Phase field modeling on the multi-physical damage of composites

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The understanding of water penetration, diffusion, and swelling-related strength degradation is critical for assessing the durability of polymer-based composite materials exposed to marine environment. When moisture intrusion and various external loads are concurrently applied to polymer matrix materials, the multi-physical diffusion process, and the correlation with the complex cracking phenomenon is far from been discovered.

To approach this uncertainty, we explored fully coupled moisture diffusion, stress redistribution, and damage evolution of composites for revealing complex failure patterns and rules. A thermodynamically consistent moisture diffusion model is established to couple the moisture diffusion and viscoelastic response of the multiphase material. A two-constituent phase-field fracture model is developed to describe the hygroscopic swelling in the matrix and interfacial decohesion within a concise and universal continuum mechanics framework. We also propose a crack filter theory to characterize the fluctuation of moisture flux along with the evolution of regularized crack.

We showcased the capability of the model and derived two critical processes related to fundamental physical insights into moisture damage. Moisture diffusion is predicted to accelerate at the interface and vicinity of crack tips with distinct reasons. The moisture diffusion around the fiber/matrix interface is accelerated by the additional moisture gradient generated by the fiber and matrix. The moisture diffusion around the crack tip was accelerated by the hydrostatic stress gradient introduced by the crack. When the moisture-containing composite was subjected to an external load, the hydrostatic stress inside the material increases. Then, the moisture was attracted to the area with a higher positive hydrostatic stress (i.e., the crack tip) and accelerate the inversible material degradation in this area. Thus, a reasonable inference is that the moisture re-diffusion, dominated by the external load, increases the likelihood of failure of the region that tends to fail owing to stress concentration. This inference would be applicable to the other chemo-mechanical coupled problems.

We further revealed the effects of hydro-damage on the mechanical behavior during moisture-induced aging. With multipoint damage caused by moisture diffusion, the crack profiles of composites are predicted to be distinct with dry system subject to tensile loading, which are highly consistent with experiments. Within hydro-composites, the main crack gradually forms according to the coalescence of multiple damage points and tends to nucleate near the diffusion boundary. For dry composites, the main crack tended to appear near the mid-thickness and propagated from a single nucleation point. Generally, increasing these factors will aggravate the moisture-damage (i.e., interfacial decohesion) owing to the increased discrepancy in displacement between the fiber and matrix. This work might provide a new insights into the coupled damage mechanism of polymer composites and facilitating microstructure design to enhance its performance in ocean environments.

References

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