Abstract

Properties of polymer-fiber laminates can change during service life due to the degradation of individual components. Enhancing the environmental resistance of materials and extending the lifespan of products are critical directions for further research. Among the factors contributing to laminate degradation, photodegradation caused by ultraviolet (UV) radiation is likely the most prevalent cause. The lack of systematic knowledge about the photodegradation of polymer-fiber laminates and the absence of standardized guidelines for composite photodegradation testing were the main motivations for this study.

The research investigated the impact of UV radiation on the structure and properties of laminates and developed methods to mitigate its adverse effects. Photodegradation was studied under natural conditions over 36 months and in laboratory settings using both standard and non-standard methods. The innovative method addressed the limitations of standard techniques by including UV-C radiation and enabling photodegradation testing at a constant immersion depth in water.

The study focused on laminates reinforced with carbon fibers in an epoxy resin matrix and laminates reinforced with glass fibers in both epoxy and polyester resin matrices. Regardless of the reinforcing and matrix materials, UV radiation caused noticeable changes in the samples, such as discoloration, dulling, loss of transparency, cracking, and progressive resin erosion, which led to the exposure of reinforcing fibers. Photodegradation initially occurred in a thin surface layer but, as it progressed, became visible throughout the composite's volume.

Epoxy resin-based laminates primarily degraded due to photodegradation. Polyester resin-based laminates, in addition to photodegradation, exhibited a tendency for hydrolytic degradation caused by water molecule osmosis. This resulted in changes at the interphase boundary, increasing the mobility of reinforcing fibers within the polymer matrix. Epoxy resins swelled physically upon contact with water, and when combined with photodegradation, these synergistic effects exacerbated resin erosion on the surface and altered mechanical properties. The most significant changes were observed in flexural strength, interlaminar shear strength, and glass transition temperature.

As part of this work, methods for the conservation and repair of polymer-fiber laminates were developed, including the use of protective coatings with UV stabilizers employing diverse mechanisms of action. These coatings can be applied both preventatively and reparatively. The findings fill a significant gap in knowledge about the mechanisms of polymer-fiber laminate photodegradation under real-world and laboratory conditions. The developed research methods could serve as new standards for assessing laminate photodegradation processes. The results offer practical applications in the design and manufacture of more durable laminates.

The most notable achievement of this work is the unique investigation of GFRP laminates under natural outdoor conditions and the development of a novel, innovative method for studying laminate (and other material) photodegradation processes under constant underwater immersion.