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Effect of Hot-Wet Conditioning on the Mechanical and Thermal Properties of IM7/ 8552 Carbon Fiber Composite

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ABSTRACT
Carbon fiber composite IM7/8552 laminates with unidirectional (UD) and quasi isotropic (QI) lay-up sequence were fabricated by autoclave process. Standard test specimens for compression and thermal tests as well as traveler coupons for hygrothermal aging were cut and prepared from these laminates. Prior to testing, hot-wet specimens along with traveler coupons were hygrothermally aged in a chamber maintained at 70ºC and 85% relative humidity (RH) until moisture absorption saturation was attained. Compression properties and glass transition temperature (T_g) of composites were determined in both room temperature and in hot-wet conditions. Moisture absorption rate and maximum moisture content was observed to depend on the lay-up sequence. UD laminate absorbed moisture at a higher rate than that of QI. Also the diffusion coefficient (D_c) was observed to be higher in UD than in QI laminate. Compressive strength was observed to decrease by about 28%-37%.whereas compression modulus was unaffected due to moisture absorption. The T_g was observed to reduce by about 17% due to moisture. The mechanisms of moisture absorption behavior and the consequent degradation in the mechanical properties are discussed.

Keywords:*Hot-wet, compression, glass transition temperature, IM7/8552 composite.*

1. INTRODUCTION

The use of composites in aerospace applications is expanding rapidly with carbon fibre/epoxy composite being one of the most important materials for these applications. The long-term performance of composite in such applications is of great importance as they are expected to be in service for quite long times under various types of loads and environmental conditions. It is well-established that epoxy resins absorb significant amounts of moisture in service which leads to considerable degradation of mechanical and thermal properties [1,2].

Moisture absorption in polymer composites is a function of several variables such as temperature, fiber volume fraction, reinforcement orientation, diffusivity etc [3]. Moisture penetration into the composite materials is conducted by diffusion process. Epoxy matrix plasticization and degradation of the fiber/matrix interface due to presence of moisture have been attributed to degradation of mechanical properties of composites [4,5].

The glass transition temperature (T_g) of a thermoset matrix in polymer composite defines the critical service temperature of the component and consequently their applications and engineering design parameters. Polymer composites used at temperatures higher than their glass transition temperatures exhibit a substantial degradation of their mechanical and physical properties. Therefore a material's glass transition temperature and its change with moisture absorption are of practical importance [6].

Carbon fiber composite IM7/8552 is an advanced aerospace structural material. Limited studies have been made on the degradation of mechanical and thermal properties of this material due to moisture. The present work aims to contribute in this regard with the study of compression and glass transition temperature behavior of IM7/8552 carbon fiber composite in room temperature and in hot-wet

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conditions. Also, effect of fiber orientation on the moisture absorption behavior and its consequent effect on degradation of mechanical properties are investigated.

2. EXPERIMENTAL

2.1 Material and Specimens

A polymer composite with carbon fiber IM7 reinforced in a thermosetting epoxy matrix 8552 was considered in this investigation. The IM7/8552 composite UD prepreg was obtained from Hexcel Corporation, USA. The prepreg thickness was about 0.13 mm. The prepreg was cut and laid up in required sequence and cured in an autoclave to fabricate laminates of about of 2.1 mm thickness. Two types of laminates were manufactured viz., (i) 16 layered unidirectional (UD), and (ii)16 layered quasi-isotropic (QI) $(\pm 45/0/90)_{2s}$. The weight fraction of fibers was measured and found to be about 61%.

Test specimens for both room temperature and hot-wet conditions and also traveler coupons (representative specimens used to measure the mass gain during aging) for hygrothermal aging were cut and prepared from these laminates. In-plane compression tests specimens of about 12.5 mm wide and 140 mm long and 2.1 mm thick were cut from the laminate, as per ASTM D3410 test standard specifications [7]. Glass transition temperature test specimens weighing about 25 mg were also cut and prepared as per ASTM D3418 test standard specifications [8]. Traveler coupons of about 25mm x 25 mm x 2.1 mm for hygrothermal aging were cut and prepared following ASTM D5229 test standard specifications [9].

2.2 Hygrothermal Aging

All the hot-wet test specimen**s** along with traveler coupons were aged in an environmental chamber maintained at 70°C and 85% relative humidity (RH). During the conditioning process, traveler coupons were periodically removed, surface dried with a tissue, weighed on a Sartorius balance. The frequency of weighing was initially quite fast up to one week and then reduced as the conditioning process continued. The moisture absorption was measured by weight changes of traveler coupons according to ASTM D 5229 [9]. Conditioning was continued for up to about four months. For each type of specimens, five samples were used and the average weight gain was determined.

2.3 Mechanical Testing

In order to understand the effect of moisture on the mechanical properties of IM7/8552 composite, tests were conducted in both room temperature and in hot-wet conditions. As moisture is expected to affect mainly the epoxy matrix, the mechanical property which is dominated by matrix material was considered. In-plane compression tests were conducted to determine strength and modulus of the material. Back-to-back strain gages were bonded to the specimen surface in loading direction and the average modulus was obtained from data of both of these stain gages.

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 1 mm/min. Load, stroke and strain data were acquired in a high-speed data acquisition system, System- 5000 continuously during testing. Specimens were visually observed to identify the failure mode after the completion of each test. Seven replicate tests were performed and the average compressive properties were determined.

For hot-wet tests, after moisture absorption saturation was attained in the chamber, the test specimens were removed from the environmental chamber and tested. The hot-wet environment of 96±2°C and >85%RH condition was maintained during the compression test as well using an in-house made environmental chamber which was attached to the test machine. Controlled steam and hot-air supplies were provided to this chamber during testing to maintain the specified environment.

2.4 Glass Transition Temperature

Both dry and wet glass transition temperature, T_g of the IM7/8552 composite system were determined using Differential Scanning Calorimeter (DSC 2910, TA instruments), following ASTMD3418 test standard specifications [8]. The specimen was heated at a rate of 5°C/min. The wet specimens, prior to testing, were hygrothermally aged at 70^0C and 85% RH condition.

3. RESULTS AND DISCUSSION

3.1 Moisture Absorption Behavior

The moisture absorption curves determined for IM7/8552 composite specimens with UD and QI layup sequence is shown in Fig. 1. Specimens were observed to gain moisture quickly in the beginning and then tend towards saturation, a typical Fickian behavior [10-12], observed in fiber/epoxy composite materials. The UD composite exhibit higher absorption rate and maximum moisture absorption saturation content (M_m) than QI composite. Thus fiber orientation appears to have effect on the absorption rate as well as M_m. Zai et al [13] have also observed that UD laminates absorb moisture at faster rate than any of the other lay-up sequences.

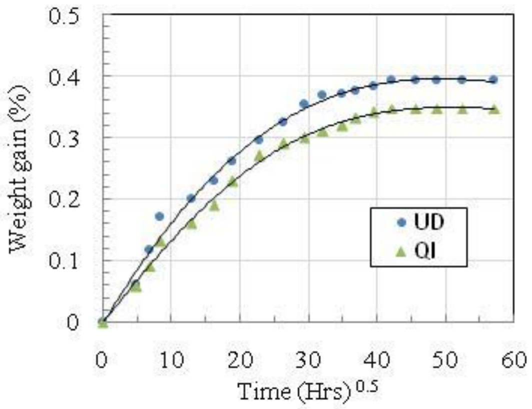


Figure 1: Moisture absorption curve determined for IM7/8552 carbon fiber composite

The moisture absorption in polymer composites is a diffusion controlled process. The diffusion coefficient (D_c) was calculated from the initial slope of the moisture absorption curve (Fig. 1) according to the equation [11]:

$$D_c = \pi\,[h/4M_m]^2\,[(M_2 - M_1)/\sqrt{t_2} - \sqrt{t_1})]^2 \qquad (1)$$

Where, M_m is maximum moisture content, M_1 is moisture content at time t_1, M_2 is moisture content at time t_2 and h is thickness of the specimen. D_c values were calculated using Eqn. (1) and are summarized in Table.1.

Table1. Moisture absorption and Diffusion Coefficient values determined for IM7/8552 CFC.

Lay up		Max. moisture gain (Wt. %)	Diff. Coeff. Dc ($\times 10^{-7}$) mm^2/sec
Lay-up Id	Lay-up Sequence		
UD	$(0)_{16}$	0.39	4.14
QI	$(\pm 45/0/90)_{2s}$	0.35	3.54

It may be noted that, diffusion coefficient decrease with the fibre orientation indicating that diffusion of water molecules will be faster along the fibres, where there are straight diffusion pathways than across fibres. Such effect of fiber orientation dependence on diffusivity of water molecules has been observed earlier by other investigators also [10].

3.2 Compression Properties

Typical compression stress-strain curves determined for UD laminate of IM7/8552 carbon fiber composite tested under room temperature conditions is shown in Fig. 2. The strains obtained from front and back face of the specimen in either RT or in HW conditions match quite closely with each other until almost end of test suggesting the in-plane pure compression loading of composite

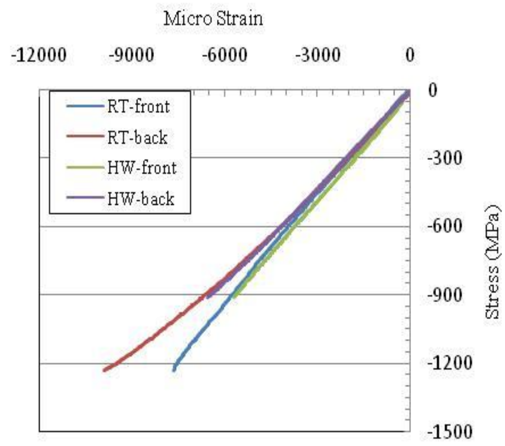
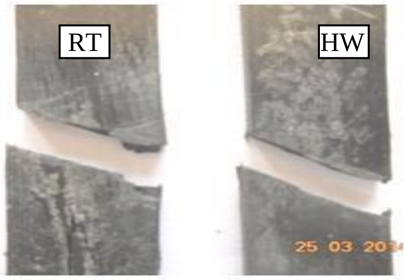


Figure 2: Typical compression stress-strain curves determined for UD in RT and hot-wet conditions



a) UD laminate

b) QI laminate

Figure 3: Typical failure modes observed in compression tests

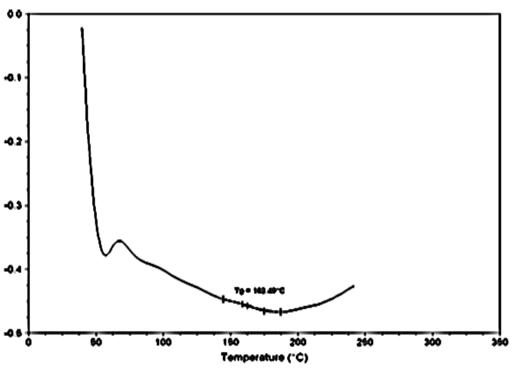


Figure 4: Typical DSC Plot obtained for IM7/8552 carbon fiber composite in hot-wet conditions

Table 2. The compression properties of IM7/8552 carbon composite under RT and hot-wet conditions.

Compression Property	Room Temperature		Hot-wet		Percentage Degradation	
	UD	QI	UD	QI	UD	QI
Strength (MPa)	1131±128	603±65	812±165	377 ±18	28.2	37.4
Modulus (GPa)	151±5	58±2.0	150.7±10	57.9±1.0	0.12	0.17

without any buckling. The failure mode observed in various test conditions is shown in Fig. 3. The UD laminates were observed to fail by lateral fracture whereas QI by rupture. It may be seen that the moisture absorption does not affect the failure mode in either UD or in QI laminate.

The average compression properties determined from data shown in Fig. 2 and from such similar seven replicate tests are shown in Table 2. The absorption of moisture clearly appears to degrade the compression strength significantly. The compression strength of UD is reduced by about 28 % whereas that of QI is reduced by about 37%. The compression modulus appears to be unaffected by moisture in both UD and QI laminates.
The presence of moisture within a polymer composite can lead to significant changes in its mechanical properties [12,13]. Two possible mechanisms have been suggested to explain the effects of moisture on most composite systems: matrix plasticization and degradation of the fiber/matrix interface [4,5]. Since, the degradation is dependent on the fiber orientation to the loading axis as well, the QI containing many off-axis plies appear to degrade more than UD laminate even though, the total moisture content in the QI is less than that of UD.

3.3 Glass Transition Temperature

The glass transition temperature, T_g was determined under both dry and wet conditions. Fig. 4 shows the typical plot obtained from DSC showing the wet T_g of IM7/8552 composite system. The dry and wet T_g values determined were 195°C and 162°C respectively. It may be clearly seen that absorption of moisture reduces the T_g by about 17%.

4. CONCLUSIONS

Based on the results obtained for IM7/8552 composites in this investigation, following conclusions may be drawn:

1. Moisture absorption follows Fickian behaviour. UD composite absorbs moisture at higher rate and also exhibit higher maximum moisture content than QI suggesting that moisture uptake is a function of fiber orientation.
2. Compression strength reduces by about 28%-37% due to moisture absorption depending on the lay-up sequence. The QI exhibit higher strength reduction than UD. Compression modulus is almost unaffected by moisture.
3. The glass transition temperature reduces by about 17% due to presence of moisture.

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