# HYGROTHERMAL EFFECT ON MECHANICAL AND THERMAL PROPERTIES OF FILAMENT WOUND HYBRID COMPOSITE

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**ABSTRACT:** This study focused on the hygrothermal effect on filament wound glass-carbon/epoxy hybrid composite. Non-geodesic pattern of filament winding with a winding speed of 15.24–30.48 lm/min was used. Fiber tensioning weight of one kg and a winding angle of 30° were created to produce wound samples of the hybrid composite. The hybrid composite was wound by using a ±30° orientation with a total of six layers. Hygrothermal effect was conducted in a humidity chamber for three days (72 h). Control temperatures of 60 and 80°C were established, and humidity percentages of 50%, 70%, and 90% were used. Moisture absorption test showed that heat and humidity in most of the hybrid samples gradually increased. As a result, glass-carbon 80°C/90% showed the highest absorbed moisture at 0.77%. The involvement of highest heat and humidity showed the decline in the values of tensile and flexure strengths at 75.80 and 157.15 MPa, respectively. Fractography analysis using Stereo Microscope Stemi 2000-C indicated that glass-carbon/epoxy 80°C/90% showed catastrophic damage, large crack, and longest delamination of fiber pullout at 10.39 mm. The fracture criterion revealed that the involvement of heat and humidity significantly affected the mechanical and physical properties of hybrid composite material.

**KEYWORDS**: *Hygrothermal; filament winding; hybrid composite; moisture; flexure*

## 1.0 INTRODUCTION

Polymer matrix composites, such as glass or carbon fiber-reinforced composites, offer enhanced fatigue behavior because microcracks in a polymer matrix do not freely propagate in a composite product and are confined in the fiber, unlike in metal [1-2]. Normally, a polymer matrix composite is less affected by stress concentration, such as notches and holes, compared with metal. Hybrid composites have recently been highlighted as a new alternative to material composites, and many research activities have focused on hybrid technology, particularly for critical application in the automotive, aerospace, and engineering structural industries. Abu Talib et al., [1] developed a hybrid carbon/glass fiber-reinforced epoxy composite drive shaft for automotive application. In addition, composite drive shafts have been proven to be able to solve automotive and industrial problems that accompany the usage of conventional metal.

In manufacturing, the filament winding process is preferred in the composites industry. Filament winding is the most cost-effective method of producing pressure retaining structures from fiber-reinforced polymeric composites. Although this method has been used for a considerable amount of time, the effects of heat and humidity on filament wound product had only been investigated to a limited extent. In addition, investigative studies on the hygrothermal effect of hybrid composite are limited. Therefore, a filament winding technique was introduced in this study. The method is selected because the tension that develops during the winding process can compact the fibers. The method also provides a good definition and eliminates many surface problems, such as blistering, porosity, cracking, and splitting. Furthermore, filament winding that could also produce specific orientations within the component would have higher specific density, which results in less void and air. Then, the anisotropic properties of fiber in the sand were utilized to produce a highly structured product [3]. Correct placement of fiber by filament winding results in a high strength/weight ratio. The study provides an overview of the mechanical and physical properties of hybrid composite after hygrothermal conditioning. Hybrid composite contributes to the reduction in cost and strength/ weight ratio. Moreover, the composite provides additional alternatives to enable people to develop hybrid composites instead of focusing on a single laminate fiber.

This study deals with the hygrothermal effect on the mechanical properties of glass-carbon/epoxy hybrid composite. Although hybrid composite material has many advantages and outstanding characteristics compared with a conventional polymer composite material, heat and humidity remain significant factors that affect the mechanical and physical properties of hybrid composites. All polymer composites absorb moisture in a humid atmosphere and when immersed in water. The effect of moisture absorption leads to the degradation of the fiber-matrix interface region, thereby creating poor stress transfer efficiencies that diminish mechanical properties [4-5]. Wu et al., [6] observed that the maximum reduction in interlayer shear performance occurred in the composite that is exposed to deionized water, whereas the maximum decrease in tensile performance is due to the effect of seawater. Chemical degradations also occurred in the fiber-matrix interface, which reduced the bending modulus and strength of the composite [7]. Furthermore, fiber-matrix interface and matrix failures increase in the composite specimen at a long immersion time in seawater [8]. If these materials are designed for exterior component applications such as tanks, pipes, and automotive parts, then high water uptake is mandatory. Therefore, investigating these problems is important.

## 2.0 EXPERIMENTAL

Glass-carbon as reinforcement and epoxy resin as matrix material were selected for the hybrid composite. These materials underwent filament winding process to produce the samples. Figure 1 shows four axes of the filament winding machine, which were used to fabricate the samples.

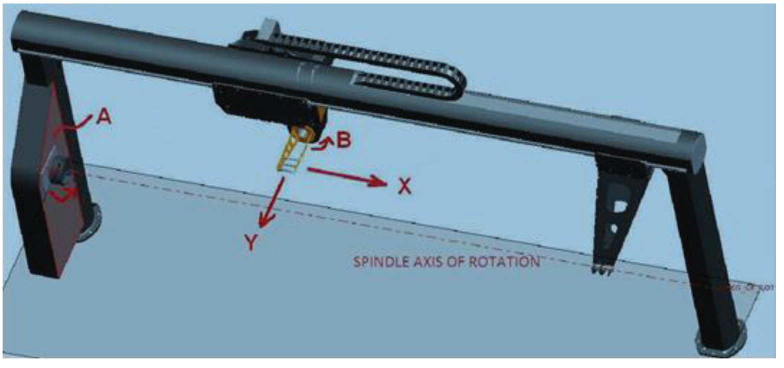



Figure 1: Filament winder axis configuration.

The selected parameters were non-geodesic types of winding with an angle of 30° of glass-carbon/epoxy hybrid composite. Hygrothermal conditioning was applied to hybrid composite samples to increase heat and humidity by using a humidity chamber (GOTECH). Heat temperatures were 60 and 80°C and humidity percentages were at 50%, 70%, and 90%, as shown in Table 1.

Table 1: Accelerated hygrothermal conditioning parameters

| Conditioning Time | Temperature (°C) | Humidity (%) |
|---|---|---|
| 72 hrs (3 days) | 60°C | 50% |
| | | 70% |
| | | 90% |
| | 80°C | 50% |
| | | 70% |
| | | 90% |

Moisture content, flexure, and tensile tests were conducted to determine the hygrothermal effects on the properties of filament wound hybrid composite-reinforced epoxy. The percentage of moisture content was calculated after completely accelerating the hygrothermal effect. Flexure and tensile tests were conducted and further studied. Flexure and tensile tests strictly followed ASTM D790 and ASTM D638 standards, respectively. Microstructure analysis was conducted to observe the hygrothermal effect on the fracture morphology of the hybrid composite. The microstructure of the surface fracture and its criterion were investigated by using Carl Zeiss Stereo Microscope Stemi 2000-C. For thermal properties, the analysis was conducted by using Dilatometer Netzsch DIL 402 C to observe the thermal behavior after the hygrothermal effect.

## 3.0 RESULT AND DISCUSSIONS

### 3.1 Moisture absorption

Moisture absorption behavior is an important subject that should be explained to ensure correlation with the mechanical properties and microstructure. Figure 2 shows that the percentage of moisture absorption gradually increased after the samples were soaked in a humidity chamber for three days (72 h).

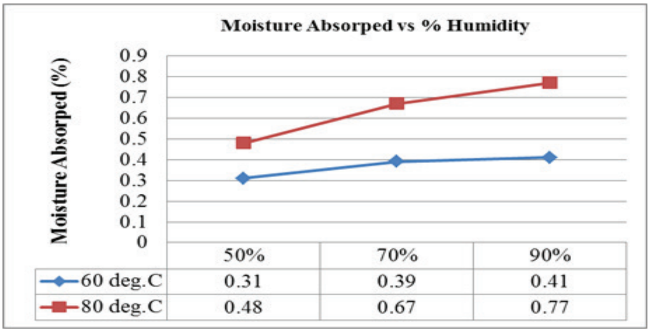



Figure 2: Graph of moisture absorption behavior after 72 h conditioning.

Glass-carbon/epoxy samples soaked at 80°C with 90% humidity shows the highest absorbed moisture compared with other parameters. Furthermore, higher moisture was absorbed in the samples as higher temperature was applied. Applying higher temperature causes the hydrogen and oxygen ($H_2O$) particles to become smaller and vaporize, which makes the soaked samples easy to penetrate. Liao and Tan [9] reported that moisture absorption induced larger strains than high temperature exposure for unidirectional polymer composites primarily because the coefficient of moisture expansion was greater than the coefficient of thermal expansion. However, higher temperatures accelerate the diffusion rates of moisture and generally accelerate aging [10].

### 3.2 Flexure properties

The test results showed that the flexure strength of the hybrid sample decreased under the applied temperature and humidity conditions. Higher temperature and humidity will have a greater effect on the mechanical properties. Glass-carbon/epoxy 60°C/90% had the lowest flexural strength at 148.1 MPa, whereas glass-carbon/epoxy 60°C/50% had the highest flexural strength at 181.61 MPa. Humidity could strongly affect the composite material. The moisture attacks the glass fiber surface with the free hydroxides that form, which further degrades the silica structure at a higher temperature [11].

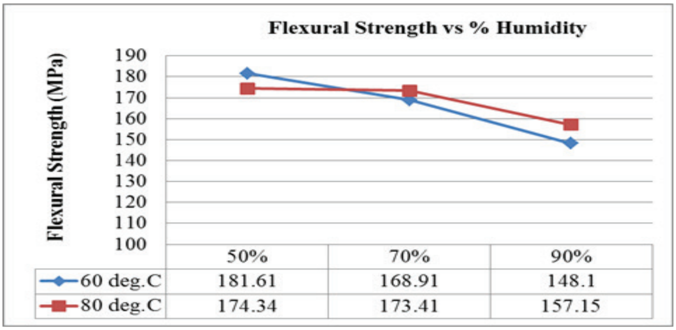



Figure 3: Graph of flexural strength versus % humidity.

### 3.2.1 Flexure load fractography

The effect of flexure load on the hybrid samples was studied and observed by using Stereo Microscope Stemi 2000-C with 6.0x magnification. The delamination criterion of each sample after the application of flexure load was studied through morphology observation. The length of delamination for each sample after the application of flexure load was measured and explained.

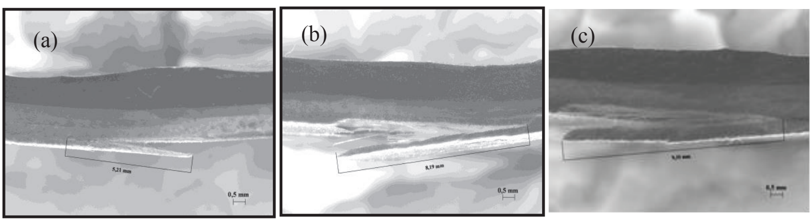



Figure 4: Effect of flexure load on delamination of glass-carbon/epoxy at 60°C with various humidity percentages;
50% (a), 70% (b), and 90% (c).

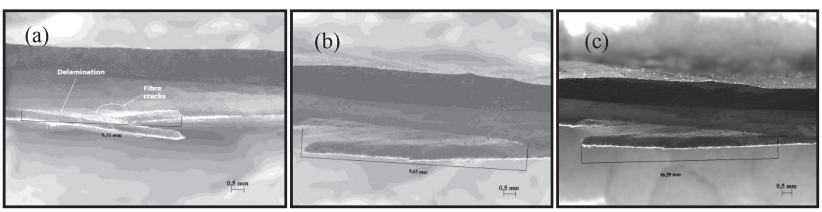
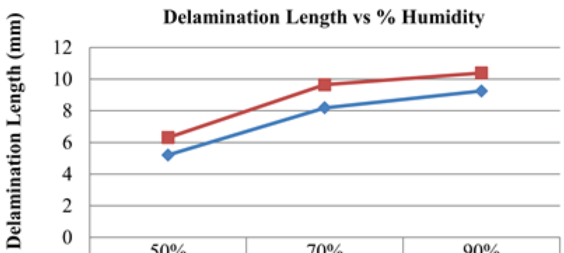



Figure 5: Effect of flexure load on delamination of glass-carbon/epoxy at 80°C with various humidity percentages;
50% (a), 70% (b), and 90% (c).




| | 50% | 70% | 90% |
|---|---|---|---|
| 60 deg.C | 5.21 | 8.19 | 9.25 |
| 80 deg.C | 6.31 | 9.65 | 10.39 |

Figure 6: Graph of delamination length generated after flexural test versus % humidity.

Figure 4 and 5 show the length of fiber delamination that was generated at the interface of the samples after flexure load was applied. Figure 6 shows that glass-carbon/epoxy had the longest delamination after flexure load was applied, which indicates that applying higher temperature and humidity gradually increased the total length of delamination as considered in fiber pullout from the matrix resin. Applied moisture and heat could strongly affect the structure of the composite material. According to Braj et al., [12] In contrast to fiber breakage, fiber pullout occurred in most of the samples because of a weak bond between the fiber and the matrix at the interface. Hydroxyl groups (-OH) in the main backbone chain of a resin provided sites for hydrogen bonding to the surface of the natural fibers, which contain many hydroxyl groups in their chemical structure [12]. Thus, epoxy resins with no hydroxyl group in its backbone chain generally had the weakest bond and hence the lowest adhesive properties compared with other resins. According to Tsai et al., [10], moisture absorption also softens the matrix and degrades the stress transfer function, which results in a substantial loss of Tg and SBS strength. In this case, the fiber will pull out of the matrix, which will result in loss of strength in the composite material.

### 3.3 Tensile properties

Tensile test result showed the decline in tensile strength after the samples were soaked for 72 h at various temperature and humidity levels, as shown in Figure 7. The result showed that glass-carbon/epoxy 80°C/90% had the lowest tensile strength at 75.80 MPa, whereas glass-carbon/epoxy 80°C/50% had the highest tensile strength at 88.99 MPa.

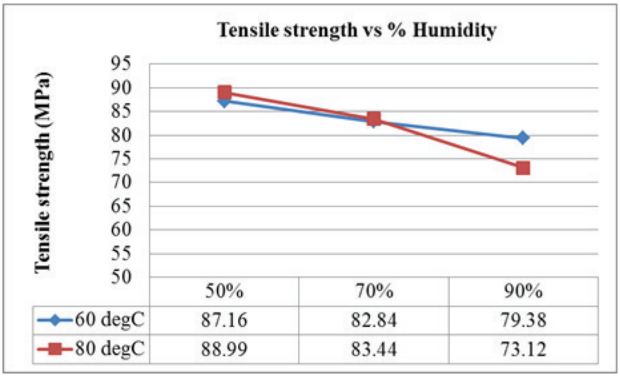



Figure 7: Graph of tensile strength versus % humidity.

The effects with these two factors, namely, humidity and temperature, on the composite material were obvious. Absorbed moisture can damage the interface over time by interrupting the hydrogen bond within the matrix and fiber, thereby weakening the interface. Furthermore, stresses created by swelling can be high and may eventually damage the interface. Moisture absorption causes plasticization of the resin, which occurs concurrently with swelling, and reduces the glass transition temperature of the resin. This condition adversely affects the fiber matrix adhesion properties, which results in debonding at the fiber-matrix interfaces as well as microcracking in the matrix, fiber fragmentations, continuous cracks, and several other phenomena that degrade the mechanical property of the composites [12,16]. Degradation due to the hygrothermal environment damages the fiber-matrix interface, which generally decreases the strength and modulus. Moisture absorption also softens the matrix, degrades the stress transfer function, and results in a substantial loss of glass temperature and strength of the material [10].

### 3.3.1 Tension load fractography

After the tensile test, the samples were observed based on their fracture criterion. The characteristics of the fracture revealed the effect of heat and humidity on the hybrid samples.

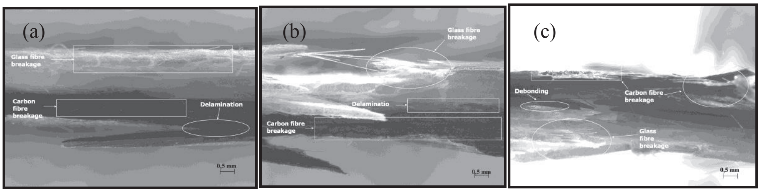



Figure 8: The effect of tension load towards fracture of Glass-Carbon/ Epoxy at 60$^{o}$C with various percentages of humidity, (a) 50%, (b) 70% and (c) and 90%.

Figure 8 and 9 show the catastrophic damage on the samples after tension load was applied. The highest temperature at 80°C and humidity at 90% caused breakage in the samples. Glass-carbon/epoxy, 80°C/90% samples showed serious defects such as fiber breakage and laminate cracks compared with other parameters. Therefore, applying moisture and heat could affect the structure of the composite material. Wan et al., [13] stated that degradation due to the hygrothermal environment often damages the fiber-matrix interface and generally decreases the strength and modulus.

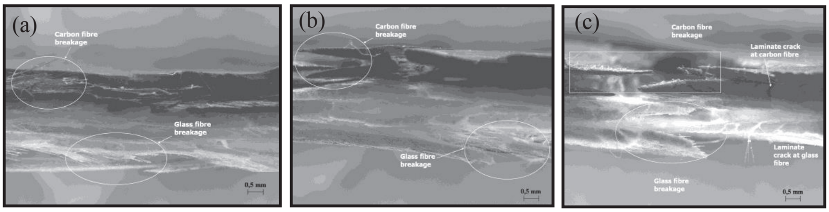



Figure 9: Effect of tension load on the fracture of glass-carbon/epoxy at 80 °C with various humidity percentages; (a) 50%, (b) 70% and (c) and 90%.

## 3.4 Thermal properties

Table 2 shows that the Tg of the glass-carbon/epoxy hybrid composite gradually decreased as humidity percentage increased. Glass-carbon/epoxy 60 °C/90% had the lowest Tg at 61.8 °C. At 60 and 80 °C, both declined in Tg.

Table 2: Glass temperature (Tg) after thermal analysis using Dilatometer Netzsch DIL 402-C

| Samples | Material, Temperature/Humidity | $T_g$ (°C) / Peak point | % of Moisture Absorbed | Thermal Expansion (T.Alpha/(1K)) | |
|---|---|---|---|---|---|
| | | | | 40°C – 60°C | 80°C – 100°C |
| 1 | Glass-Carbon/Epoxy, 60°C/50% | 67.3 | 0.31 | $6.6 \times 10^{-6}$ | $-35.7 \times 10^{-6}$ |
| 2 | Glass-Carbon/Epoxy, 60°C/70% | 65.3 | 0.39 | $8.7 \times 10^{-6}$ | $-33.9 \times 10^{-6}$ |
| 3 | Glass-Carbon/Epoxy, 60°C/90% | 61.4 | 0.41 | $6.7 \times 10^{-6}$ | $-27.2 \times 10^{-6}$ |
| 4 | Glass-Carbon/Epoxy, 80°C/50% | 68.6 | 0.48 | $9.5 \times 10^{-6}$ | $-38.6 \times 10^{-6}$ |
| 5 | Glass-Carbon/Epoxy, 80°C/70% | 64.8 | 0.67 | $8.2 \times 10^{-6}$ | $-33.9 \times 10^{-6}$ |
| 6 | Glass-Carbon/Epoxy, 80°C/90% | 64.0 | 0.77 | $14.2 \times 10^{-6}$ | $4.6 \times 10^{-6}$ |

Thermal expansion increased as temperature rose from 60°C to 80°C as shown in Table 2. The applied heat softened the matrix, thereby causing the thermal expansion to increase. By contrast, thermal behavior after Tg point, which ranges from 80 °C to 100°C, indicated that the polymer matrix continued to soften as thermal expansion decreased. The trend showed that epoxy resin was affected by high temperature and had weak mechanical properties. As the amount of water absorbed by the composite increased over a percentage of humidity, reductions in Tg and strength were measured. The change in Tg as a function of the moisture temperature and time is presented in Table 2, which showed that the hygrothermal environment strongly affected the rate of decline of Tg. Researcher claimed that the presence of moisture within FRP can significantly change the chemical and physical characteristics of the polymeric matrix, which explains the effects of moisture on the matrix plasticization and degradation of the fiber-matrix interface in most composite systems [11,14]. Moisture absorption by epoxy matrix composites has a plasticizing effect, as shown by Tg reduction in the matrix [15].

## 4.0 CONCLUSIONS

Glass-carbon/epoxy hybrid composite samples were hybridized by using the filament winding process. Then, hybrid samples were conditioned to accelerate the hygrothermal effect at temperatures of 60 and 80 °C and humidity percentages of 50%, 70%, and 90%. Moisture absorption test showed that most of the hybrid samples gradually increased with the heat and humidity. As a result, glass-carbon 80 °C/90% showed the highest absorbed moisture at 0.77%. The highest levels of heat and humidity decreased the tensile and flexure strengths to 75.80 and 157.15 MPa, respectively. Thermal analysis results showed the reduction in Tg as heat and humidity increased, which indicates the hygrothermal effect. Fractography analysis by using Stereo Microscope Stemi 2000-C showed catastrophic damage, large crack, and longest delamination of fiber pullout for glass-carbon/epoxy 80 °C/90%. The fracture criterion revealed that the involvement of heat and humidity significantly affected the mechanical and physical properties of the hybrid composite material.

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