

The Molecular Choreography of Polymers under Mechanical Stress

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Mechanophores are molecular probes that report on mechanical stresses and strains in polymers through changes in their optical properties. These powerful tools offer insights into the molecular “dance” of solid-state polymeric materials under load, including unfolding, bending, stretching and ultimately, breaking.

Using fluorescent supramolecular mechanophores, which unfold in response to relatively small molecular forces, we mapped heterogeneous deformation around defects, inclusions, and regions of concentrated stress in polymeric materials using fluorescence microscopy.[1],[2] This approach produced quantitative strain maps that reveal how local strains deviate from the macroscopically applied load. To gain insights into the chemical consequences of these strain and stress concentrations, we developed a new coumarin-based mechanophore that undergoes a force-induced chemical transformation to produce a coumarin fluorophore, enabling the mapping of permanent molecular damage.[3] This platform provides control over both the force threshold for activation and the photophysical properties of the coumarin fluorophore, which will allow us to probe the broad force distribution in solid-state polymeric materials at the molecular level.

Looking ahead, we are developing next-generation mechanophores to detect the earliest stages of damage by integrating force probes with quantum dots and photo-switchable molecules. These probes aim to extend molecular-level force mapping to the nanoscale, bridging the gap between macroscopic mechanics and the dynamics of individual polymer chains under stress.

Together, these strategies illuminate the molecular choreography of polymers under mechanical stress, allowing us to understand the chemical origins of polymeric material failure and guiding the design of more durable polymeric materials.

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2. L. Deng, C. Graafsma, J. M. Clough, F. Meyenhofer, I. Scarlat, L. Bertossi, C. Weder, J. M. Clough, “Mechanochromism of Glassy Polymers Enabled by a Loop-Forming Supramolecular Mechanophore,” *Advanced Functional Materials* (2026): e31535 <https://doi.org/10.1002/adfm.202531535>.
3. Y. Li, J. M. Clough, “Optical Force Monitoring in Polymeric Materials with a Coumarin-Based Mechanophore,” *Angewandte Chemie International Edition* (2025): e202513283 <https://doi.org/10.1002/anie.202513283>.