# Abstract

Manufacturing industries are adopting adhesive bonding for high structural integrity, but forming reliable adhesive joints in composites is challenging due to degradation from temperature and humidity. Limited understanding of this degradation makes predicting joint reliability difficult. This study aims to examine the failure behavior of composite epoxy adhesive joints under fresh and hygrothermal exposure in order to address this limitation.

The composite joints were made using carbon fiber reinforced plastic (CFRP) for the adherend and either a ductile adhesive (Araldite® 2015) or a brittle adhesive (Araldite® AV138). In mode I fracture tests using double cantilever beam (DCB) specimens, it was found that the ductile adhesive joint had much higher toughness in both crack initiation and steady-state phases compared to the brittle adhesive joint. Initially, both adhesive joints showed cracks forming within the adhesive, but in the steady-state region, the crack path changed to a combination of cracks within the adhesive and at the interface. To analyze this behavior, digital image correlation (DIC) was used to study crack tip images, resulting in the determination of a tri-linear traction-separation law (TSL) for the ductile adhesive joint and a bi-linear TSL for the brittle adhesive joint.

Also, fracture tests with end notched flexure (ENF) specimens along with DIC technique were used to extract the mode II TSL, respectively. It was found that the experimentally determined TSLs can be closely approximated with the bi-linear TSL. Subsequently, the FE model employed cohesive zone modeling (CZM) with the utilization of the bi-linear TSLs to predict the failure behavior of SLS joints. The FE predicted failure response of the SLS joints closely matched with the experiments on SLS joints, thereby validating the FE model and the extracted TSLs.

This work also proposes a framework to study and predict mode I and mode II failure behavior of aged CFRP adhesive joints. Fracture testing of open-faced specimens (DCB, ENF) aged at 40°C

and 82% RH helped determine the correlation between the degradation in TSL parameters and aging. This correlation was used along with the 3-D FE model of the closed joint to predict the failure response of an aged closed joint. Both the epoxy adhesive and CFRP adherend exhibited water absorption and desorption behaviors that conformed to the Fickian model. Notably, even after extended drying periods, there remained residual water present in both the adhesive and CFRP adherend. The TSL extracted using the direct method closely followed a bi-linear TSL for mode I and a trapezoidal TSL for mode II. The fracture toughness and maximum traction values from this adhesive system degrade fast initially, but subsequently decrease to a steady linear decline. Two FE models predicted aged closed joint failure load: one with non-uniform degradation, the other with uniform. Both models reasonably matched experimental results. Non-uniform degradation model was slightly better at predicting degraded failure load.

Another study examined the failure behavior of composite adhesive joints and closed CFRP laminates under hygrothermal conditions. The study performed mixed-mode failure tests on SLS specimens for both composite laminate and adhesive joints aged at 40°C and 82% RH, and the results indicated a drop in the failure load with aging conditions for both joint conditions.

In conclusion, this study examines composite joint failure under fresh and hygrothermal exposure and offers insights into adhesive joint degradation. Cohesive zone modeling, traction-separation laws, and accelerated degradation tests aid long-term strength and reliability prediction. The findings inform the design and manufacture of more durable adhesive joints for prolonged environmental exposure.