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PhD Dissertation Defense

Entitled

Experimental investigation and prediction of long-term effects of sustained loads and harsh environments on fiber-reinforced polymer composites

by

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Abstract

Fiber reinforced polymeric (FRP) materials are increasingly used in engineering applications because of their light-weight, corrosion resistance and high strength and stiffness. Their applications range from marine and aerospace structures to pipelines for gas and water desalination. The corrosion resistance of FRP makes the material effective in marine applications. These composites are subjected to different environmental conditions during their operational life, such as moisture, humidity and temperature, which can adversely affect their performance over time. The goal of this work is to investigate the long-term effect of different environmental conditions (e.g. sea-water and high temperature) and sustained loading on the structural properties of the FRP composite materials. Following are the main objectives of the work:

1) To develop an innovative hydraulic multi-sample loading frame to evaluate the durability of polymers and polymer composite materials subjected to both harsh environmental conditions (temperature and seawater) and sustained load.

2) To determine the combined effect of seawater, high temperature and sustained loading on the structural properties of thermoset composite materials

3) To develop analytical models using the experimental data to predict the performance of composite structures in seawater and offshore applications

In this work, a multi-sample loading frame was designed and manufactured which comprises nine sub-frames and can accommodate 9 test specimens simultaneously under seawater at different temperature and sustained load. Each sub-frame structure was independent of the others and equipped with heaters located inside the environmental chambers. The loading frame utilized a compression load cell (secured between the top plate and the hydraulic jack) for measuring the applied load transferred to the specimen using a hydraulic jack. The load cell was connected to a data acquisition device for sustained load measurements and monitoring of applied load. The load monitoring device comprises a microprocessor for receiving and monitoring the sustained load of all test specimens.

Two thermoset composites, E-glass/epoxy and E-glass/polyurethane were

immersed in seawater under sustained load (10%, 15%, 20%, 25% of failure load) and varying temperature (23° to 95°C) for the period of 15 months. Mechanical, physical and thermal properties were experimentally investigated. The effects of temperature, moisture, and immersion time on the deterioration of the composite material were studied for both composites. It was observed that the weight of the samples increased with the immersion time and temperature for both the composites. The highest increase in weight of the samples under 15% sustained load (15% of failure load) was 2.5% and 1.9 % for E-glass/epoxy and E-glass/polyurethane composites respectively for the immersion period of 15 months at 65 °C. The tensile strength of the E-glass/epoxy composite immersed at room temperature without load decreased at a low rate to 99% of its original strength after 15 months of immersion in seawater. At an elevated temperature of 45 °C and 65°C, the strength decreased to 95% and 89% of its original value after 15 months of immersion in seawater. The tensile strength of the E-glass/epoxy composite immersed at 23 °C under 15% sustained load (15% of failure load) decreased by 6% whereas at an elevated temperature of 45 °C and 65°C, the strength reduced by 11% and 18% respectively after 15 months of immersion in seawater. The tensile strength of the E-glass/polyurethane composite immersed at room temperature without load decreased significantly to 81% of its original strength after 15 months of immersion in seawater. At an elevated temperature of 45 °C and 65°C, the strength decreased to 74% and 65% of its original value after 15 months of immersion in seawater. The tensile strength of the E-glass/polyurethane composite immersed at room temperature under 15% of failure load decreased by 27% whereas at an elevated temperature of 45 °C and 65°C, the strength reduced by 32% and 38% respectively after 15 months of immersion in seawater. Differential Scanning Calorimetry (DSC) and Scanning Electron Microscope (SEM) analysis were conducted to evaluate the degradation of fiber matrix interface. Results revealed that moisture, temperature and sustained load have a deteriorative impact on the performance of the composite. It was observed that degradation mechanism accelerated at elevated temperature results in breakdown of chemical bonds between matrix and fiber at the interface.

Furthermore, this experimental data was used for the development of two prediction models to predict the tensile strength of two composites for long term exposure in seawater. These prediction models were used to predict unseen data. The results of all models were in good agreement with the experimental data.

Keywords: E-glass/epoxy composite; E-glass/Polyurethane composite; long term durability; Sustained load; Sea water; Temperature; Mechanical properties.