Environmental effects on the mechanical properties of E-glass and S-glass fiber epoxy composite ring specimens used in aircraft fuel pipes

Sujith BOBBA*,[1], Z. LEMAN[2], B. HARISH BABU[1]

*Corresponding author
[1]Department of Automobile Engineering,
Vignan's Foundation for Science, Technology & Research (VFSTR),
Guntur, AP, India,
sujith.bobba@mail.com*
[2]Advanced Engineering Materials and Composites Research Centre (AEMC),
Universiti Putra Malaysia, 43400 Serdang, Malaysia,
zleman@upm.edu.my

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Abstract: *An experimental investigation was performed in predicting the consequences of the exposure to seawater and moisture absorption on the mechanical properties of two different GFRE pipe rings made of E-glass and S-glass fiber and utilized in aircraft fuel pipe line system. Filament winded tubular composite pipe rings were immersed in seawater for two, four and six months, respectively and their moisture absorption was noted. The outcomes exhibit a remarkable decrease in fatigue life for saturated GFRE sample rings. In contrast, a water absorption up to 40% of the maximum content exhibited no impact. The tests revealed debonding and cracks in the fiber and matrix interphase in the case of samples immersed in seawater on a long-term basis, although the applied mechanical load was zero.*

Key Words: *moisture absorption, aircraft fuel pipe, E-glass, S-glass, fatigue life, GFRE sample rings*

1. INTRODUCTION

The composite fuel pipes used in aircrafts seriously compromises the high safety requirement. Though much research has been made, the problem has not been solved yet. The glass fiber composite materials used in aircraft systems have extreme properties when compared with traditional materials; among them, superior corrosion resistance, high strength to weight ratio, and the tendency to fabricate the material system for a given particular requirement. The present research aims to predict the moisture absorption of glass fiber reinforced epoxy composites at two different temperatures, and decide by which method the mechanical multi-axial properties are attained and finally establish an association between moisture absorption, time period, and mechanical behavior of the composite pipe rings. Failure analysis of pipes fabricated with glass reinforced plastic with an exterior crack by the influence of static internal pressure was analyzed by Arikan et al. [1]. He concluded that the crack propagation was found in Mode II and also concluded that the mixed mode must be determined in order to study the failure of pipe with crack. Sookay et al. [2] studied the resilience of glass fiber laminates following various humid and dry weather. The tensile strength due to tension was noticed to fall with the rise in the disclosure period. Abdel Magidet et al. [3] examined the angular creep and tensile behavior of E-glass epoxy composite laminates at a given room temperature. Both creep and tensile strengths are reduced with the rise in temperature. Ellyin and Rohrbacher [4] investigated the environmental resilience of E-glass epoxy composite laminates after immersing in distilled water at normal and inflated temperatures by conducting tensile tests. The test results show that E-glass epoxy composites submerged in distilled water at ambient temperature had inconsequential results of the tensile properties of the composite. However, the strength and ductility decreased as a result of immersion in water at higher temperatures. The expeditious research and growth in the field of GFRP manufacturing promote the realization of the properties that change in the material for different environmental conditions in order to certify for their long-term durability. Hence, the current product requires various investigations to establish sustainability in various hygrothermal conditions by comparing aged and dry samples. Moreover, the polymeric matrix material is often plasticized, swelled, and alleviated when subjected to a hygrothermal environment. The primary deterioration of polymeric resin showed weak bonding between the fiber-resin bonds [5, 6]. Ellyin [7] examined the mechanical permanence of the E-glass epoxy laminate following submersion in distilled water at various temperatures and also constraints for dry condition treatments for about two years. Amid the above-described conditions, the samples are disclosed to cycles of wet and dry conditions at elevated temperatures of the E-glass epoxy laminate. Usually, the water absorption by the matrix results from capillarity action along with the fiber matrix interface, some cracks, voids detected in the resin. Various diffusion models have been predicted over the years to model the hygrothermal outcomes in fiber-reinforced polymer pipes. The first diffusion model has been declared by Fick, by the analogy of the heat conduction model. Many investigators entirely depend on Fick's second law to predict out moisture absorption [8, 9]. According to another research work performed by Merah et al. [10] subjection of the salted sea, water submersion exhibited deleterious consequences after a time period of 300 hours of subjection and also found out that high exterior temperature and moisture engagement reduced the fiber and matrix interlinkage strength which finally results in reducing fracture strain, ultimate strength, and stiffness of the GFRE samples. A study on the consequences due to moisture absorption and elevated temperature subjection on the mechanical parameters of glass fiber reinforced epoxy composite tubes was performed by Ellyin F and Maser R [11], wherein the research findings it was concluded that strains produced in the fibers caused leakage failure which in turns showed little deflection in the existence of temperature and moisture with the irregularity in the hoop tensile loading. In the current research conducted, the consequences of both natural open weather and natural seawater on hoop tensile behavior of GFRE pipe rings are estimated for uncovering periods of 2 to 6 months under normal environmental conditions.

2. EXPERIMENTAL PROCEDURE

2.1 Materials and Testing Procedures

The composites used in the study were E-glass epoxy and S-glass epoxy composites which were manufactured by a resident company and the composite pipes were made by filament winding process, as shown in Figure-1, having dimensions of 100 mm inner diameter, 1.75 mm thickness, and 5 m in length, as shown in Figure-2.

It has a 6-plies structure with the fibers wound at an angle of 55^0, because the proposed winding angle exhibits optimal mechanical properties to gain hoop and axial strength to the hand layup composite pipes.

Epoxy resin was utilized as a matrix material with a hardener to fabricate the sample composite pipes. The properties of the glass fibers are shown in Table 1 below.

Table 1: Mechanical properties of glass fibers (as provided by the manufacturers) [12]

Data provided by the manufacturer	E-glass	S-glass
Thickness of the glass fiber in GSM	900	630
Tensile strength, MPa	2000	2000
Density, g/cm^3	2.55	2.43
Ultimate strain, %	4.5	3.2

Figure 1: Fabrication process of the GFRE composite pipes and pipe rings

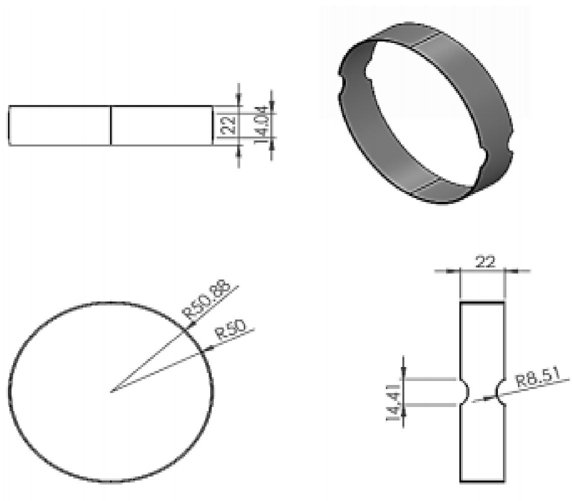

Figure 2: Dimensional measurements of the specimens used in the tests

2.2 Moisture Absorption

Water absorption specimen rings was immersed as per ASTM D 570 [13] and submerged in seawater at room temperature (23ºC) for 2, 4 and 6 months, respectively as shown in Figure-3. The water absorption proportion was determined by using eq. [1]. A graph of the moisture intake percentage versus time in hours was plotted and the diffusion coefficient (m^2/sec) was formulated using

$$\text{Seawater absorption}(\%)= \frac{\text{Ultimate weight after immersion-intial weight before immersion}}{\text{Total weight before immersion}} \quad (1)$$

$$\text{Diffusion coefficient } (m^2/\text{sec}) = \pi x \left(\frac{B}{4Ms}\right)^2 x\ (\text{Slope})^2 \quad (2)$$

Figure 3: Submersion of E-glass and S-glass fiber reinforced epoxy rings under artificial seawater

2.3 Mechanical Testing

The hoop tensile strength and modulus of elasticity of water submerged E-glass and S-glass composite pipe rings were determined according to the ASTM D2290 standard [14]. The tests were performed with a head speed of 2.3 mm/min on a UTM and with the help of a 26 kN load cell as represented in Figure-4. Five samples of both E-glass and S-glass fabricated pipe rings were tested on the UTM. The tensile strength and modulus of elasticity of the composites before and after water immersion were evaluated following ASTM D 2290. Five specimens were tested at room temperature for each configuration, with the same parameters previously described for the tests.

Figure 4: Split disk test setup according to ASTM D2290 on the UTM machine

3. RESULTS AND DISCUSSIONS

Once the composite is submerged in the liquid medium and sustained at room temperature for different months (2, 4, 6 months), the matrix material in the composite must not get separated from the glass fiber and respond with the liquid. In this context, as shown in the graph, when the number of months of immersion in the water rises, the composite ring samples absorb more water than the dry samples. The specimen rings were maintained at room temperature and specimen rings which were under 6 months under seawater found to absorb 24.13% water higher than 4, 2-month specimen rings during the period of time.

Whereas during the moisture absorption level, 6-month specimen rings had much variation when it comes to the point of E-glass composite pipe when compared to S-glass composite pipe rings.

Similarly, in the case of both 2 and 4 months E-glass and S-glass specimen rings, during the consideration of the absorption of the moisture level during the starting month it was found to be 0.1%, of total weight.

Also, the graph depicts that for room temperature the moisture extent was 0.16%. All the values which were stated were to be for short span of the time period in the case of E-glass specimen rings. This shows that the number of months in the sea water plays a major role in due respect of absorption peaks in all the specimen rings.

Table-2 shows that all the samples have shown good accordance between the theory and data obtained because all the proportionate graphs follow Fick's behavior.

It was detected that at 2 months immersion time in seawater, the samples absorbed only 0.78% and 0.66% of the total weight in the case of E-glass and S-glass with the corresponding diffusion coefficient of 1.2 × 10-6 (m^2/s) and 0.98 × 10-6 (m^2/s); similarly, the 4-month E-glass and S-glass specimens absorbed 1.25% and 1.1% of the total weight with the corresponding diffusion coefficient of 1.543 × 10-6(m^2/s) and 1.253 × 10-6(m^2/s), whereas, finally, in the case of 6-months E-glass and S-glass specimen rings, the rings absorbed 2.1% and 1.85% of the total weight with a diffusion coefficient of 2.01 × 10-6 (m^2/s) and 1.86 × 10-6(m^2/s).

The diffusion coefficient shows much variation, which was fully based on the rise in the time period of submersion in natural seawater.

As the diffusion time increases, it leads to a high weight again on the specimen rings. This shows that the time period of immersion in seawater acted as the utmost factor for all the moisture absorption examinations.

Table 2: Diffusion coefficient values for corresponding time periods (In months)

Specimen	Immersion time (In months)	moisture absorption(%)	Diffusion coefficient (m^2 /s)
E-glass	2	0.78	1.2 × 10-6 (m^2/s)
S-glass	2	0.66	0.98 × 10-6 (m^2/s)
E-glass	4	1.25	1.543 × 10-6(m^2/s)
S-glass	4	1.1	1.253 × 10-6(m^2/s)
E-glass	6	2.1	2.01 × 10-6(m^2/s)
S-glass	6	1.86	1.86 × 10-6(m^2/s)

Moisture absorption of different specimens of E and S-glass composite rings were plotted with the square root of the months as on the x-axis, and different levels of moisture absorption on the y-axis.

The diffusion coefficient was calculated for all the variations of both E-glass and S-glass epoxy composite pipe rings. The diffusion coefficients have an influence on moisture intake into the composite pipe rings.

The natural seawater immersion of composites induced a lower amount of water absorption in S-glass fiber-reinforced composite pipe rings due to their salinity and density, which were superior to E-glass fiber-reinforced composite pipe and can be seen in Table-2.

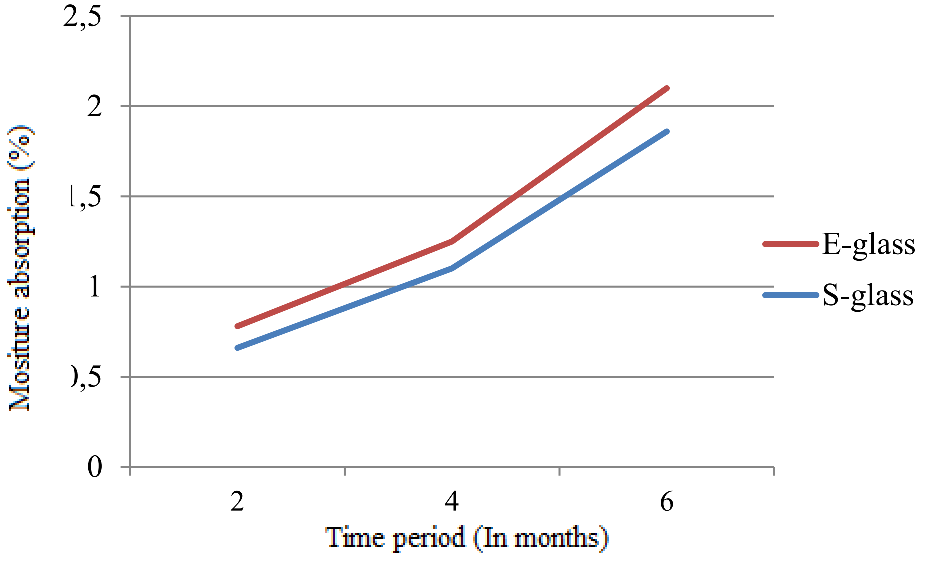

Figure 5: Moisture absorption vs time period between E-glass and S-glass composite pipe rings

From Figure 5, it can be noticed that during the initial period of study for all proportions (samples of E-glass and S-glass), the sample moisture absorption was very high when compared to all the other months.

The values concerning the weight variation in kgs of E-glass and S-glass fiber epoxy reinforced elbow pipe under seawater is represented in Table-3 below.

Table 3: Weight variation in kgs of E-glass and S-glass fiber/epoxy reinforced elbow pipe under sea water in months

Month / Type	0 month	2^{nd}month	4^{th}month	6^{th} month
S-glass	0.152	0.154	0.155	0.156
E-glass	0.226	0.235	0.238	0.239

3.1 Effect of water absorption and diffusion on hoop tensile strength

Normally, all the modern elements require superior and dependable mechanical properties, even ensuing exposure to different time periods and moisture.

This is also relevant for composite pipes, which are commonly known to be implemented under moist environments.

Hence the mechanical properties were studied under natural seawater from dry samples to 2, 4 and 6 months samples.

In the study, the mechanical behavior (hoop strength) was analyzed for different immersion time periods, and it has shown the hoop strength for E-glass epoxy pipe rings as 85.45, 74.45, and 62.1 MPa and that of S-glass epoxy composite pipe rings as 78.2, 65.23, 59.36 MPa of strength for respective proportions with the help of the split disk tests performed according to ASTM D2290 standard.

For both the E-glass and S-glass pipes, an increase in the time period of immersion in seawater caused a decrease in the hoop stress.

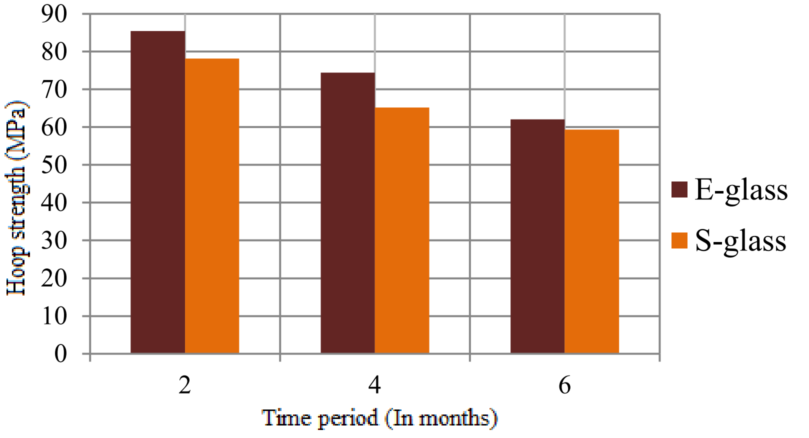

Figure 6: Hoop tensile strength results for different time periods (In months) under natural sea water

The water absorbed partially destroys the contact region. This will be associated with fiber cracking in most samples, as dominant as failure manner/ mode, and finally, when considering the overall view of the study, it shows that when the time (2, 4, 6 months) of immersion increases, the hoop strength decreases in composite pipe rings.

Normally, the tensile strength of fiberglass-reinforced composites was fiber sensitive and the fiber damage in water would damage the flexural and tensile strength [15]. The damage to glass composites by both the matrix element and fiber can also damage the cover between the elements and there will be a loss in bonding strength that will damage every mechanical parameter of the composite fiber [16].

Figure 7: Fractured part of the test specimen after hoop tensile test

4. CONCLUSIONS

Glass fiber reinforced epoxy composite samples are submerged for various periods (in months) till the samples reach their saturation point and then the samples are put through mechanical testing. The substantial drop in hoop tensile strength of glass composites was due to the protuberance of glass matrix in artificial seawater for a given interval of time and the fractured surfaces revealed inner fuel between the reinforcement and matrix after tests. Sample prepared using S-glass fabric demonstrated much developed mechanical properties under seawater conditions when compared to rings fabricated by E-glass fabric for different loading conditions. Consonant outcomes were obtained with a small difference. Tests with S-glass fiber epoxy composite rings showed higher deviation values when compared to E-glass epoxy composite rings.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests in the case of publication of this manuscript.

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