acidic Environment on Bending Behaviour of Glass-Carbon/Epoxy Based Hybrid Composites

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**Abstract**

In this study, the effect of an acidic environment on the bending properties of hybrid composites was investigated. Instead of conventional glass fibre/epoxy and carbon fibre/epoxy polymer composite materials, glass-carbon fibre reinforced epoxy polymer (GCFREP) hybrid composite materials against the low strength of glass fibre and high cost of carbon fibre have been used. Sulfuric acid ($H_2SO_4$) - nitric acid ($HNO_3$) combination has been formed to simulate an acid rain environment. Synthetic acidic solutions of $H_2SO_4$ - $HNO_3$ at pH values of 1.0, 2.0, and 3.0 at -10, 25, and 40 °C have been prepared. GCFREP hybrid composite materials have been immersed in these solutions periodically for one day and 1-3-6-9-12 weeks. Samples of GCFREP hybrid composite materials that complete the exposure to acidic media within specified periods have been subjected to three-point bending tests.

As a result of the research, it has been observed that the bending properties of GCFREP hybrid composites change significantly as the acidity of the environment and ambient temperature values increases. These changes have become more evident with prolonged exposure durations.

***Keywords:*** Hybrid composites, acidic environment, bending behaviour, mechanical properties

## Introduction

Composite materials are used in many fields and applications to meet many needs that come to the fore today. The main reasons these materials become an alternative to traditional materials are their high strength, rigidity, lightness, and design tendency [1]. Despite the positive developments in the field of materials, the vital need for lighter and cheaper new materials with improved strength values has led to research on “hybridisation”. Hybrid composites, which contain more than one fibre type in the same structure, have become alternatives that can serve these needs to collect many desired properties in a single material and achieve a better balance. Research on hybrid fibre composites began in the seventies after Hayashi [2] revealed that the fracture strains of carbon fibre layers in the carbon/glass hybrid composite were 40% higher than in the reference carbon fibre composite material. Many researchers have contributed to the understanding and modelling of the subject by working on the hybrid effect [3–5]. The main mechanisms responsible for the hybrid effect include residual thermal stresses [6,7] due to differences in thermal expansion of different fibres. In addition, it has been commented that the formation of fibre fracture clusters [8–10] and dynamic stress concentrations [11] cause changes in damage development and may also be effective in this mechanism. Swolf et al. [12] indicated that the hybrid effect is well defined but not yet fully understood. Studies to explain the primary mechanism of the hybrid impact are limited and fall short of explaining the complex interaction.

In this study, synthetic acid rain exposure environments with pH 1.0, 2.0, and 3.0 were set up by combining $H_2SO_4$ and $HNO_3$ acids, and GCFREP hybrid composites produced using the vacuum-assisted resin transfer moulding (VARTM) technique were exposed to these acidic environments for varying durations from 1 day to 12 weeks. Flexural strength, flexural strain, and flexural modulus properties of the specimens whose exposure process was completed were determined by performing three-point bending tests.

## Material Production and Acidic Environment Preparation

The fabrics of composite material examined in this study are E-glass (plane, woven - 300 g/m$^2$) and carbon (plane, woven - 245 g/m$^2$) fibre fabrics, which are frequently used as reinforcement materials in industrial and academic studies [13–15]. Also, Araldite 1564 epoxy resin as matrix material (density: 1.1 g/cm$^3$, viscosity: 1200–1400 MPa·s, epoxy index (ISO 3001): 5.8–6.05 Eq/kg, epoxy equivalent:

170 g/equivalent) [16–18] and Aradur 3487 hardener was used as the curing material. A hybrid composite material sequence was selected as the symmetric $[G_2C]_s$ sequence, and the VARTM process was used to produce the composite material. Figure 1 illustrates the carbon and E-glass fibres in hybrid composite plates with $[G_2C]_s$ layer arrangement, and Figure 2 represents the production process of GCFREP hybrid composite plate using the VARTM technique.

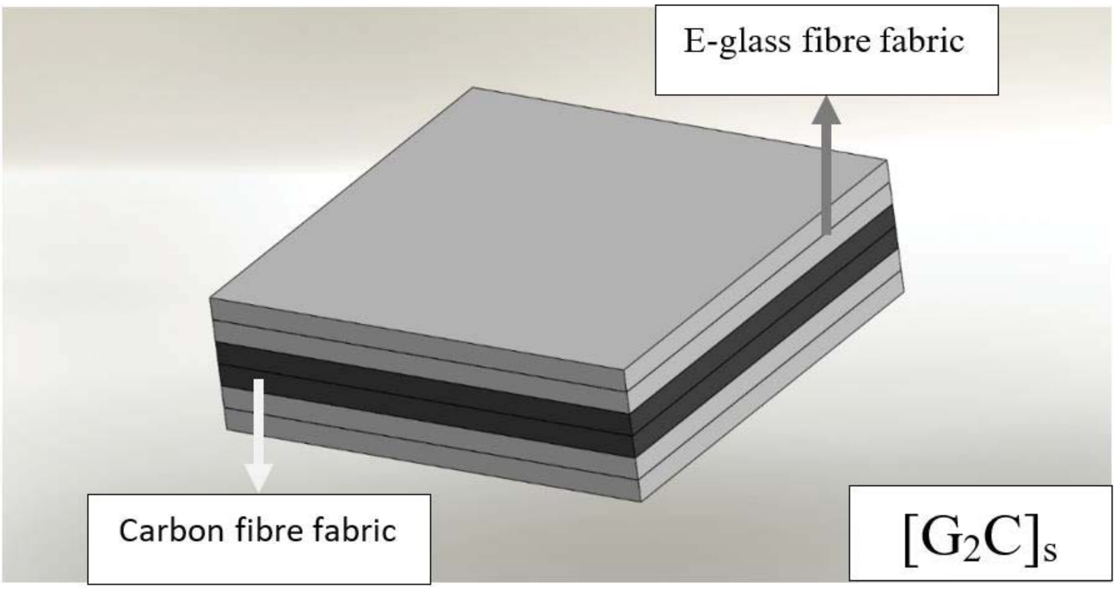



Figure 1. Schematic representation of carbon and E-glass fibres in hybrid composite plates with $[G_2C]_s$ layer arrangement

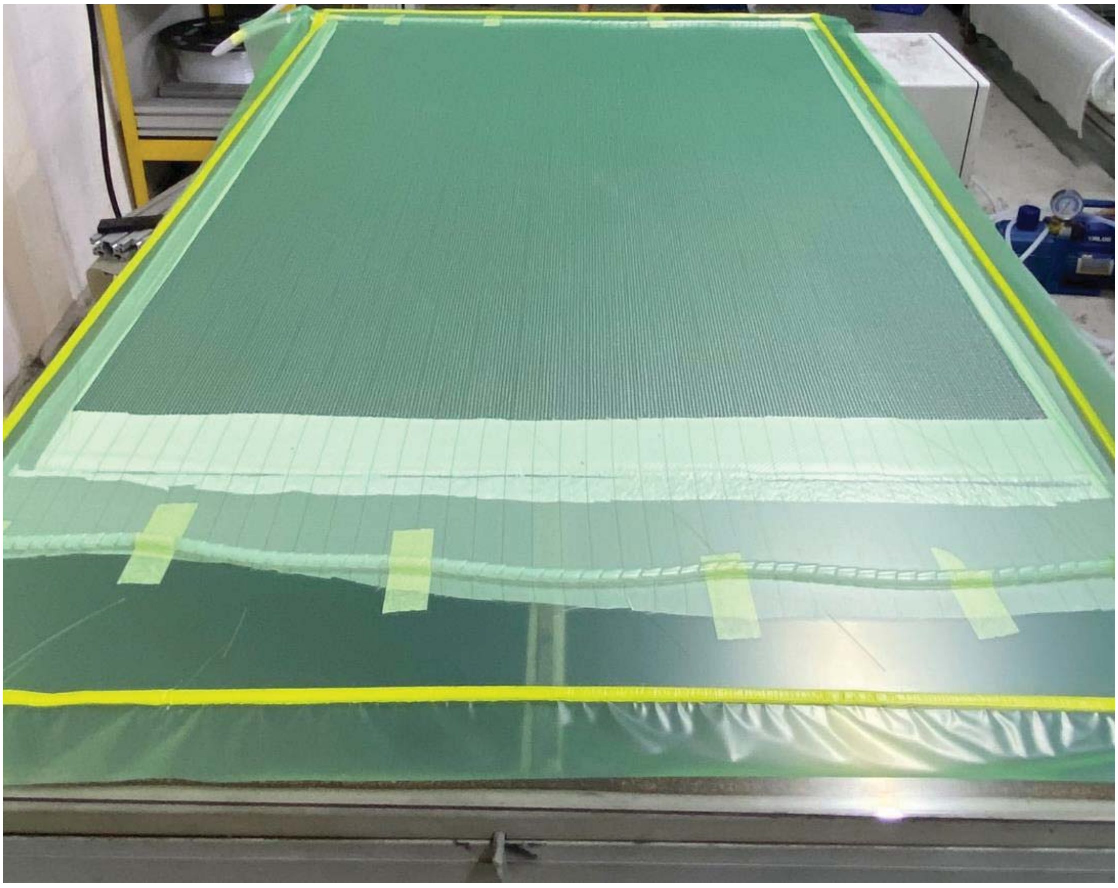


Figure 2. Production process of GCFREP hybrid composite plate using VARTM technique

The acids used in this study are sulfuric acid ($H_2SO_4$) and nitric acid ($HNO_3$). The combination of these acids is chosen because they are the most common acid types in acid mine lakes and acid rains [19–21]. Nitrogen oxides ($NO_X$) are one of the chemicals that play an active role in the formation of acid rain. A large percentage of $NO_X$ in the atmosphere comes from vehicle exhaust and industrial plants. The nitrous oxide ($N_2O$), nitrogen dioxide ($NO_2$), and nitrous oxide (NO) gases released into the atmosphere with the use of fossil fuels cause chain reactions that result in the formation of $HNO_3$ with the natural gas cycle in the atmosphere. Another gas involved in the formation of acid rain is sulfur dioxide ($SO_2$). $SO_2$, formed from fossil fuels such as coal for energy production, forms $H_2SO_4$, a strong acid when combined with water vapour in the atmosphere [22]. The combination of $H_2SO_4$ and $HNO_3$, the main components of acid rain, has been simulated in an artificial acidic environment with different pH values and temperatures [23,24]. The pH values of the acid were chosen as 1.0, 2.0 and 3.0 to examine the effect of high acidity. Figure 3 outlines the experimental parameters employed in this study.

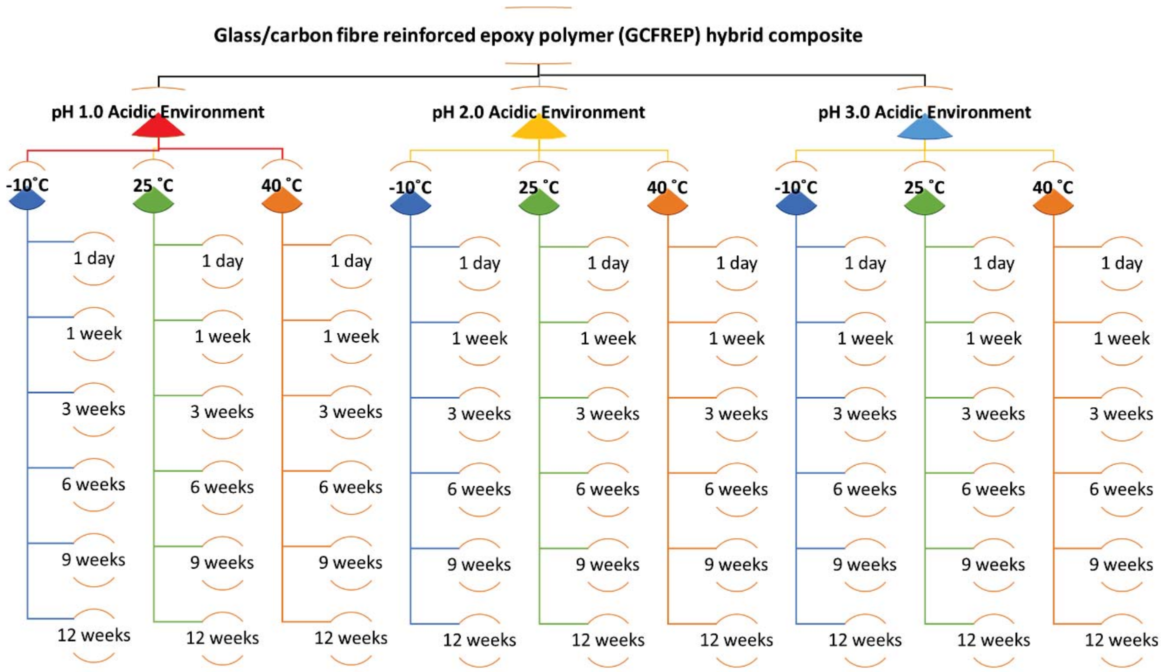


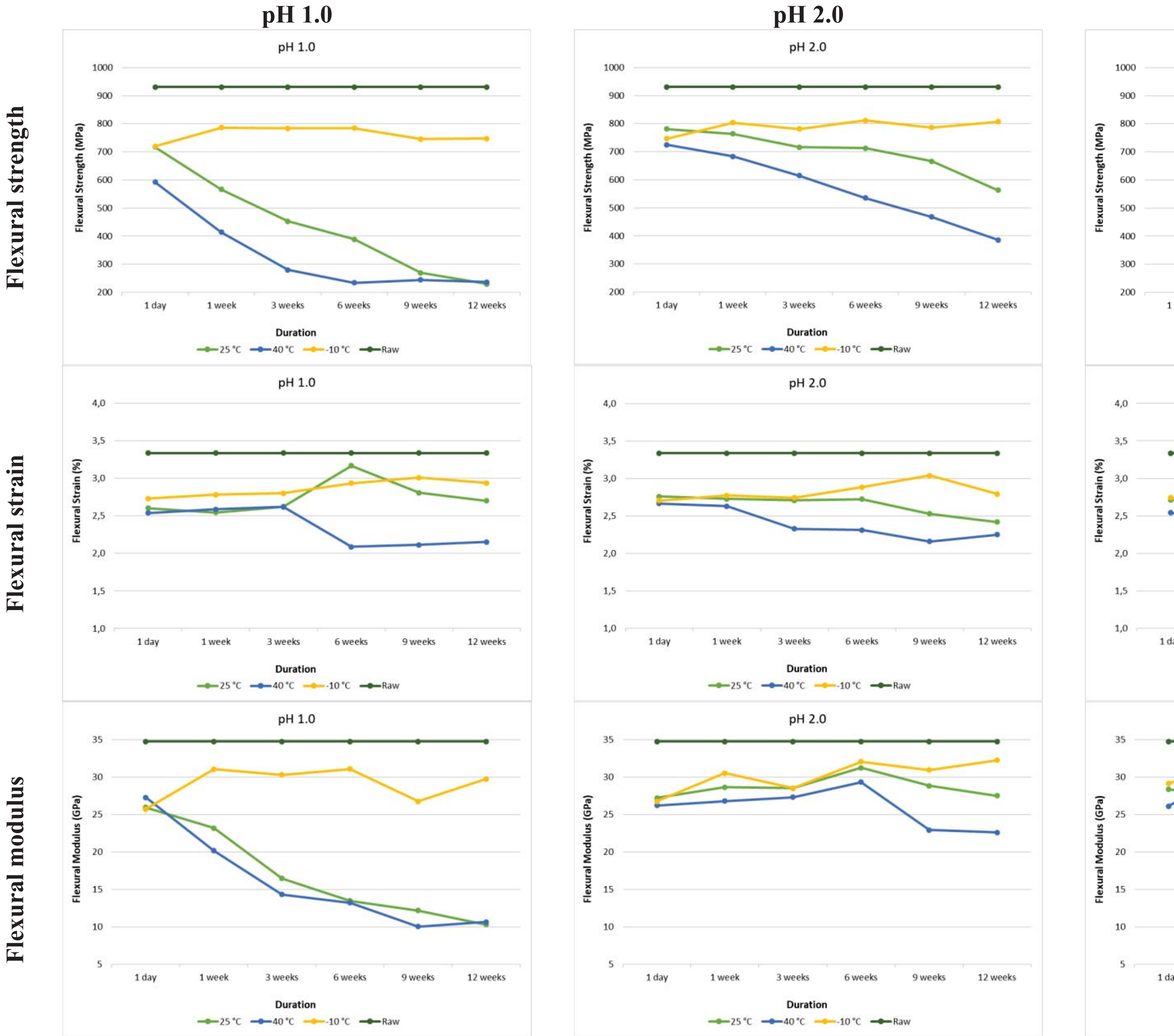

Figure 3. Experimental parameters of the study

## Results and Discussion

The flexural strength, modulus, and strain properties of GCFREP hybrid composites kept in pH 1.0, 2.0 and 3.0 acidic environments for one day to 12 weeks were determined by performing three-point bending tests by ASTM D7264 - Flexural properties of composites standard [25]. Three-point bending tests were performed at room temperature at 1 mm/min speed using a Shimadzu 100 kN capacity instrument. Flexural properties of the specimens are given in Figure 4.

The flexural strength of the samples kept in 40 and 25 °C exposure environments decreased as the duration increased. No significant change was observed in the flexural strength of the samples kept in a -10 °C exposure environment. The lowest flexural strength was observed in the samples kept at 40 and 25 °C for 12 weeks. The decreases in the flexural strength of the samples immersed in the pH 1.0 acidic environment for 12 weeks at 25 and 40 °C were approximately 74% compared to the raw samples, while 19% in the samples kept at -10 °C.

Irrespective of the temperature, keeping the hybrid composites in an acidic environment decreased the flexural strain and flexural modulus compared to the raw samples. The maximum decreases in the flexural strain were seen in the specimens which were kept in the pH 1.0 and 3.0 acidic environments at 40 °C. The lowest flexural modulus among the specimens was observed in the samples kept in a pH 1.0 acidic environment at 25 and 40 °C for 12 weeks.




(a) (b)

Figure 4. Flexural strength, flexural strain, flexural modulus of GCFREP hybrid composites for (a) pH 1.0, (b) p

## Conclusion

The results of this study, which examined the changes in flexural properties of GCFREP hybrid composite material kept in a pH 1.0, 2.0, and 3.0 acidic environment for varying periods from 1 day to 12 weeks, are as follows:

* Compared to the raw sample, it was observed that the flexural strength, flexural strain, and flexural modulus of all samples decreased due to the acidic environment.

* Exposure to the acidic environment caused a lowering effect on the flexural strengths of all samples kept at -10, 25, and 40 °C, and those that were kept at 40 and 25 °C at most. As the exposure time increased, the flexural strength decreased and reached its lowest level at the end of 12 weeks.

* The lowest flexural modulus was observed in the specimens which were kept in a pH 1.0 acidic environment at 25 and 40 °C, and the lowest level was seen at the end of 12 weeks.

* There was no significant change in the flexural strength, elongation, and modulus of the samples kept at -10 °C.

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