International Symposium of Research Students on Material Science and Engineering
December 20-22, 2004, Chennai, India
Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras

EFFECT OF MOISTURE ON THE MECHANICAL PROPERTIES OF GFRP COMPOSITE FABRIC MATERIAL

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ABSTRACT

Glass fiber reinforced polymer matrix (GFRP) woven fabric composite material was tested to determine tensile, compressive and in-plane shear (IPSS) strength under both room temperature (RT) and hot-wet conditions. Prior to testing, hot-wet specimens were hygrothermally aged in an environmental chamber, maintained at 71 ^{0}C and 85 % relative humidity (RH) until moisture absorption of about 1 wt.% was attained. Tests were performed in a computer controlled 100 kN servo-hydraulic test machine. For hot-wet tests, a split type environmental chamber was fixed to the machine which was also maintained at 71 ^{0}C and 85 % RH. The test data obtained was statistically analyzed to determine mean strength and B-basis design allowables. In general, hot-wet strength was lower by about 11% to 18%, compared to strength at RT. Presence of moisture in the epoxy matrix, in the fiber-matrix interface and the chemical attack of moisture on the glass fibers are thought be the main reasons for reduced strength of GFRP material in hot-wet condition.

Key Words: GFRP, Moisture, Tensile, Compression, IPSS

1. INTRODUCTION

Fiber reinforced polymer matrix (FRP) composites are extensively used in airframe structural applications. Carbon (CFRP), Glass (GFRP) and Kevlar (KFRP) are the most commonly used composite materials in aerospace industry. Some of the general applications of composite materials in helicopter airframe structures include, the empennage consisting of vertical fin, horizontal stabilizers and end plates made from CFRP, GFRP and KFRP, main rotor hub and blade made from CFRP and GFRP, tail rotor blades made from KFRP and GFRP, while cockpit frame is made from CFRP and KFRP composites.

In service, composite materials are exposed to varying humidity and temperature conditions[1,2]. Over a long duration of time, composites absorb moisture[3,4] and it affects mechanical properties of these materials significantly[4-7]. In this study, the effect of moisture on the mechanical properties of GFPR composite material was investigated. GFRP composite woven fabric material was tested to determine tensile, compression and IPSS properties both in RT and hot-wet conditions. Tests were performed in both warp and weft directions as per ASTM standard test procedure specifications. Hot-wet specimens were hygrothermally aged, prior to testing, until moisture weight gain of about 1wt% was attained. The test results obtained were statistically analyzed to determine mean strength and B-basis design allowables. Results obtained are briefly discussed and conclusions were drawn with respect to strength degradation by moisture.

2. EXPERIMENTAL

E-glass fiber reinforced in V913 polymer matrix (GFRP) in the woven fabric form was used in this investigation. The nominal ply thickness was about 0.24 mm and the fiber volume fraction was about 0.5. Standard tensile, compression and IPSS test specimens were fabricated from these materials as per ASTM[8-10] test standard specifications. Strain gages were bonded at the mid-section for strain measurements. Hot-wet test specimens, prior to testing, were hygrothermally aged in an environmental chamber which was maintained at 70^0C ± 2 ^{0}C and 85% ± 4 % Relative Humidity (RH) along with traveler coupons. The weight gain was monitored on these traveler coupons using a precision balance, regularly until moisture weight gain of about 1.0 wt% was attained. Specimens were then removed form the chamber and tested for their mechanical properties. All the tests were performed in a computer controlled 100 kN servo-hydraulic test machine under stroke control mode with a constant cross-head speed of 1mm/min. For hot-wet tests, a split-type environmental chamber was fixed to the test machine. Saturated steam and hot air were passed inside the chamber to maintain 70 ^{0}C ± 2 ^{0}C and ≥ 85% RH. The temperature and RH in the test chamber was monitored by a thermocouple and a hand held humidity meter, respectively. A photograph of the hot-wet test set-up is shown in Fig. 1.

Unlike metals, composites are known to exhibit a large scatter in test results. Thus, statistical analysis of the strength data is invariably associated with testing and evaluation of composite materials[11-13]. In this investigation, about 30 specimens (10 specimens each from three different laminates) for each property and environmental condition were tested to obtain the average ultimate strength. The Mean, Standard Deviation (SD) and the B-Basis design allowable were determined.

3. RESULTS AND DISCUSSION

3.1 Hygrothermal aging

The moisture absorption characteristics determined for the GFRP composite material is shown in Fig. 2. The percentage weight gain is plotted against square root of time. It took about 40 days for attaining moisture weight gain of about 1 wt%. Many earlier investigations[7,14-19] have also shown similar moisture absorption characteristics in composite materials. The theoretical moisture concentration, based on diffusivity of the material[3] was calculated and plotted in Fig. 2 as a solid line. It can be clearly seen that moisture absorption follows Fickian diffusion law as observed in many composite materials[16, 17,19].

3.2 Mechanical Properties

The mean ultimate tensile strength (UTS) of GFRP material under RT and hot-wet conditions in both warp and weft directions are shown in Fig. 3. On an average, UTS was reduced by about 11% in both warp and weft directions. Lateral (net-section failure) mode was observed in most of the test specimens as shown in Fig. 4.

The ultimate compressive strength (UCS) of GFRP material under RT and hot-wet conditions in both warp and weft directions are shown in Fig. 5. On an average, UCS was reduced by about 18% in both warp and weft directions. Lateral (net-section) failure mode was observed in most of the test specimens as shown in Fig. 6. The In-plane shear strength (IPSS) of GFRP material under RT and hot-wet conditions is shown in Fig. 7.

IPSS was reduced by about 18%. Typical failure modes observed in IPSS test specimens are shown in Fig. 8. It has been shown that moisture plasticizes the epoxy matrix and reduces the glass transition temperature[7,20,21]. Also, presence of moisture at the fiber-matrix interface reduces the strength of the composite material[5]. Thus, moisture generally affects any property, which is dominated by the matrix and/or interface. Hence, being matrix dominated properties, both compression and IPS strength is expected to be lower in hot-wet condition. However, the tensile strength being a fiber dominated property, the strength reduction occurs only if the fibers themselves are affected by moisture. It has been shown that moisture can cause degradation at the fiber level in glass fibers[22,23]. Degradation is initiated by moisture-extracting ions from the fiber, thereby altering its structure. These ions combine with water to form bases, which etch and pit the fiber surface, resulting in flaws that significantly degrade strength and can result in premature fracture and failure of the fibers. This is probably the main reason for observed tensile strength reduction in hot-wet conditions.

4. CONCLUSIONS

Following conclusions may be drawn from the results obtained in this investigation:

1. The moisture absorption follows Fickian diffusion law in GFRP fabric material.
2. Tensile, compression and In-plane shear strength of the GFRP material is reduced by presence of moisture. The strength reduction varies from about 11% to 18% depending on the type of property.
3. Presence of moisture in the matrix, fiber-matrix interface and also the moisture attack on the glass fibers are all thought to be the main reason for reducing the mechanical properties under hot-wet condition.

ACKNOWLEDGEMENTS

Authors are thankful to Dr. B.R. Pai, Director, NAL and Dr. P.K. Dash, Head, SID, NAL for facilitating the conduct of these experiments. Staff members of MEL, SID are thanked for their help in conducting the experiments.

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Figures

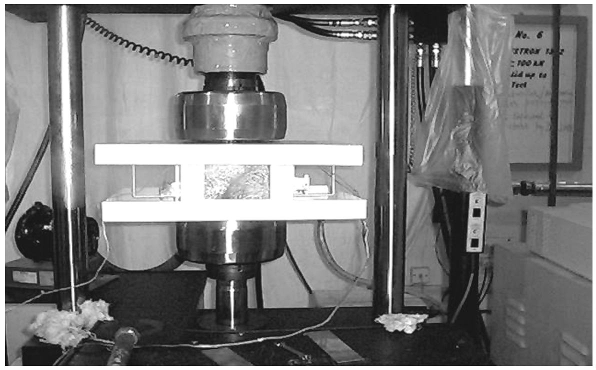

Figure 1. A photograph of the hot-wet tensile testing of composite materials

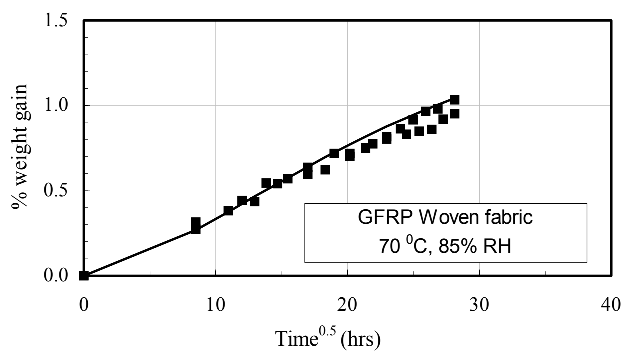

Figure 2. Moisture absorption kinetics in GFRP composite materials

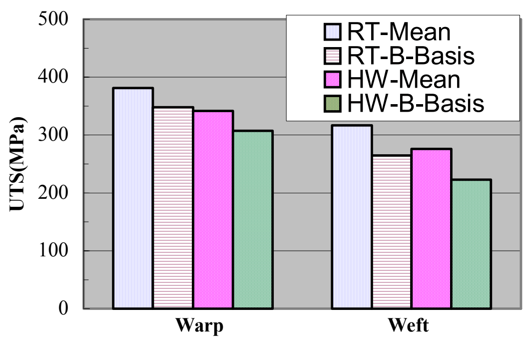

Figure 3. Effect of moisture on the UTS

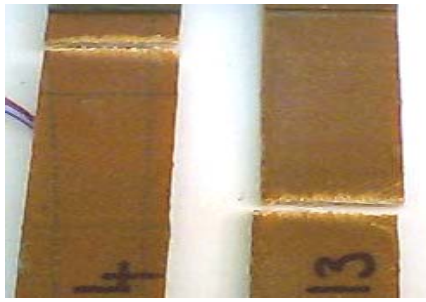

Figure 4. Typical tensile failure modes

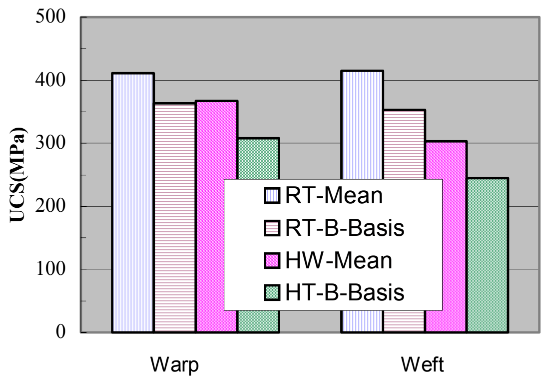

Figure 5. Effect of moisture on the UCS

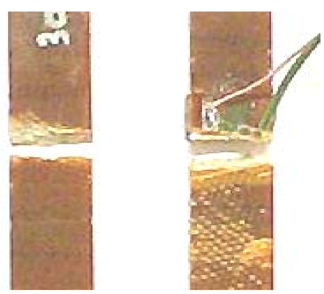

Figure 6. Typical failure modes in compression

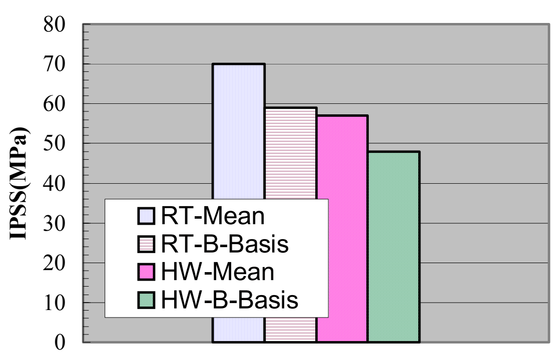

Figure 7. Effect of moisture on the IPSS

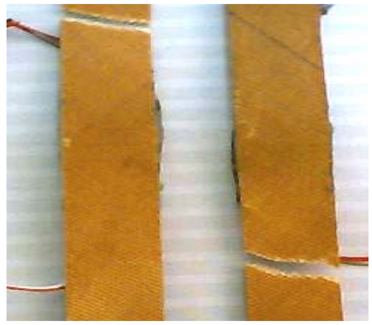

Figure 8. Typical IPSS test failure modes