

## Abstract

For marine structural applications which pose significant challenges to the choice of materials due to the presence of corrosive seawater, polymer matrix based fiber reinforced composites are increasingly becoming the material of choice instead of conventional materials like steel largely due to light weight material, high strength to weight ratio and good resistance to corrosive materials and sea-water. However, the key challenges that effect the performance of the composite are, the moisture absorbed by the composites under marine environment and ageing of the composites that degrade the composite and hence the overall lifetime. Fiber reinforced polymer (FRP) composites manufactured by incorporating nanoparticles in the resin are expected to improve the performance properties and enhance its durability. However the effective incorporation of nanoparticles in the resin and establishing proper manufacturing technology for fabricating the composite using nanoparticle dispersed resin as polymer matrix and glass fiber as reinforcement, is very challenging. Three different resins namely Unsaturated polyester (USP), Vinylester (VE) and Epoxy were used for this study along with the corresponding Montmorillonite (MMT) based nanoparticles which are compatible with them namely Cloisite 30B, Cloisite 15A and Nanomer I30E respectively. In order to disperse the nanoparticles in the resin, probe type sonicator was used for ultrasonication process. Vacuum assisted resin infusion molding (VARIM) was used for fabrication process of the FRP-Nanocomposite. The performance of the FRPNanocomposites were assessed by determining the amount of moisture absorbed and the reduction of mechanical properties due to the effect of moisture absorption over a long term period as long as 12 months in a simulated sea-water environment at temperatures including sub-ambient as well as elevated temperatures below glass transition temperature. Diffusion mechanism of the sea-water in the composite was investigated by modeling the hygrothermal ageing data with different predictive diffusion models and the best fit model was found out from regression analysis. The corresponding model parameters were evaluated. The lifetime of the composite was estimated by developing a model with ageing data considering that the degradation is caused by sea-water diffusion and reaction kinetics.

It was observed that Vinylester nanocomposites absorb lesser moisture compared to USP and Epoxy based nanocomposites. Also, nanomaterial incorporation decreased the moisture absorption by 40 to 50% for USP nanocomposites and 25-40% for VE nanocomposites. Similarly, there was 30-40% decrease in percentage reduction of flexural strength in case of

USP nanocomposites and 20-25% decrease for VE nanocomposites as we increase the loading level of nanoparticles. Moisture absorption data was modelled and parameters were evaluated for different predictive diffusion models and it was observed that diffusion relaxation and dual sorption models fit well with the data. Lifetime of the FRPnanocomposite was estimated for all the resin systems using the ageing data and the model parameters of the selected diffusion models. It was observed that lifetime of nanocomposite increased with the increase in nanoparticles loading and dual sorption model was observed to provide superior lifetime compared to diffusion relaxation model. Lifetime estimation using dual sorption model increased the lifetime by nearly 2 to 3 folds with 4% and 6% loading levels of nanomaterials in USP and VE-FRP-Nanocomposites. Failure study of the FRP nanocomposite was also performed by investigating the morphological and structural changes, delamination and presence of free volume, using different characterization techniques such as Scanning electronic microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), Dynamic mechanical thermal analyser (DMTA) and Positron annihilation lifetime spectroscopy (PALS). All the analyses found to validate with the experimental observations obtained in moisture absorption and ageing study.

*Keywords:* FRP-Nanocomposite laminates, Barrier properties, Dispersion study, Diffusion mechanism, Lifetime estimation, Failure study