Detection of Fracture Precursor in Polymer Networks by Space-Resolved Multi-Speckle Diffusing Wave Spectroscopy

Jianzhu Ju[1], Luca Cipelletti[2], Tetsuharu Narita[1, 3]* and Costantino Creton[1, 3]*

[1]Sciences et Ingénierie de la Matière Molle, CNRS UMR 7615, ESPCI Paris, PSL University, Paris, France
[2]Laboratoire Charles Coulomb (L2C), University of Montpellier, CNRS, Montpellier, France
[3]Global Station for Soft Matter, Global Institution for Collaborative Research and Education, Hokkaido University, Sapporo, Japan

In order to investigate the mechanism of toughness of soft polymer networks, it is necessary to cover a wide range of length scale: from the molecular scale with bond breaking in stretched chains to the macroscopic scale with the crack propagation and rupture of the material. It is essential to understand the mechanics of the networks in the intermediate length scale where the stress and damage are spread in much larger zone near the crack tip. Experimental tools which allow us to study the polymer dynamics related to the local damage, or fracture precursor with adequate spatial and temporal resolutions in this mesoscopic scale are limited. In this project we develop a dynamic light scattering technique coupled with a macroscopic mechanical tester to provide a new approach to study fracture mechanics in mesoscopic scale.

Diffusing wave spectroscopy (DWS) is a variation of dynamic light scattering technique, sensitive to dynamics change in sub-micron scale. The key requirement for DWS measurements in polymer networks is introduction of probe particles (typically 0.1 – 1 µm in diameter) with a high enough concentration to provide multiple scattering in the system. With space-resolved multi-speckle diffusing wave spectroscopy (MSDWS) where 2D images of speckles are acquired by a CCD camera, ensemble averaged dynamics of the probes reflecting local changes in the damaged network can be achieved with both temporal and spatial resolutions.

We developed a setup combining space-resolved MSDWS optics and delayed fracture tester in uniaxial traction, and applied it to a tough soft elastomer of poly (ethyl acrylates) double network. Dynamic distribution mapping was performed with high temporal (1 s) and spatial (400 µm x 400 µm) resolutions. During induction period of macroscopic fracture, we discovered heterogeneous dynamics distribution which corresponds to fracture precursor. Transient high dynamics around the crack tip can also be observed before the detectable crack propagation. Under different deformation, the dynamics distribution on the sample shows different patterns, which corresponds to the stabilization or propagation of the crack. The technique and the combination with other characterization methods will provide us complete vision to the research of fracture mechanism and advanced molecular design for soft material development.