MOISTURE ABSORPTION, DESORPTION AND REABSORPTION EFFECTS ON MECHANICAL PROPERTIES OF GLASS-EPOXY COMPOSITES

Shylaja Srihari; A. Revathi
Centre for Societal Missions and Special Technologies (CSMT)
CSIR-National Aerospace Laboratories
HAL Airport Road, Post Box No. 1779
Bangalore-560 017, India
Email : shylasri@nal.res.in

R. Vivek Rao; Satyajith Shettigar;
Venkatesh Bhat; Sriram Sriravara
Department of Mechanical Engineering
PESIT
Bangalore, India

Abstract

The glass-epoxy composite laminates were fabricated using BID glass fabric and RT cure epoxy matrix by Room Temperature Vacuum Bag Moulding (RTVBM) Technique. The Inter laminar shear strength (ILSS), compression and flexural strength values were determined at room temperature for their dry mechanical property evaluation. The test specimens were exposed to a temperature/humidity condition at 45° C/95% RH for moisture absorption studies. The moisture desorption studies were carried out in a temperature oven at 45° C and 85° C. The mechanical properties of the exposed specimens were evaluated during absorption and desorption conditions. Scanning Electron Microscopy (SEM) studies were carried out on the dry and exposed specimens to determine the effect of moisture on the fracture behaviour of glass-epoxy composites. Results show that, moisture reabsorption and full desorption are faster than the absorption and partial desorption. This may be due to, change of material properties after a cycle of moisture absorption and desorption phenomenon. The mechanical strength (ILSS, compression and flexural) has been found to reduce continuously with increased duration of environmental exposure, but a slight shift back of the strength has been observed for desorbed samples.

***Keywords**: Epoxy, composite, mechanical properties, ILSS, compression, Flexural*

Introduction

Thermosetting epoxy resins are widely used as adhesives, composites and laminates due to its good thermal, mechanical and chemical properties. However, in most applications the epoxy-based component has the potential of being exposed to a humid environment and susceptible to the moisture absorption. The capability of polymer materials to absorb moisture from the environment is one of the major reliability concerns for composites used in aerospace applications. The absorbed moisture has deleterious effects on the physical and mechanical properties of epoxies and therefore, greatly compromise the performance of an epoxy based component. Moisture uptake by polymers and their composites is unavoidable and undesirable because it can cause permanent physical/chemical changes and even leads to failure of components. Although many investigators are concerned with the problems induced by moisture in recent years [1-7], the durability of the polymer still needs to be investigated in-depth, particularly with regard to hygrothermal aging.

In this study, moisture absorption (at 45° C / 95% RH), partial desorption (at 45° C), reabsorption (re-preconditioned under 45° C / 95% RH) and full desorption (at 85° C) characteristics of glass-epoxy composites have been investigated. The effect of moisture on the ILSS, compression and flexural strength are also studied respectively. The ILSS specimen fracture surfaces have been observed by a Scanning Electron Microscopy (SEM).

Experimental Work

The epoxy system used in this study was diglycidyl ether of bisphenol - A (LY556) and aliphatic amine hardener (HY951) supplied by M/s. Huntsman Advanced Materials (India) Pvt Ltd and bidirectional E-glass fabric of 280gsm supplied by CS Interglass U.K to fabricate the glass-epoxy composite laminates.

The glass-epoxy composite laminates were fabricated by wet lay-up process followed by Room Temperature Vacuum Bag Moulding (RTVBM) technique. The laminates were cured for 24hrs at room temperature and then subjected to different post cure schedules (i.e 50° C-1/2 hr, 70° C-1hr and 85° C-2hr). After post curing, laminates were cut into ILSS, compression and flexural test specimens as per ASTM standards to carry out the mechanical tests.

Moisture Absorption - Desorption - Reabsorption Experiments

In order to determine moisture absorption, desorption and reabsorption characteristics of glass-epoxy laminates, different experiments were conducted. Two sets of specimens were exposed to hygrothermal condition at 45° C/95% RH in a temperature/humidity chamber. The specimens were weighed at regular intervals of time until the weights of the specimen becomes saturated. One set of moisture saturated specimens were tested for wet mechanical properties. The second set of specimens were removed from the environmental chamber and dried in a hot-air oven at 45° C for partial desorption studies. Some of the partially dried specimens were tested and remaining specimens were subjected to 45° C/95% RH condition for reabsorption studies. After moisture saturation, some specimens were tested and remaining specimens were fully dried in a hot-air oven at 85° C and then tested. During the moisture absorption, desorption and reabsorption experiments, the specimens were weighed periodically using electronic weighing balance to determine the percent moisture content.

Mechanical Property Evaluation

In order to investigate the effects of moisture on the mechanical behavior of glass-epoxy composite specimens, the ILSS, compression and flexural tests have been carried out as per ASTM standard for dry and moisture saturated specimens. These tests were performed using Universal Testing Machine at room temperature with a crosshead speed of 2mm/min. Five specimens for each mechanical property were tested and the average value reported.

Scanning Electron Microscopy (SEM)

For fracture surface morphology analysis, fracture surfaces of the ILSS specimens were coated with a thin gold layer and examined using scanning electron microscopy (Model: LEO 440i, UK).

Results and Discussion

Moisture Absorption, Desorption and Reabsorption Characteristics

Fig.1(a-d) shows the moisture absorption, partial desorption, reabsorption and full desorption curves. In this figure, different symbols represents the moisture absorption and desorption of different types of mechanical test specimens. From Fig.1(a), it can be easily seen that the moisture uptake initially increases, linearly with respect to time and then levels off, irrespective of the specimen type. Also, it is observed that, the equilibrium moisture uptake and rate of desorption are almost same for all specimens in Fig.1(a) and (b). The moisture absorption is around 0.82% and partial desorption observed is about 0.41 to 0.45%.

From the Fig.1(c-d), it can be seen that, both reabsorption and desorption are faster than the absorption and partial desorption process. This is due to change of material properties after a cycle of absorption and desorption. Also it has been reported that the penetration of the moisture into the polymer will increase the free volume by the swelling effect [8]. Further complete desorption is faster than the partial, because specimens are dried at higher temperature (i.e 85° C).

Effect of Moisture on the Mechanical Properties of Glass-Epoxy Composite

The ILSS, compression and flexural tests were carried out for the dry, moisture saturated, partially desorbed, reabsorbed and fully desorbed specimens respectively, in order to determine the effects of the hygrothermal aging on the mechanical behavior of the glass-epoxy system. Fig.2 shows that, the effects of moisture on the Inter laminar shear strength of the epoxy system. Every data point shown is the average value of five specimens tested for each condition. The reduction in the ILSS of the saturated, partially desorbed, re-saturated and fully dried samples are 27.04%, 20.23%, 29.18% and 8.01% respectively, compared to the dry samples. The effects of moisture on the compression strength of the glass-epoxy specimens are shown in Fig.3. The reduction in the compression strength of the saturated, partially desorbed, re-saturated and fully desorbed samples are 24.63%, 16.08%, 27.39% and 8.42% respectively, compared to the dry samples. Fig.4 shows the effects of moisture on the flexural strength of the glass epoxy composite system. The reduction in the flexural strength of the saturated, partially desorbed, re-saturated and fully desorbed samples are 19.28%, 15.21%, 21.05% and 7.72% respectively, compared to the dry samples. Due to the effect of moisture, the mechanical strength of the saturated, partially desorbed, resaturated and fully desorbed samples are reduced, in comparison to the original dry samples. This could be attributed to the plasticization effect of absorbed moisture [9]. The extent of this plasticization process increases markedly with the exposure time or absorbed moisture. Also it is noticed that there is slight shift back or better retention of the strength in the case of desorbed samples.

Fracture Surfaces Analysis

In order to know the cyclic effect of hygrothermal conditioning on the fracture mechanisms, fractographic analysis of the fracture surfaces are performed by SEM for the dry and moisture saturated specimens. The SEM micrographs of the fracture surface of the dry and saturated ILSS specimens are shown in Fig.5(a-e), respectively. It is well known that there is one slow crack growth zone near crack initiation point at the beginning of the crack growth, and one rapid crack growth zone away from crack initiation-point when the instability criterion for crack growth is met with increased loading (Fig.5a). Fibre breakage and pull out are the main mode of failure in dry specimens (Fig.5b). For the moisture saturated specimens which are hygrothermally conditioned at 45°C/95%RH, it can be seen from Fig.5c that narrow shear band appears first in the slow crack growth zone. This fracture surface pattern shows that, due to cyclic effect, the crazes grow and simultaneously the crack propagates slowly as a result of plasticization effect on matrix by absorbed moisture. The voids and matrix cracking were also seen in the hygrothermally aged specimens (Fig.5d) [10-12]. As the composite material is exposed to hygrothermal cyclic aging, the moisture weakens the fiber matrix interface leading to debonding. Microcracks and debonding are seen in Fig.5e at higher magnification [13].

Conclusions

In this study, moisture absorption, desorption and re-absorption characteristics of the glass-epoxy composite laminates have been investigated by conducting hygrothermal aging studies. The effects of the moisture on the mechanical behavior and fracture surfaces of the epoxy system are determined. It is concluded that moisture reabsorption and full desorption processes are faster than the absorption and partial desorption processes. Due to the effect of the hygrothermal aging, the ILSS, compression and flexural strength of the studied epoxy system have been reduced, but after desorption a slight shift back of the strength is observed. Fractographic analysis results show that the absorbed moisture can change the fracture mechanisms of the polymer, and there is an evidence of the transition from brittle to ductile for the dry and saturated specimens.

Acknowledgements

Authors are grateful to Mr. D.V. Venkatasubramanyam, former Head, FRPD for all the support received during the investigations and Dr. G.N. Dayananda, Head, CSMST for the encouragement. They also acknowledge Mr. Rajendra Prakash, CSMST for mechanical testing and Mr. Raghavendra, Material Science Division, NAL for SEM Scans.

References

1. Xu, K., Chen, M.C., Zhang, K. and Hu, Jw., "Polymer", No.45, 2004, p.1133.
2. Yang, C.P., Su, Y.Y. and Hsiao, F.Z., "Polymer", No.45, 2004, p.7529.
3. Vogt, B.D., Soles, C.L., Lee, H.J., Lin, E.K. and Wu, W.L., "Polymer", No.46, 2005, p.1635.
4. Pegoretti, A. and Penati, A., "Polymer", No.45, 2004, p.7995.
5. Lin, C.H., "Polymer", No.45, 2004, p.7911.
6. Sun, Y.Y., Zhang, Z.Q. and Wong, C.P., "Polymer", No.46, 2005, p.2297.
7. Wong, T.C. and Broutman, L.J., "Polym Eng Sci", No.25, 1985, p.521.
8. Soles, C.L. and Yee, A.F., "Polym Phy", J. Polym Sci, Part-B, No.38, 2000, p.792.
9. Ray, P.K., Bhushan, A., Bera, T., Ranjan, R., Mohanty, U., Vadhera, S. and Ray, B.C., Proceedings in

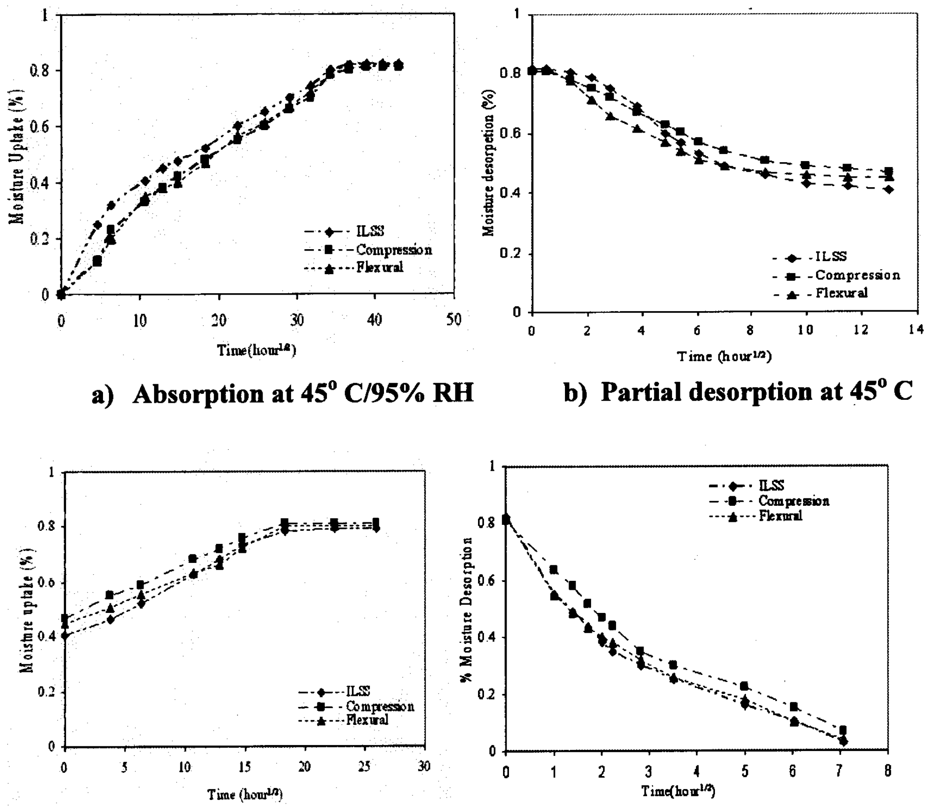
"Emerging Trends in Structural Mechanics and Composites", 2003.

10. Liu, K. and Piggcyit, M.R., "Polym Eng Sci", No.38, 1998, p.60.

11. Liu, K. and Piggcyit, M.R., "Polym Eng Sci", No.38, 1998, p.69.

12. Sreejith, M., Murthy, H.N.R.N., Krishna, M., Rai, K.S., Jeena, J.K. and Iranian., "Polymer Journal", No.19 (2), 2010, pp.89-103.

13. Jana, R.N. and Bhunia, H., "Polymer Composites", 2008, p.665.



a) Absorption at 45° C/95% RH b) Partial desorption at 45° C

c) Reabsorption at 45° C/95% RH d) Full desorption at 85° C

Fig.1 Moisture Absorption and Desorption Curves

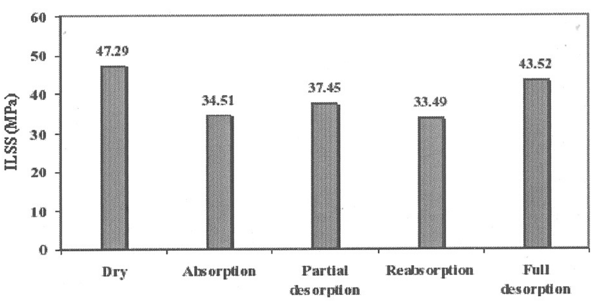


Fig.2 Interlaminar Shear Strength of Glass-epoxy Composite

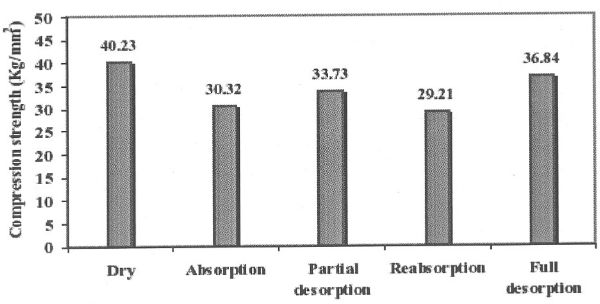


Fig.3 Compression Strength of Glass-epoxy Composite

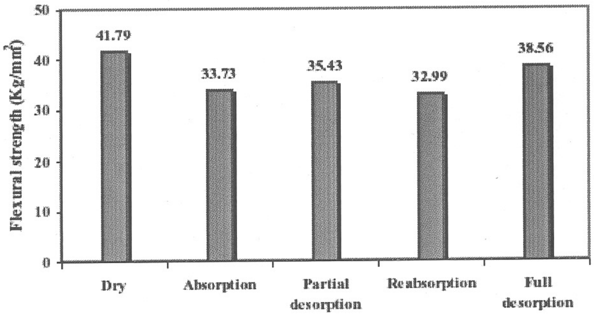


Fig.4 Flexural Strength of Glass-epoxy Composite

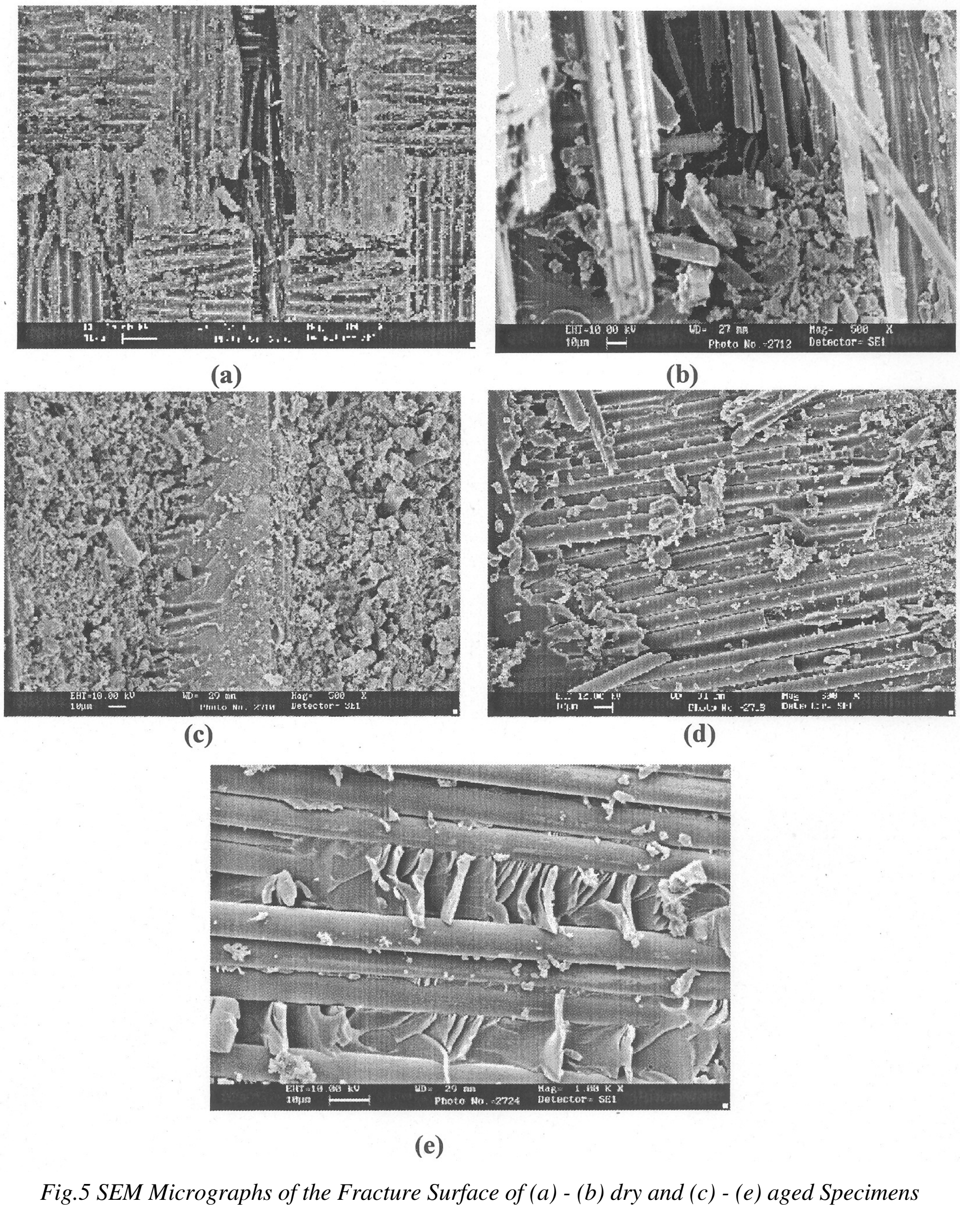


Fig.5 SEM Micrographs of the Fracture Surface of (a) - (b) dry and (c) - (e) aged Specimens