Environmental Exposure of Glass-fibre Reinforced Composites

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Summary

Environmental degradation tests on polymer composites have been undertaken to determine the mode and rate of degradation of these materials due to exposure in Southern Africa. The exposure tests were performed by placing laminates in the natural environment and periodically removing specimens for examination and testing. Discolouration of the matrix and exposure of reinforcing fibres due to matrix erosion, occurred during the exposure period. Matrix erosion was quantified using scanning electron microscopy (SEM).

Introduction

Polymer composites are increasingly being used in new and varied environments across the world. Their use is no longer primarily in specific geographic locations in which the response to the material has already been established. This study has therefore been initiated to determine the mode and rate of degradation of polymer composite materials in Southern Africa. There are at present no published degradation tests performed in Southern Africa. Data on the material degradation is required to optimise maintenance and repair schedules on composite components and prevent catastrophic failure of the structures that may otherwise occur. Knowing the degradation rates, a safe service life of the components may be determined.

Environmental degradation tests have been conducted in the USA and Europe. Once such test, involving laminate exposure in USA and Europe, was reported by Dexter [1]. Dexter noted that fibre exposure had occurred and strength had decreased with time over the test period. Fukuda [2] has also reported on an outdoor exposure test, over a period of five years, that was conducted in Japan. Durability tests, reported by Chester and Baker [3], have been performed in the tropical environments of Australia and Malaysia. This test, of nine years duration, investigated the degradation on specimens' representative of aircraft structures.

Environmental exposure tests have begun in climatically different areas in Southern Africa. The materials tested include glass-fibre reinforced laminates manufactured from five different resin systems. Specimens are periodically

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examined and tested to determine the predominant mode/s and rate of degradation. Data from these tests will be used as input to a mathematical model that would enable the safe service life of the material to be predicted.

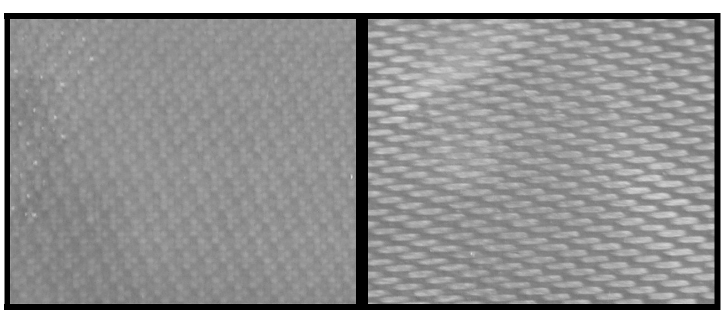
Method

Laminates for exposure testing were predominantly reinforced with the same 2×2 twill weave glass fibre. The five type of matrices used, consisted of two types of epoxy, a vinylester and two types of polyester resin. The epoxy resins tested, of aerospace grade, were in the form of a prepreg (Epoxy 1) with the other being a wet lay-up system (Epoxy 2). The prepreg was reinforced with an 8 harness satin weave glass fibre, with the nine-layer-laminate being compacted and cured using an autoclave. The remaining epoxy system was hand-laid, with ten layers of reinforcement, and cured at ambient conditions. Epoxy 2 laminates were then post-cured as per manufacturer's recommendations.

The exposure panel was manufactured from a steel frame, with an outer cover having cut-outs of dimensions 130mm×40mm through which the laminates received their exposure. The frame was mounted, using supports, at an angle of 30˚ to the horizontal to maximise the solar irradiance received by the specimens. These exposure panels were placed at six locations within South Africa, representing the entire range of climates, from hot and dry, to cool and wet. Specimens are sampled bi-annually for examination and mechanical testing.

Results

Only specimens manufactured from epoxy matrices and exposed at Durban will be discussed. Epoxy laminates examined and reported herein had the longest exposure duration and observable degradation had occurred. The first set of mechanical test results, recorded after ten weeks of exposure, revealed specimens in Durban to have lost the most strength, hence laminates exposed at this location were initially examined.



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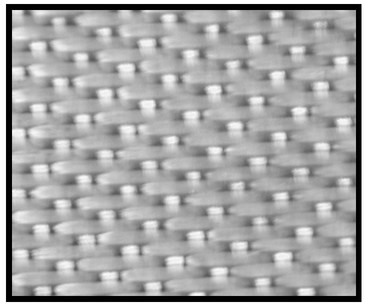
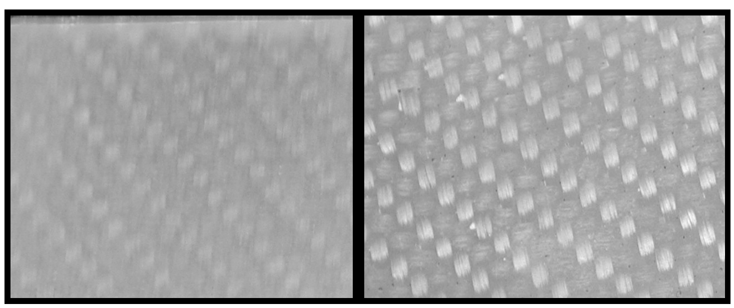


94 weeks

Figure 1 - Exposed surfaces of Epoxy 1 laminates after different exposure periods

The images in Figure 1 are of the exposed surfaces of Epoxy 1. After ten weeks of exposure, the only visible change observed was a change in colour of the surface from light brown to a darker shade of brown. After 42 weeks of exposure, the fibre tows in the longitudinal weave were observed. The change in colour was not as noticeable as had occurred after 10 weeks of exposure. After 94 weeks of exposure, fibre tows in both the transverse and longitudinal direction were observed. The colour change could not be determined as the exposed fibre tows dominate the exposed surface resulting in the surface appearing white.



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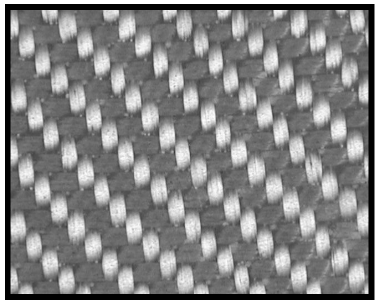

94 weeks

Figure 2 - Exposed surfaces of Epoxy 2 laminates after different exposure periods

The images in Figure 2 are of the exposed surfaces of Epoxy 2 laminates. After 10 weeks of exposure, the impression of the glass fibre weave below the surface was observed. The matrix colour changed to a light yellow from originally being clear. Fibres on the transverse weave are barely visible after 42 weeks of exposure and the resin changed to a darker yellow colour. Fibre tows in both the transverse and longitudinal directions were visible after 94 weeks of exposure. The longitudinal tows are not as apparent in Figure 2 against the resin which has changed to a dark yellow colour.

Table 1 – Change in laminate depth due to natural exposure

	LAMINATE	
EXPOSURE DURATION	Epoxy 1	Epoxy 2
	[mm]	[mm]
20 weeks	none	0.17
42 weeks	n/a	0.38
68 weeks	0.07	0.39

Epoxy one laminate had no measurable change in thickness after 20 weeks of exposure. The data for thickness measurements after 42 weeks of exposure are inconsistent across the length of the laminate examined, and therefore not available at this stage. Further examination of laminates removed at this stage of exposure is required to determine the change in thickness that did occur as evident by fibre tows being visible on the surface. After 67 weeks of exposure, the change in depth of resin recorded was 0.07mm. In contrast, Epoxy 2 recorded much faster rates of change in thickness. After 20 weeks of exposure, the change in thickness was 0.17mm, at which stage the fibre tow impression was visible on the surface, but most fibres remained covered by the excess resin on the surface. After 42 weeks of exposure, 0.38mm of resin had been lost from the surface of the laminate. At this stage of exposure, fibre tows closest to the surface were visible. The rate of change of thickness recorded subsequently decreased as the change in depth after 68 weeks of exposure was 0.39mm.

Discussion

A noticeable change in colour from light to darker shades of brown occurred during the early stages of exposure, i.e. 10 weeks and 20 weeks, of epoxy 1. Exposure of the underlying resin to the environment was reduced with time due to exposed fibres occupying an increasing surface area as matrix erosion occurred. In contrast to Epoxy 1 laminates, the colour change from clear to increasingly darker shades of yellow, on Epoxy 2 laminates, appears to have continued until the 94 week exposure period. This may probably be due to the large surface layer of resin being exposed for a longer duration to the environment therefore being more susceptible to damage. The fibres would therefore not offer protection to the underlying matrix from natural UV radiation. Changes in colour of laminates due to UV exposure has been measure by Bank *et al 4*. An alternative explanation would be that due to the fibres occupying an increasing surface area, colour changes in the matrix are not as perceivable as the resin become “covered” by the fibres.

The receding matrix front is evident when the laminates are viewed under a microscope. The fibres remain in position relative to the laminate as the matrix appears to recede into the laminate. As this occurs, the fibres become exposed to the environment and are no longer protected by the matrix. Hence after 42 weeks, the topmost fibre tows on the longitudinal weave become visible in epoxy 1. At this point in time, the transverse fibre tows on the same layer of reinforcement remain unexposed within the matrix as the matrix has not been eroded to that level as yet. After 94 weeks of exposure, the transverse and longitudinal tows on the first layer of reinforcement are visible as the matrix has been eroded to almost the thickness of the first layer of reinforcement. Due to Epoxy 2 being a clear resin system when cast, fibres were visible close to the surface (approximately 20μm). Fibre impression was first observed on laminates after 10 weeks of exposure, at which stage all fibres were protected by the matrix. After 20 weeks of exposure, the fibres in the transverse weave were exposed to the environment and fibre impressions of the longitudinal weave below the surface of the matrix were observed. After 94 weeks of exposure, both fibres on the transverse and longitudinal weave were observed. The matrix has receded below the level of the first layer of fibres at this stage. The surface of the laminate appeared white due to fibre tows becoming increasingly exposed.

Quantifying the change in thickness on epoxy 1 laminates has been difficult due to the apparent superior durability of the matrix to weathering. No measurable change in thickness of the laminate was determined after 20weeks of exposure, with a measurable change of 0.07mm being recorded after 68 weeks of exposure. The change in thickness of the laminate after 42 weeks of exposure will help to determine the initial rate of change of matrix loss from the surface. Rapid erosion of the matrix from the surface is initially expected, due to the matrix receiving full exposure. As the upper layers of fibres become increasingly exposed, protection of the matrix below the fibres would improve resulting in a slower erosion rate. Quantify the rate of change of thickness of Epoxy 2 laminates was easier than with Epoxy 1, as the rapid rate of erosion facilitated measurements of the change of dimension of the matrix. After the 20 week exposure, 0.17mm of resin was lost from the surface of the laminate, at which stage, fibre exposure had not occurred. After 42 weeks of exposure, the matrix had receded to a depth of 0.38mm with the fibres becoming exposed. The rate of matrix erosion then slowed, as expected, as evident by erosion measuring 0.39mm after 68 weeks of exposure.

Conclusion

Environmental exposure of glass-fibre reinforced epoxy laminates has begun in Southern Africa with laminates being placed in climatically differing regions. Examination of exposed laminates revealed a change in colour. Matrix erosion from the surface occurred as fibres became increasingly visible with increasing exposure duration. The change in laminate thickness due to matrix erosion was quantified and was found to differ among the epoxy systems tested. Mechanical testing is being performed to determine change in bulk material properties with time. The effect of protective measures on reducing damage incurred on the laminates due to the natural environment is currently being assessed.

References

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