How Varying Fatigue Loads Affect the Damage Evaluation in Front of the Crack in Hydrogels

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Abstract

Industrial materials are exposed to different types of loads over many years. Therefore, understanding crack initiation and propagation under cyclic loads is one of the keys to making a successful design. However, the complexity of damage evaluation under fatigue loading and the lack of clear observations makes it very difficult to reveal and understand the mechanisms behind fatigue fracture. Polyacrylamide hydrogels, with their unique combination of brittleness and elasticity, serve as ideal material models for studying fatigue fracture in brittle systems. This study investigates strain field evolution and plastic deformation near the crack tip in hydrogels subjected to cyclic loading. Our experimental findings reveal that even when the applied energy release rate is below the fatigue crack propagation threshold, microdamage occurs in the process zone. Strain field analysis shows early strain concentration near the crack tip, leading to localized microdamage. When the applied energy is insufficient to sustain fatigue crack propagation, strain relaxation mechanisms are observed. These mechanisms act as a form of toughening, reducing strain concentration. In contrast, when the applied energy exceeds the threshold, strain relaxation is not observed. The maximum strain near the crack tip and the size of the damaged zone converge at values dependent on the applied energy. For energy just above the threshold, crack propagation rates are linear with no plastic deformation in the unloaded state. However, at significantly higher energy levels, consistent with Region II of the Paris law, crack propagation rates initially decrease and eventually stabilize, reflecting an energy-dependent equilibrium.

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