Multiscale Fatigue Measurement Visualizes Bending Fracture Process of Polymer Films

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Semi-crystalline polymers consist of both crystalline and amorphous regions, exhibiting the combination of flexibility and toughness due to their complex higher-order structures. These properties make polymer films well-suited for applications in flexible devices.[1] However, these devices often face fatigue-related issues, where cyclic bending or large deformations lead to performance degradation. Improving the bending durability of polymer films is critical to maintaining device performance.[2] While various approaches, such as layering and compounding,[3,4] have been reported to enhance bending resistance, the intrinsic fatigue mechanism of polymer films remains unclear. To ensure the durability and reliability of flexible devices, understanding the fatigue process in polymer films are essential. Recently, we conducted bending fatigue tests on various polymer films and evaluated the bending shape, represented by the radius of curvature *R*. This revealed that *R* values significantly varied depending on the polymer type and correlated strongly with the number of bending cycles until fracture.[5] In this study, we further investigated the fatigue fracture process of polymer films. In addition to analyzing the value of *R*, we directly observed surface cracks and strain distribution and conducted X-ray scattering analysis visualizing molecular-level fatigue behavior.

The polyethylene terephthalate (PET) film was selected as the test material. The samples were repeatedly bent at an angle of 0–60° at a rate of 1.5 Hz (**Fig. 1a**). The radius of curvature was evaluated from cross-sectional images of the bending process to quantify shape changes over the bending cycles (**Fig. 1b**). Cracking during the fatigue process was monitored by confocal laser microscopy, revealing that failure originated from the inner bending surface. Digital image correlation (DIC) analysis showed an asymmetric stress distribution between the inner and outer bending surfaces, initiating failure at the inner bending surface (**Fig. 1c**). Small-angle X-ray scattering (SAXS) and wide-angle X-ray diffraction (WAXD) measurements demonstrated that cyclic bending disrupts the crystalline order and lamellar long-period structure (**Fig. 1d**). Multiscale analyses clarified the nanoscale structural disruption and macroscopic fracture process.

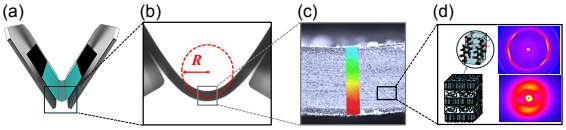

Fig. 1. (a) Schematic of the bending setup for the PET film. (b) Cross-sectional image during bending test, evaluating the radius of curvature *R*. (c) Strain distribution in cross-sectional direction analyzed using DIC. (d) Schematic illustration of the lamellar structure of PET and the representative 2D SAXS and WAXD patterns.

1) F. Yan *et al., Nano Energy* **2016**, *28*, 151. 2) B. Kim *et al., Materials* **2019**, *12*, 2490. 3) T.-S. Kim *et al., ACS Appl. Mater. Interfaces* **2019**, *11*, 13416. 4) B.-S. Bae *et al., Composites, Part* **2022**, *247*, 110336. 5) A. Shishido *et al.*, *J. Phys. Chem. C* **2023**, *127*, 14510.