Microstructure and mechanics of crumpled materials

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Abstract

Crumpled materials are primarily regarded as model systems by physicists due to their fascinating topology and their related scaling laws close to those observed in many other materials or systems such as for example polymerized membranes, biological cells or plants. More recently, several studies have shown that crumpled materials could also be potentially used in many structural applications (e.g., shock absorbers, core of sandwich panels) due to their low-cost, simple fabrication route and promising mechanical properties. However, the selection and the use of a specific crumpled material for a particular engineering application require a proper control of the process-induced microstructures and a comprehensive understanding of their role on the mechanical behavior. In the last decade, significant effort was made to understand the physics of crumpling phenomena and the microstructures of crumpled sheets. Despite this effort, further studies are still required to fully elucidate the links between the three-dimensional self-locked architectures of these cellular materials and their resulting mechanical properties.

Within this context, several low-density crumpled paper-based materials were fabricated by varying both the volume fraction and the geometry and mechanical properties of initial paper sheets. Their 3D architecture was investigated using X-ray microtomography. Several microstructure descriptors such as the pore size distribution, the mean curvature distribution and the volume fraction of ordered domains were finely analyzed. Their mechanical properties were also assessed using both quasi-static uniaxial compression and dynamic impact tests with a Split-Hopkinson pressure bar. 3D real time and in situ observations during compression experiments were also performed using fast X-ray synchrotron microtomography.

The results gathered in this study highlighted the role played by some key microstructure descriptors of crumpled materials, such as ridges and ordered domains, on their mechanical behavior under quasi-static and dynamic loadings. The evolution of the elastic, plastic and shock-absorption properties were studied as a function of their relative densities and compared with experimental data available in the literature for other cellular materials, showing that crumpled papers are promising renewable alternatives to standard polymer foams for several engineering applications.

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