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EFFECT OF HUMIDITY ON THE DIMENSIIONAL STABILITY OF POLYMER COMPOSITE MATERIALS

Zia Ullah Khan[*1], **Abdul Shakoor**[2]

[*1,2]*Departement of Mechanical Engineering University Engineering And Technology(UET) Peshawar Pakistan*

[*1]engrziakhan@uetpeshawar.edu.pk, [2]shakoor@uetpeshawar.edu.pk

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Corresponding Author: *
Zia Ullah Khan

Abstract

This research analyzes the hygrothermal properties of carbon fiber epoxy composites by investigating the effects of temperature (ranging from 10 C° to 50 C°) and high relative humidity (90%) on the dimensional stability over different durations. A full experimental procedure was done on thirty specimens placed in a climate chamber at the specified temperatures and 90% relative humidity for different time intervals up to 432 hours. A baseline of 14.76 mm Average width and 3.19 mm Average thickness was established.

Dimensional changes included width increase at 10 C° (1.63% to 15.00 mm), 20 C° (1.35 % to 14.96 mm), 40 C° (2.03% to 15.06 mm) and 50 C°(0.27% to 14.80 mm), however, thickness slightly change (0.31%) at 10 C° , 20 C, 50 C° and (0.94%) at 40 C° temperatures. While at 30 C°, width increase (0.068% to 14.77 mm) and the thickness remains the same .The temperature and humidity conditions had clear and profound effects on the mechanical properties of composite materials, thus hygrothermal testing should be used to enhance the durability of composites.

I. INTRODUCTION

Composite materials form a significant and expansive category in the realm of engineering materials. The production of composite materials exceeds 10 million tons annually, reflecting their widespread use [1]. Composites find application in various areas because they offer improved stiffness, strength, fatigue resistance, impact resistance, environmental protection (corrosion resistance), and thermal conductivity etc. making them versatile for diverse uses. On the other side, there are some defects in composite materials, either during the manufacturing processes or due to the failure from different stresses. One of the main defects is delamination effect. Delamination is an important reason to failure in fiber-reinforced composites because of Hygrothermal effect. Delamination is indeed a critical issue in fiber-reinforced composites, and it is often exacerbated by hygrothermal effects [2–4]. The research provides a detailed overview of evaluating the effect of hygrothermal conditions on composite materials using a climate chamber. The climate chamber controls both temperature and humidity in a controlled setting. The aim of this study is to conduct comprehensive experimental work to evaluate, before and after exposure to hygrothermal conditions, key material properties such as, moisture absorption, swelling, and dimensional stability. Understanding how variations in temperature and humidity affect the physical properties of composites is crucial for improving performance, durability, and design in practical applications.

Moisture can penetrate the composite structure, weaken the bond between fibers and the matrix, and result in delamination, significantly reducing the material's structural integrity. This has implications for various applications, including aircraft, marine, automotive and structural components, which are exposed to changing environmental conditions [5]. It is crucial to precisely simulate the impact of moisture and temperature on composites to fully understand and unlock their capabilities.

II. LITERATURE REVIEW

Fiber-reinforced composite materials are widely used in structural engineering, particularly for lightweight yet high-strength and stiff structures. Composite laminates have higher specific stiffness and strength than conventional materials, making them desirable for applications ranging from sports equipment to aerospace components [6–8]. It is crucial to understand how hygrothermal environmental factors, such as moisture and temperature, affect their mechanical properties. These factors can degrade composites over time by causing chemical or physical damage to the polymer matrix, weakening the fiber-resin bond, and reducing the strength and stiffness of the fibers. Rafiee et al. (2021) [9] investigated the combined influence of hygrothermal exposure and constant mechanical loading on Hoop tensile strength and moisture absorption of glass fiber/epoxy composite rings by subjecting them to water immersion at 25 °C, 40 °C, and 70 °C for a maximum period of 90 days. Hassan et al. (2021) [10] studied the influence of seawater aging on fracture toughness of stitched glass fiber/epoxy laminates, in particular for marine usage. The research immersed composite test specimens in seawater at 25 °C for 24 and 35 days to mimic degradation in marine environments. J.H. Almeida et al.(2016) [11] conducted research on carbon fiber-reinforced composite with an epoxy filament-wound matrix to investigate how hygrothermal environments affect tensile and compressive properties in plane and inter laminar shear. The specimens were exposed in a chamber at a temperature of
80 C° and 90% relative humidity for a period of 60 days. A. Thuault et al.(2015) [12]conducted research on flax fibers. This study focuses on the mechanical properties of flax fibers and how hygrothermal environments can affect them. The samples were tested in a climate chamber (with a temperature range from −40 C° to 140 C°) at temperature of 25 C° and 85 C°, and 50% relative humidity, and under various aging conditions. Y. Xue et al. (2006) [13] Work on Aspen fibers and polypropylene composites material, referred to as APC, investigates how hygrothermal environments can affect the properties of APCs. The samples were subjected to different temperature and humidity conditions for extended periods, totaling over 7000 hours. The study specifically focused on the impact of two different fiber-loadings under these conditions at a temperature of 40 C°. Dry/Hot and and Dry/Cold with 30% relative humidity and Wet/Hot and Wet/Cold with 82% relative humidity. This study is an attempt to fill these research gaps by investigating the mechanical response of carbon fiber composites under hygrothermal exposure. Past studies have emphasized materials like CFF/PEEK, flax fiber, glass fiber, and PEEK/PPS composites. Nevertheless, this research highlights carbon fiber composites. Research carried out at high temperatures received more attention compared to moderate temperatures applicable to actual applications such as pressure vessels, pipes, and automobile parts. Experiments emphasize long-term exposure and immersion in water, but controlled humidity and shorter exposures, which are closer to actual operating conditions, receive less attention. Experiments usually measure properties such as weight gain and degradation, and mechanical properties like hoop tensile strength etc. but dimensional stability, and moisture absorption are not necessarily researched , particularly under moderate hygrothermal conditions. The provided literature is not ring-shaped sample oriented, and it becomes important to carry out further research, particularly for real-world applications like pipes and pressure vessels.

III. MATERIALS AND METHODS

To study the performance of composite materials, a fully detailed experimental setup has been proposed to conduct hygrothermal analysis. A standard methodology should be followed to enhance the credibility and validity of the analysis. Experiments were performed at temperature limits of 10 C°, 20 C°, 30 C°, 40 C°, and 50 C°, with a constant relative humidity of 90%. A total of 30 samples were analyzed which were divided into 10 groups, with 3 samples in each group . Three specimens were subjected to 50 C° and 90% relative humidity, while six specimens each were exposed to conditions of 10 C°, 20 C°, 30 C°, and 40 C°, all with the same humidity level. The test specimens were exposed to hygrothermal conditions for different durations as indicated in Table 1. The exposure occurs by placing the samples in a controlled climate chamber.

Table 1: Exposure durations, Temperature/Humidity in the climate chamber

S.No	Temperature (C˚)/Humidity (%)	Time (Hours)	S.No	Temperature (C˚)/Humidity (%)	Time (Hours)
1	Ambient conditioning	-	16	30/90	336
2	Ambient conditioning	-	17	30/90	336
3	Ambient conditioning	-	18	30/90	336
4	50/90	48	19	20/90	264
5	50/90	48	20	20/90	264
6	50/90	48	21	20/90	264
7	40/90	432	22	20/90	264
8	40/90	432	23	20/90	264
9	40/90	432	24	20/90	264
10	40/90	432	25	10/90	168
11	40/90	432	26	10/90	168
12	40/90	432	27	10/90	168
13	30/90	336	28	10/90	168
14	30/90	336	29	10/90	168
15	30/90	336	30	10/90	168

A. Test Specimens

Thirty composite samples were prepared and all of these have the same dimension 14.76 mm in width and 3.19 mm thick as detailed in Figure 1. The test specimens were rings of composite material. By cutting them with machining from a single sheet of composite material. The process starts with the carbon fiber T 700, and resin matrix LY 1564 + XB 3486, so key determinants of composite strength and durability. Carbon fiber was then accurately trimmed to size so that each piece measured the same. Part Orientation was conceived to utilize anisotropy inherent in the carbon-epoxy composite being used. Then, the resin was applied equally to impregnate the fibers without leaving any air pocket or defect. They were subsequently subjected to a temperature and pressure controlled curing cycle, which serves as heat cure that solidifies the resin, delivering strong adhesion of fibers. The samples were then trimmed to their final dimensions after curing, which allowed the desired size and uniformity.

Figure 1: Test Specimens

B. Climate Chamber Conditions

A climate chamber, alternatively known as an environmental chamber or climate test chamber, is a controlled environment that is employed to simulate diverse conditions such as temperature and humidity. These chambers are extensively used in research, development, testing, and quality control in sectors like aerospace, automotive, electronics, pharmaceuticals, materials science, and others. Through these devices, researchers and engineers get the opportunity to study how materials and products operate in different environmental conditions by creating a controlled environment, thus gaining new information of their durability and functionality. They can be used to give vital information about the materials and products before deploying them in real-world applications.

According to the mentioned experiments, in figure 2 all samples were first immersed in a climate chamber that kept the relative humidity (RH) at 90% over the entire testing period after the preparation of composite samples. Meanwhile, the temperatures were sequentially altered to 10 C°, 20 C°, 30 C°, 40 C°, and 50 C° for different periods of time. These temperatures specifically were selected in order to mimic a spectrum of application scenarios that might be encountered by the composite materials. The combination of cyclic humidity excursions and temperature variations was utilized to simulate the effect of the environmental conditions that may affect the composite material characteristics. This investigation served as an insight into how the materials would demonstrate their performance under the variety of environmental stresses.

Three samples were placed in a climate chamber for 48 hours with a temperature of 50 C° and 90% relative humidity. After 48 hours, their dimensions were measured. After that following the procedure, six samples were put into the climate chamber for 432 hours at a temperature of 40 C° and 90% relative humidity. After that for 336 hours, six more samples were added to the same chamber and the temperature was adjusted 30 C° besides maintaining 90% relative humidity. Then, later, six more samples were placed in the chamber for 264 hours with the temperature being reduced to 20 C° by keeping its relative humidity at 90%. Furthermore, six more samples were put into the chamber and the temperature was decreased to 10 C° with the same humidity for 168 hours.

Figure 2: Carbon Fiber Composite in Climate Chamber

C. Digital Caliper

In figure 3 a digital caliper was utilized to record the width and thickness of the samples with high accuracy. The instrument provides precise reading and shows measurements digitally in millimeters. It was simple to use and delivered repeatable measurement results. The samples were cleaned prior to each reading to remove any moisture. The caliper was switched on, placed on millimeters, and zeroed to avoid error. When measuring thickness, the sample was carefully placed between the jaws of the caliper, and measurements were taken at three points. The same was done for measuring width. The measurements were repeated after hygrothermal exposure and. Ultimately, the average of the three measurements for both the thickness and width was computed to maintain accuracy.

Figure 3: Digital Caliper

IV. RESULTS AND DISCUSSION

The effect of temperature and humidity on the dimensions of carbon fiber epoxy composites was analyzed in a study. Thirty specimens divided in to ten groups each groups contain three samples were prepared for the present study. The first group was measured before hygrothermal conditioning so the average width of the sample is 14.76 mm and the average thickiness is 3.19 mm at room temperature at 28 C° and 40% relative Humidity in table 2. In addition, the other groups were exposed to 90% relative humidity at different temperature and duration in climate chamber.

Table 2: Baseline of the specimens

S.NO.	Average Thickness (mm)	Average Width (mm)
1	3.19	14.76

A. Results

In figure 4 & 5 for 48 hours at 50 C°, the dimensions of the samples were increase to be 14.80 mm in average width, a 0.27% increase, and 3.20 mm in average thickness, a 0.31% increase. At 40 C° for 432 hours The dimensions expand to 14.88 mm in average width, a 0.81% increase, and 3.19 mm in average thickness (no change) for the first group, and 14.88 mm in average width, a 0.81% increase, and 3.20 mm in average thickness, a 0.31% increase for the second group. . When the temperature was dropped to 30 C° for 336 hours, The dimensions of the first group's samples got no change in average width, and no change in average thickness, while the second group reached 14.77 mm in average width, a 0.067% decrease, and no change in average thickness. Upon reducing the temperature further to 20 C° for 264 hours, In terms of dimensions, the first group increased to 14.94 mm in average width, a 1.22% increase, and no change in average thickness, while the second group reached 14.96 mm in average width, a 1.35% increase, and 3.20 mm in average thickness, a 0.31% increase. Finally, at 10 C° for 168 hours, The dimensions of both groups increased, with the first group measuring 15.00 mm in average width, a 1.63% increase, and 3.20 mm in average thickness, a 0.31% increase and the second group measuring 14.98 mm in average width, a 1.49% increase, and 3.19 mm in average thickness, no change. The overall results are describe in table 3.

Table 3: Average Dimension of the samples before and after hygrothermal analysis

S.NO.	Temperature /Humidity	Time	Average Thickness (mm) (±0.1 to ± 0.02 mm)	Average Width (mm) (± 0.1 mm to ±0.22 mm)
1	Ambient Conditions	-	3.19	14.76
2	50 C° /90 %	48	3.20	14.80
3	40 C° /90 %	432	3.22	15.06
			3.22	15.06
4	30 C° /90 %	336	3.19	14.76
			3.19	14.77
5	20 C° /90 %	264	3.20	14.94
			3.20	14.96
6	10 C° /90 %	168	3.20	15.00
			3.20	14.98

B. Evaluation of Width Variations

The graph shows how the width of a material changes with temperature at hygrothermal conditions. At 10 C° and 20 C°, the width increases from the baseline,likely due to the material expanding at these temperatures. The width equal or slightly increase to the baseline is the most telling indicator of the material at 30 C°. The study confirms that 30 C° with high relative humidity is the best condition for maintaining the stability of carbon fiber composites. Nevertheless, with the temperature increment to 40 C° and 50 C°, the width expands again. Moisture absorption and high temperatures might be the reason for this pretreatment, which might result in swelling or dimensional changes, and thus, the material would be less stable.

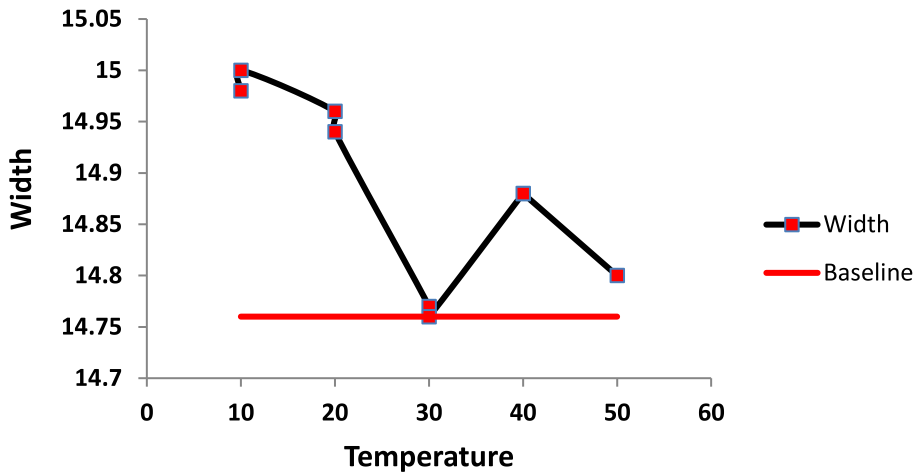

Figure 4: Analysis of Baseline and Exposure Width Vs Temperature

C. Effect of Hygrothermal Treatment on Composite Thickness

The graph provided offer insight into how the material's thickness varies with the temperature due to the climatic conditions. The graph shows that the thickness of a material changes with temperature under hygrothermal conditions.

At 10 C°, the thickness of the material slightly increases 3.20 mm in Group 1, and in Group 2. The reasons can be minor thermal expansion at lower temperatures for this small change.

At 20 C° the thickness of the material slightly increases 3.20 mm in both groups. This may be a result of some moisture absorption.

The graph data show that at 30 C° the thickness is the same is the baseline. This indicates that there is no moisture absorption.

At 40 C° and 50 C° the thickness is slightly increase as the initial (3.22 and 3.20 mm) respectively, which means that at these higher temperatures, the material absorbed more moisture absorption . This thickness change is an important factor for the material's structural integrity, because the fluctuations in thickness may affect its performance under the different environmental conditions.

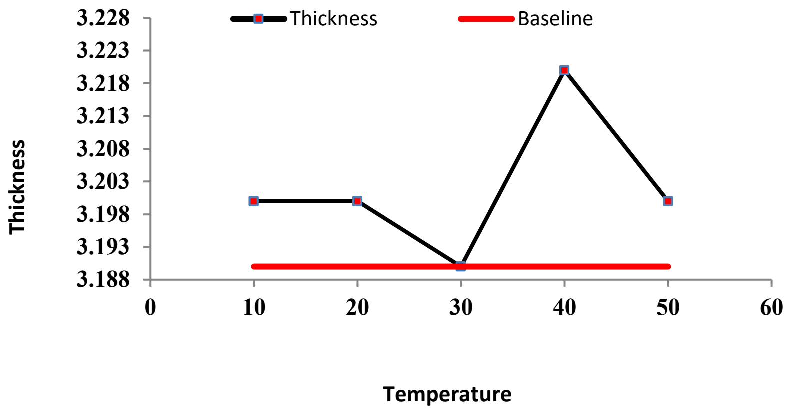

Figure 5: Analysis of Baseline and Exposure Thickness Vs Temperature

V. CONCLUSION

In this research, the effects of temperature and humidity on carbon fiber epoxy composites were investigated. The carbon fiber epoxy bracing elements were prepared and divided into ten groups, each composed of three specimens. One group was not subjected to hygrothermal conditioning to act as a baseline, while the rest of the groups were exposed to different environmental conditions. The dimensions of all the specimens were measured using digital caliper at room temperature and atmospheric pressure, with averages calculated from three specimens per group. The data were analyzed using Excel software.

The experimental results revealed significant variations across all ten groups of specimens. The dimensions increased 1.63% and 1.35% at 10 C° and 20 C°, respectively, compared to the baseline low temperature and High humidity caused some moisture absorption weakening the fiber matrix bond and reducing material strength. On the other hand, dimension slightly increased 0.067% at 30 C° because of some moisture absorption confirming that the material performed best at this temperature. While, at 40 C° and 50 C°, the dimension increased 2.03% and 0.27% respectively. High humidity with high temperature caused moisture absorption, weakening the fiber matrix bond and reducing material strength meaning the bonding between fibers and epoxy was weak. These alterations can be ascribed to moisture absorption, which is the reason for the material's mechanical properties to vary in different environmental conditions.

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